FUSION TECHNOLOGY

Annual Report of the Association EURATOM/CEA 2002

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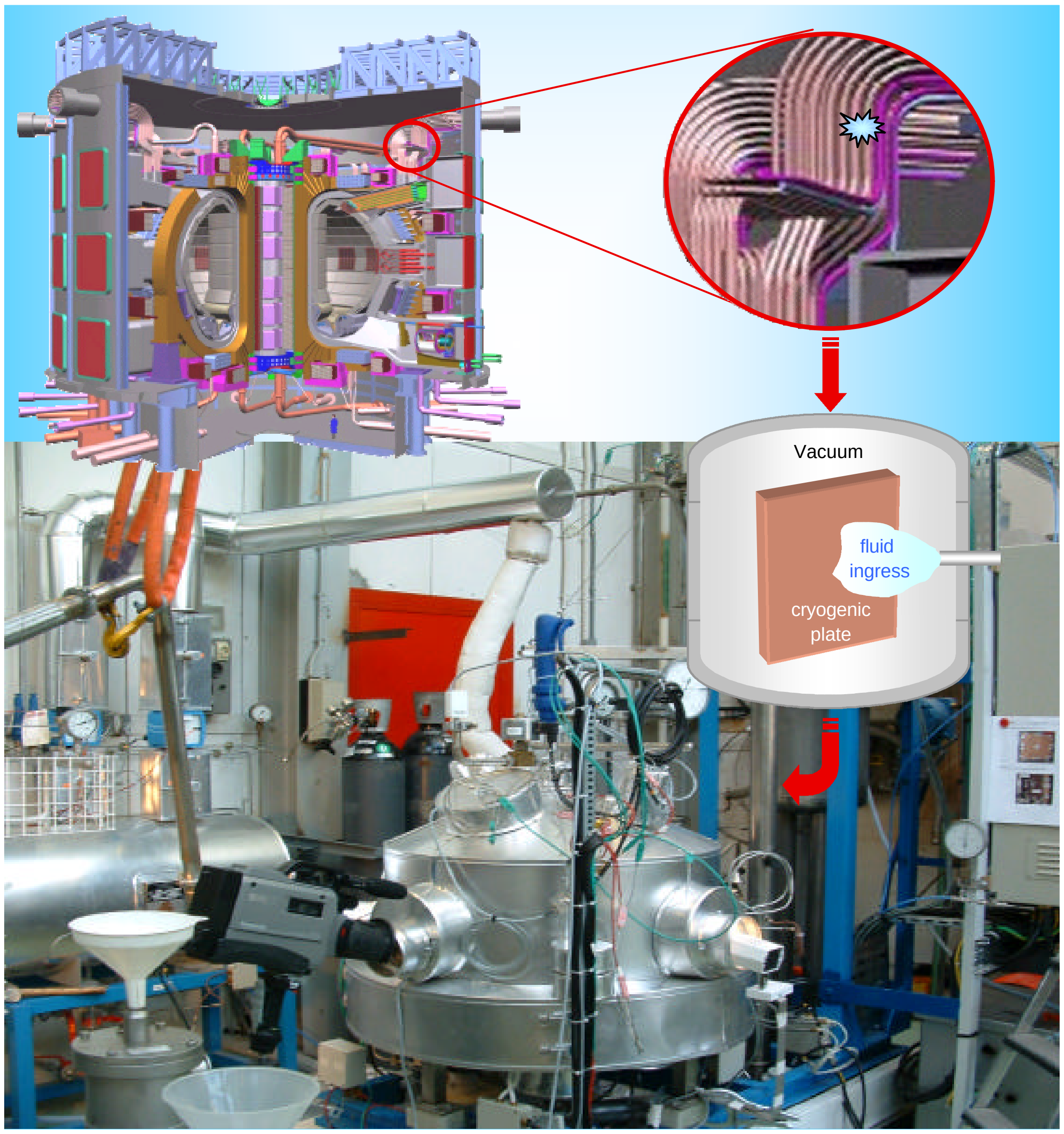

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T329-5

Task Title: IN-VESSEL RH DEXTEROUS OPERATIONS

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.

A major difficulty that must be overcome is the lack of useful video feedback due to the level of radiation encountered inside the reactor vessel.

The remote handling operations have thus to rely on a supervisory control scheme based on augmented reality. Under this approach, a virtual computer model duplicating the real environment is used both to provide visual feedback and to support high-level target-oriented motions. From a robotics point of view, the key points are:

- the use of a supervision interface implementing a robot graphical control language,
- the calibration of the prototype manipulator arm,
- the registration of the environment objects wrt. the robot reference frame.

The previous year has seen the performing of a representative maintenance operation with the full benefit of a virtual environment model. For this purpose, a MAESTRO master-slave hydraulic manipulator having a load capacity of 100 kg (equivalent to its weight) has been integrated inside the DTP (Divertor Test Platform) located at the ENEA Brasimone site.

This robot system has been used to lock and unlock Cassettes that are laid on two rails at the bottom of the toroidal vessel.

With the achievement of a long distance teleoperation demonstration and the evaluation of a water hydraulic one-axis mock-up, the main part of task T329-5 has been successfully completed.

After a number of problems impairing the use of the MAESTRO system for "blind" nuclear maintenance have been revealed during preliminary tests, the development of a new generation MAESTRO has been started.

The updated design has been completed and approved in mid-2001 and the 2002 activity (actually the final workpackage of task T329-5) consisted in the commissioning of the new and more reliable hydraulic arm better suited to the operational needs than the prototype.

2002 ACTIVITIES

The new MAESTRO hydraulic manipulator has been designed in order to ease maintenance and decontamination, as well as to increase its performances. The main modifications are:

- Revision of the position sensor (resolver) assemblies : the sensors are now more linear and they can be dismantled for calibration on a test-bed.
- Optimisation of the resolver cabling coupled with new processing boards in order to reduce noise.
- Significant reduction of the number of turning seals resulting in less friction and better performances.
- Increased modularity : axis nos 4 and 5 are now identical, while axis nos 2 and 3 are almost the same.
- Enhanced quality of the utilized seals leading to the disappearance of oil leaks.
- Enlarged cable holes and maintenance access panels.
- All the servo-valves are presently located inside axis no. 4 and can be easily maintained.
- More robust and more efficient mechanical design of both the gripper and the tool fixing device.
- Provision for using pressure-servos in place of flow-servos ; the former being simpler with better performances from a control point of view.

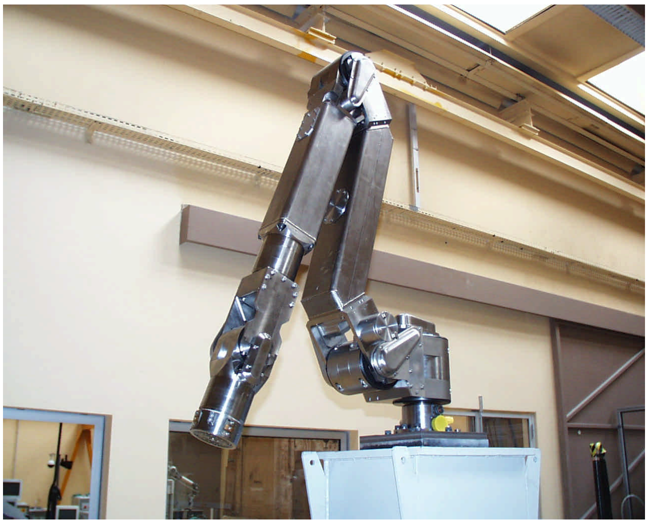
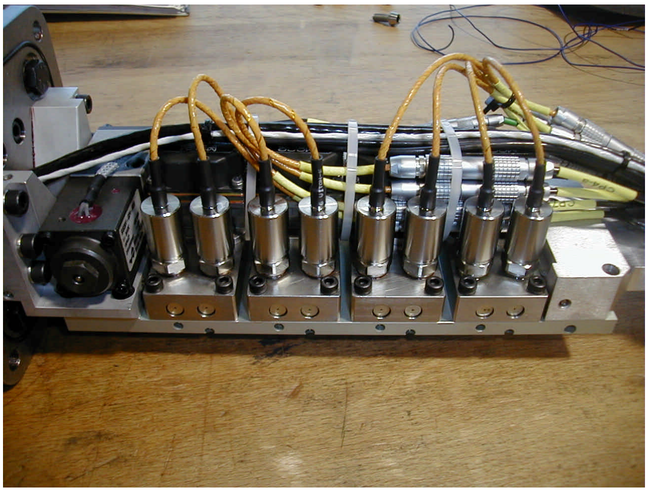
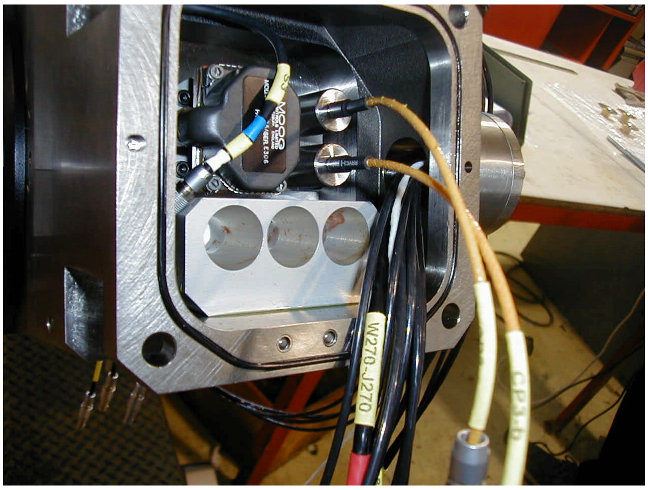


Figure 1 : The new Maestro manipulator commissioned at Fontenay-aux-Roses





Figures 2 and 3 : Servo-valves located inside axis no. 4

The manipulator and its control cabinet has been developed by CYBERNETIX (Marseilles) and both components were available at the beginning of 2002. Our activity in 2002 was fully related with the validation of the arm. As far as factory receipt is concern, the only notable event is the initial refusal of the manipulator collection due to an important oil leak. The trouble were corrected and the arm was accepted later. In a second step the arm has been commissioned in Fontenay-aux-Roses without significant difficulties.

CONCLUSIONS

2002 thus concludes task T329-5. The MAESTRO system has been developed and prepared for the DTP remote handling test campaign. It has then been shipped to Brasimone and integrated inside the existing installation. At the end, the Cassette locking/unlocking task was successfully demonstrated. Beyond this technical achievement, the experiments made in Brasimone have provided worthwhile feedbacks about the system itself and "blind" remote handling in general:

- The TAO2000 system has proved its capability as a reliable advanced telerobotics controller.
- As far as "blind" remote handling is concerned, it has been proved that all the tool displacement motions could be reasonably performed based on the 3D model. On the other hand, it is clear that the accuracy of the modelled environment and the arm calibration errors (about 1-2 cm) preclude any "blind" operation of the current tools, especially since these tools were not designed having in mind comfortable positioning tolerances. Moreover, because the manipulator often operates close to its singular positions and mechanical limits, it is not considered safe for the time being to dispense with large field of view cameras.

Two realistic goals may thus be expressed :

- suppress the large-view video by a better management of the singular and joint limit positions using dedicated simulation tools during the mission preparation phase,

- decrease the need for close-view video through a better design of the tools.

Additionally, a number of drawbacks have been identified on the prototype MAESTRO hydraulic arm.

These were rectified on a new design that was validated during this year.

These experiments have shown that we now have available a hydraulic manipulator that is quite efficient in terms of accuracy (the prototype was mainly impaired by defective resolver assemblies), calibration (the new position sensors can be calibrated on a test-bed), smooth control and operability (absence of oil leaks, maintenance, …).

REFERENCES

[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), April 1997.

[3] P. Gicquel, C. Andriot, F. Coulon-Lauture, Y. Measson, P. Desbats, "TAO2000 : a generic control architecture for advanced computer aided teleoperation systems", Proc. 9th ANS Topical Meeting on Robotics and Remote Systems, Seattle (USA), March 2001.

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

REPORTS AND PUBLICATIONS

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

T329-5 : In-Vessel RH 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.

T329-5 : In-Vessel RH Dextrous Operations – 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.

T329-5 : In-Vessel RH Dextrous Operations – Water Hydraulic Joint Results on Qualification for force feedback application (Technical Report SRSI/LCI/01RT.040), Claude Andriot.

T329-5 : In-Vessel RH Dextrous Operations – Long Distance Teleoperation Test Report (Technical Report SRSI/LCI/01RT.042), Christophe Leroy.

Etude et réalisation d'un bras Maestro de nouvelle génération - Rapport de conception, ref. CYX/AFF/C5192699/RAP001 Indice 1.0, 2001.

In vessel RH dexterous operations T329-5 / MAESTRO Installation and Tests at Brasimone / Fusion T329-5 Final Report, ref. DTSI/SRSI/LCI/02RT.021, 2002.

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TW0-DTP/1.2
TW0-DTP/1.4
TW1-TVA-IVP
TW2-TVR-IVP

Task Title: IN-VESSEL PENETRATOR (IVP) PROTOTYPICAL MANIPULATOR FOR ACCESS THROUGH IVVS PENETRATIONS

INTRODUCTION

This project takes place in the Remote Handling (RH) activities for the next step of the fusion reactor ITER. The aim of the R&D program is to demonstrate the feasibility of close inspection of the Divertor cassettes and the Vacuum Vessel first wall of ITER.

We assumed that a long reach and limited payload carrier penetrates the first wall using the 6 penetrations evenly distributed around the machine and foreseen for the In-Vessel Viewing System (IVVS).

The need to access closer than the IVVS to the Vacuum Vessel first wall and the Divertor cassettes had been identified. This is required when considering inspection with other processes as camera or leak detection.

The objective of this task is to demonstrate the feasibility of such operations along the vacuum vessel wall with access from existing IVVS penetrations. This carrier will be called In Vessel Penetrator (IVP).

This task began in 2000 includes design activities, manufacture and testing of a demonstrator of an articulated manipulator. First scope of the work concerned the analysis of the requirements to perform a realistic operation inside the Vacuum Vessel with access through the IVVS penetrations.

This phase had end up with a conceptual design of the IVP manipulator with 5 modules, 11 degrees of freedom and a parallelogram structure.

A scale one mock up of representative this segment was manufactured, focusing first on proof of performances in scope of mechanical structure resistance. This mock up was tested in 2001 and gave good results, static parameters have been measured and introduced in the design, the calculations of the complete robot are validated. The module structure has a good mechanical behaviour.

In parallel, a study technologies able to be used for the IVP design under vacuum and temperature was started. Some were validated to design an IVP able to cop with ITER environment conditions but an effort should be done to cover all the problem.

The next step of this study was the design of a completely integrated vacuum prototype to be tested under ITER relevant conditions. This was the main task performed during 2002.

2002 ACTIVITIES

VACUUM AND TEMPERATURE TECHNOLOGIES FOR THE IVP

A feasibility study of intervention operation under vacuum made in 2000-2001 and provided recommendations to modify the design for intervention under vacuum and temperature, some technologies were selected and tested in 2001.

The test of these suitable technologies were pursued in 2002, focussed on the critical ones : the thermal treatment to use bearings without lubrication and the electronics.

Tests of dry lubricated bearing was performed with a thermal treatment of Teflon (Nuflon) coating.

The results show that this could be used as dry lubrication of the IVP bearings under temperature and vacuum (Teflon has a good outgassing rate).

But the relatively short life of the coating will imposed some preventive and regular maintenance of the IVP modules to replace the needles of the bearings.

These tests of thermal treatment on bearings could be pursued in the next phase to improve the life time of lubricant.

The selected components to be used in the IVP electronics are HCMOS military components with ceramic case.

As many components are available in HCMOS, it is possible to use a Neurobot architecture, which is a serial data network, which main advantage is to limit the wiring between two modules and was already used in robotic nuclear environment.

A board was manufactured (see figure 1) and tested under temperature.

Figure 1 : Prototype Neurobot board

After several hundred hours of test, we have proved that the HCMOS non-power electronics is very reliable. All the electronics function as well at 20°C as at 160°C. The baking temperature test is also a success, as the whole Neurobot board has withstood temperatures has high as 240°C for 5 hours.

The power electronics is a more complex problem, because of the important dissipation of heat which raises the temperature of the junctions. Many solutions exist, cooling, specific electronics, and would be reliable. They will be compared during the next phase of the project.

DESIGN OF A VACUUM AND TEMPERATURE HARDENED DEMONSTRATOR MODULE

The design of the vacuum and temperature prototype module was focused, as for the electromechanical demonstrator, on the base module (the most heavily loaded of an IVP robot) with 2 degrees of freedom.

The requirements for the prototype demonstrator robot are:

- 8 meter length and 10 kg payload,
- 5 modules with rotation and elevation axis,
- to be ITER relevant for use conditions of vacuum and temperature,
- to be tested on an existing Fusion reactor.

The results of the geometric study used as basic data's for the design and the calculations of the IVP are:

- The IVP is made of 5 identical modules, with jaw an pitch joints each and an external diameter of 160 mm.

- A parallelogram structure (four bars mechanism) keeps the jaw joint axis always vertical.

- The IVP is powered by electrical motors.

- The electronics and the actuators are embedded in sealed box to permit the use of grease and non hardened components.

- The bearings are treated with dry lubricant to insure no pollution of the vacuum.

The assembly drawing of one module of the IVP is presented in the figure 2:

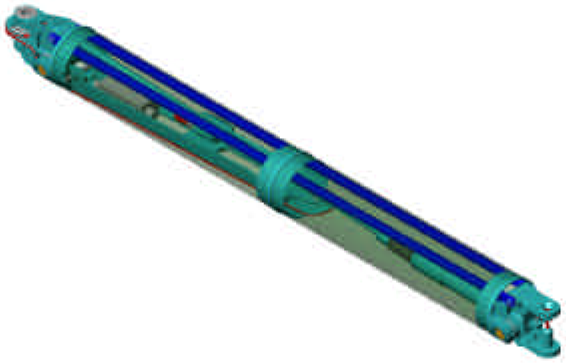

Figure 2 : IVP vacuum module design

MECHANICAL MODELLING OF THE DYNAMICS OF THE IVP DEMONSTRATOR MODULE

Figure 3

The IVP is a poly articulated robot characterized by a high length/section ratio. In order to improve its endpoint's position accuracy, a realistic mechanical model of the robot has to be built. The quasi static model of the structure will take into account the flexibilities of the different parts of the robot but also the geometrical parameters of the structure.

The final objective is to built a dynamic model of the full IVP robot

A flexible model of a similar smaller robot already existing in CEA was previously identified.

The model had to be adapted to the IVP. The main modifications were focused on the motorization.

A test campaign on the first module was performed with the support of ENEA Frascati. The survey consisted to measure the static positions and continuous motions of the robot by a laser process.

The data analysis from the static measurements shows the position of structure's flexibilities and enables the identification of the geometrical parameters. The results point out that the main deformation is situated at the base in bending loading and divided in the tube and the parallelogram in torsion loading.

This first qualitative analysis will be used as inputs for the next IVP design phase.

The continuous tests allow us to identify the stiffness parameters of the structure.

Further works will consist in developing a non linear and multivariable optimisation algorithm in order to match the position of the endpoint Cartesian coordinates from model to the measures. The identified stiffness parameters will be used as the first step for the optimisation.

By assembling the model for the five segments, we will be able to collect information on the full robot, essential as input to the next design phase.

CONCLUSIONS

The IVP feasibility study performed in 2000 - 2001 was continued with the design of a prototype module.

The needed vacuum and temperature technologies are validated to design an IVP able to cop with ITER environment conditions and had been integrated in the design of the prototype module.

A mechanical flexible model of the IVP demonstrator module was identified with the support of ENEA and by assembling the model for the five segments, we will be able to collect information on the full robot, essential as input to the next design phase.

The next step of this study is the manufacture and testing of a completely integrated vacuum prototype to be tested under ITER relevant conditions.

REFERENCES

[1] European Fusion Technology Programme - Task TW0-DTP/01.2 Divertor test platform "Prototypical manipulator for access thought IVVS penetrations" November 16th , 1999.

[2] European Fusion Technology Programme - Task TW0-DTP/01.4 Divertor test platform "Review feasibility of limited maintenance inspection operation under vacuum" June 10th , 2000.

[3] European Fusion Technology Programme - Task TW1-TVA/IVP April 12th , 2001.

[4] European Fusion Technology Programme - Task TW2-TVA/IVP October 10th , 2001.

PUBLICATIONS

CEA/DPSA/STR/LAM/00RT.053/ Issue.0 Prototypical manipulator for access thought IVVS penetrations (IVP) - Conceptual design report.

CEA/DPSA/STR/LAM/00RT.085/ Issue.0 Review feasibility of limited maintenance inspection operation under vacuum – Feasibility analysis report.

CEA/DPSA/STR/LAM/00RT.086/ Issue.0 Prototypical manipulator for access thought IVVS penetrations (IVP) - Intermediate report.

CEA/DTSI/SRSI/LPR/01RT.053/ Issue.1 In Vessel Penetrator (IVP) Manufacture and test of a demonstrator report.

CEA/DTSI/SRSI/LPR/02RT.015/ Issue.0 In Vessel Penetrator (IVP) Vacuum and temperature technologies report.

CEA/DTSI/SRSI/LPR/02RT.070/ Issue.0 In Vessel Penetrator (IVP) Analysis of the static tests. Identification of the deformations.

CEA/DTSI/SRSI/LPR/03RT.001/ Issue.0 In Vessel Penetrator (IVP) Survey analysis.

SOFT 2002 Paper H15 : Development of a long reach articulated manipulator for ITER in vessel inspection under vacuum and temperature.

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TW1-TVA-BTS

Task Title: BORE TOOL SYSTEMS (BTS) CARRIER AND BORE TOOLS FOR 4" BENT 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 swaging tool.
- Tack welding.
- Butt welding with filler metal.
- Non destructive testing to check the quality of the operation.

Feasibility of such a concept was studied during 1998. Manufacturing of a prototype carrier was made during 1999 focusing on the most critical functions needed by the carrier. Clamping modules, an alignment module, a tack welding tool and a swaging tool were designed, manufactured and tested separately. Integrated tests on a swaging operation were made during 2001. The swaging tool was set into the carrier and operated under real conditions in order to make a validation of the final cutting sequence.

Another answer to the cutting and welding operations by conventional means was studied. A laser tool was designed (see figure 1) and manufactured in order to achieve these two operations with a single tool and tested during 2002.

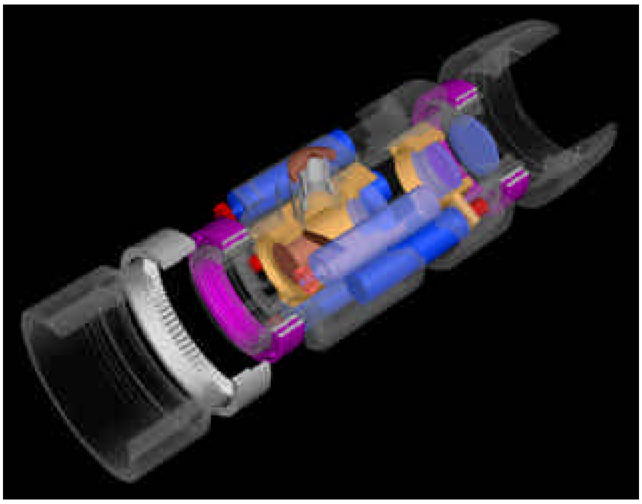

Figure 1 : CAD model of the laser tool

2002 ACTIVITIES

TESTS OF THE LASER TOOL ON TEST BENCH

Tests were performed during 2002 with the laser tool (see figure 2 and figure 3).

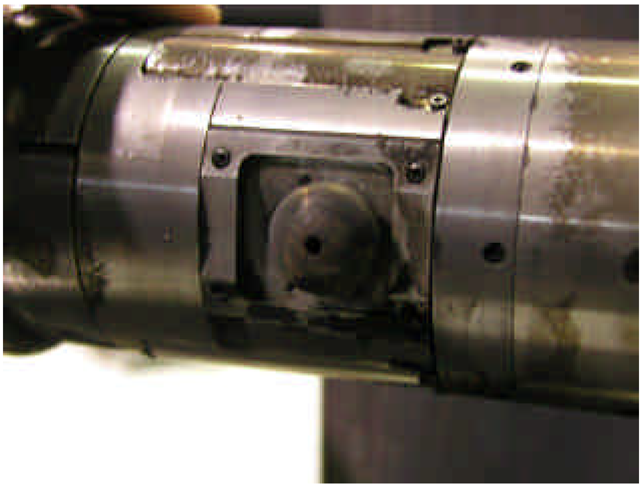

Figure 2 : Laser tool after test on the bench

Tuning of the process was fine but was finally successful. The integration of the tool in the carrier is just being started (see figure 4 and figure 5).

Figure 3 : Samples of weld and cut performed during the tests on the test bed

Figure 4 : Integration of the laser tool in the carrier

Figure 5 : Laser tool in the carrier

CONCLUSIONS

An innovative modular system of carrier was proposed and designed. A prototype dedicated to a single machining operation was manufactured. During a test campaign, final cutting of the pipe with a swaging tool was successfully performed under operating conditions very close to the initial requirements. An alternative answer to the standard cutting and welding operations is currently being assessed with help of a laser tool.

This work will be completed by a state of the art of all the existing solutions for Bore Tooling maintenance work developed for fusion or an other industry.

This work will try to define the amount of R&D work that still lays ahead to satisfy ITER's requirements.

REFERENCES

[1] European Fusion Technology Programme - Task Action Sheet T329-4 EXTENSION2 "Bore tools and carrier for 100 mm bend pipes" July 31th, 1999.

[2] European Fusion Technology Programme - Task TW0-DTP/01 Divertor test platform "Carrier and Bore Tools for bent pipes" November 16th , 1999.

PUBLICATIONS

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.

CEA/DPSA/STR/LAM/00RT.028/ Rev.0 Upgrade studies.

CEA/DPSA/STR/LAM/00RT.030/ Rev.0 Test on the swaging tool and the tack-welding tool.

CEA/DPSA/STR/LAM/00RT.049/Issue 0 160mm Bore tooling system. Check up of the status of the system and training of ENEA's operators.

CEA/DPSA/STR/LAM/00RT.035/ Rev.1 Prospective analysis of bore tooling maintenance work in 2.5" bent pipes.

CEA/DPSA/STR/LAM/00RT.089/ Rev.0 Performances after upgrade of the Bore Tools for 4" Bent pipes carrier.

Report CEA/DTSI/SRSI/LPR/01RT.025 Issue 0 "CWIE Laser module integration tests".

Report CEA/DTSI/SRSI/LPR/01RT.027 Issue 0 "M1 of TWO-DTP1.1 Integration of a laser tool in the BTS carrier and management of the umbilical".

Report CEA/DTSI/SRSI/LPR/02.RT.006 Swaging with the BTS carrier.

SOFT 2000 and Fusion engineering and design 58-59 (2001) "Overview of bore tools systems for Divertor remote maintenance of ITER." J-P Friconneau & al.

SOFT 22th Conference. Carrier and Bore tools for 4” bent pipes. O. David & al.

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TW1-TVA-MANIP

Task Title: IN-VESSEL DEXTEROUS MANIPULATOR

INTRODUCTION

Some operations involved in Fusion reactors require the use of a robotic manipulator. Within T329-5 Fusion task, some checks in the use of remote handling systems had been led at ENEA Research Centre of Brasimone (Italy) : a MAESTRO dexterous robotic manipulator (provided by CEA) and an advanced computer aided teleoperation system were involved to perform the in-vessel removal and installation of ITER Divertor cassettes from the CTM (Cassette Toroidal Mover) of the DTP (Divertor Test Platform).

As such kind of interventions assume blind conditions, it will prove much relevant to take advantage of *on-line dynamic simulations* of the robotic system inside its environment, notably to bring *condition monitoring* information. This task intends to design and develop a *demonstrator* for Maestro manipulator system, *answering this functionality*.

During 2001 activities, one reflected about the ways to perform on-line and real-time dynamic simulations of the system, considerating thus all subsequent parts of the trouble: modelization, ways of implementation, dynamic calculation for the mechanical part, link to the actuators model developed by IHA.

Analyses on advantages and drawbacks of the potential ways to answer these parts had led to some preliminary choices:

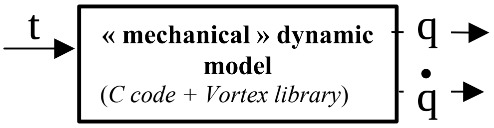
- modelization:
    - * stressing the distinctive features of the geometric and inertial parameters of the Maestro arm. Assessment of the dynamic parameters (mass, inertia) thanks to a dedicated calibration campaign,
    - * possible reviewing of some of the servo-control loops one way, and of the IHA modelizations for the actuators the other way,
- ways of implementation:
    - * real-time dynamic simulation of the system at a upper level, which lets the simulation part independent from the low level real-time control loops,
- simulation of the dynamic mechanical system:
    - * developments based on Vortex real-time multi-bodies system simulation engine,
- link to the actuators model:
    - * either use of the complete original model for the actuators or use of an equivalent reduced model (transfer function) calibrated upon IHA models and simulations, depending on preliminary checks with the dynamic simulator.

2002 ACTIVITIES

REAL-TIME DYNAMIC SIMULATION OF THE ARM

First step consisted in designing and developing the virtual model of the Maestro manipulator, to check the feasibility of simulating in real-time the dynamics of the robotic arm inside a constrained environment.

The manipulator is depicted (using Vortex engine), as a rigid multi-bodies system, respecting the kinematics of the real arm. One can apply forces or torques, either to any body, or to the joints (allowing for instance joint control simulation).



When the virtual arm moves in the scene, all constraints coming form the kinematics and the collisions with obstacles are answered in real-time, inducing a proper behaviour of the arm in the constraint environment : on the 3D scene of Petrus room at CEA – Fontenay (including tubs, bent pipes and hoses) used as a study-case, each simulation step could run within 3ms, warranting the real-time requirement we need for monitoring ability.

DRIVING OF THE VIRTUAL MANIPULATOR WITH A REAL MASTER CONTROL

One then made the link between the simulation mock-up (of the virtual Maestro inside an environment) and a real master arm, in order to check a master-slave configuration, which respects what we are interested in for a monitoring task.

The picture below brings the operational demonstration of driving in real-time the dynamic virtual model of the Maestro inside the Petrus environment, thanks to an Haption Virtuose 6D RV haptic device, while taking advantage of force feedback as the virtual arm meets the environment.

IDENTIFICATION OF THE MODEL PARAMETERS

Last, a measurement campaign was led on CEA Maestro manipulator, using the Leica laser-tracker system of ENEA, in order to get back all required real geometric data of the arm.

CONCLUSION

Most of the software and architecture developments of the demonstrator have been performed, and the ability of simulating the dynamics of the mechanical system in real-time is achieved.

As the arm availability could not meet a more thorough measurement campaign (to identify the missing parameters) by the end of 2002, the task was extended to September 2003. Further steps for global achievement will consist in:

- dynamic identification of the mass, inertia tensors and friction parameters,

- integration of these calibration parameters inside the simulator of the Maestro, and check for the realism: one will compare the torques, given by the TAO controller one way, and the simulator the other way, for some identical given joint and cartesian paths, asked separately the real arm and the virtual arm to follow,

- off-line checks of the simulator behaviour, in two distinct configurations: motions in free space then collisions with obstacles. This will express how the simulator can monitor the system, and for instance detect a collision; it will rely on comparisons of the torques and positions given by both real and virtual systems, in same configurations. Getting orders of magnitude on these values and also information about the dynamics of the simulation, will help assessing how fast and accurate events are given back,

- reflections/developments to integrate the IHA model of the oil flow actuators: the use of the complete model or the implementation of an equivalent reduced one will be subjected to the results of the off-line behaviour of the simulator,

- final analyses of the results and recommendations to implement on-line real-time condition monitoring.

REPORTS AND PUBLICATIONS

Expected sept. 03 CEA report: *"Developments and conclusion upon the dynamic simulation of a remote handling system for condition monitoring*", Catherine Bidard, Laurent Chodorge

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TW1-TVA-RADTOL

Task Title: RADIATION TOLERANCE ASSESSMENT OF REMOTE HANDLING COMPONENTS

INTRODUCTION

Works engaged on 2001 concerning the feasibility of a combined link (optic and electronic) between analog data (as simulation of a sensing information) and control room have been achieved by validation to ITER constraints of a prototype.

According to synoptic and results given on [1], the expected components, VFC and PWM converters have been irradiated to ITER environments.

In such conditions, only the PWM has achieved successfully the validating tests. Associated with optoelectronic components qualified by SCK, a full link has been designed.

A state of the art concerning useful remote functions and sensors for embedded electronic for future ITER machines sensing has been also achieved. Then, lastly, evaluation of line drivers components able to enter in a bifilar or optical link have been done.

FUNCTIONAL SYNOPTIC

Synoptic represented on figure 1 summarises work engaged on this year. Upper sensors, connected with serialise framers, are integrated are common parts of embedded digital multiplexers. Framer function, mainly designed with logic components has been engaged.

The full link; starting with analog to digital PWM conversion and directly connected to amplification and optoelectronic conversion (white box) has been designed, realised and validated for ITER constraints.

Line drivers and receivers have been tested alone.

Lastly, design of serialise framer has been started with recent CMOS technology components.

The evaluation of these technologies have been done during T252 developments [2] [3]. Results on main functions (latches, serialiser, flip-flop) should be available on mid-2003.

2002 ACTIVITIES

Works have started with the evaluation of the analog to digital converters, VFC and PWM functions. Control algorithm is very similar to those used during the previous evaluation campaign [4].

VFC components, ADVFC32 manufactured by Analog Devices, have been implemented on a new test bed (see figure 2).

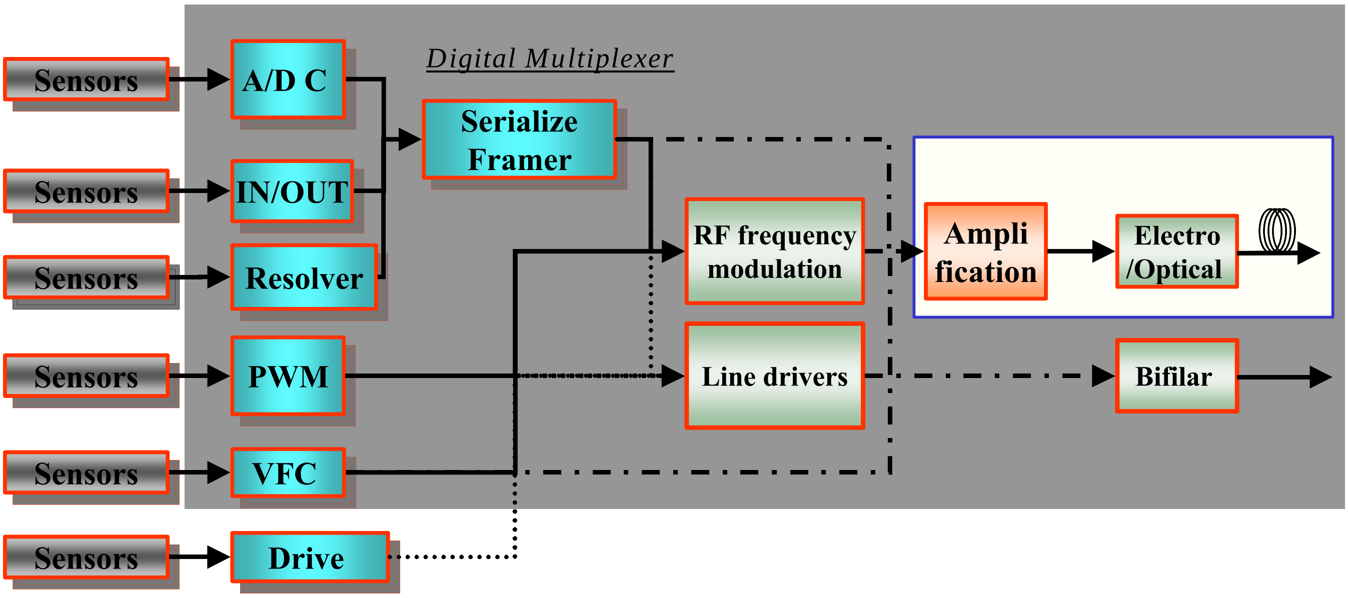

Figure 1 : Synoptic concerning functions useful for ITER

Card has been submitted at a dose rate of 20-30 kGy/h of Gamma Rays at SCK/CEN facilities as shown on figure 2 during April 2002.

After few hours of correct comportment, total failure has occurred for each component. No exchange of components has been done because the access to the bottle was no so easy. The components have been kept under irradiation up to the level of 10 MGy.

The curve shown on figure 3 (*do not take into account the lack of X axe*) gives frequency conversion with an appreciable linearity for both up and down voltage scale. After about two hours, drifts are observable for high voltage conversion. This state increases during the last control period. No more conversion was possible until this point.

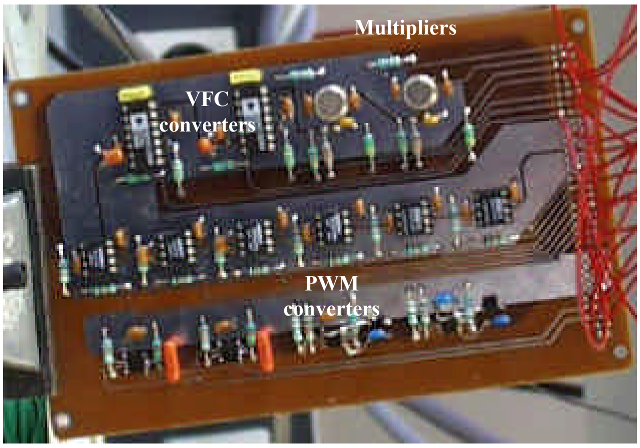

Figure 2 : Test card for SCK-CEN facilities

No recovery has been observed few days after end of irradiation during and after the post-irradiated heated week at 150°C. Conditions of control were the same than during irradiation.

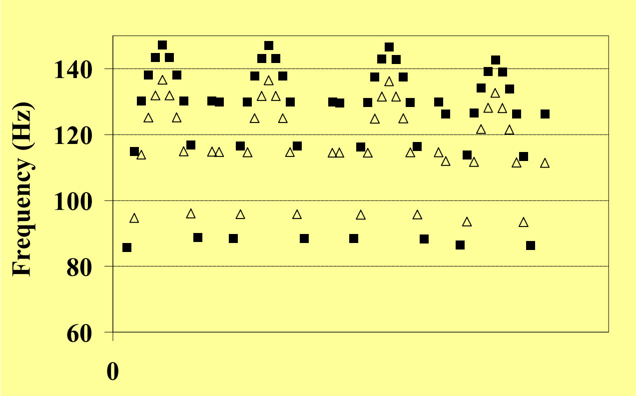

Figure 3 : Curve representative of ADVFC32 before failure

Next function to be studied is PWM conversion.

The test card used for ADVFC32 components has been completed by two new NE555, manufactured by Texas-Instrument, components.

The test protocol was the same than for previous experiments with input voltage varying from 1,5 V to 5 V, by up and down 0,5 V step and a permanent state at 3 V. Control was done every 50 minutes.

The experiment lasted up to 500 hours to reach approximately a total dose of 10 MGy with a temperature inside the bottle regulated around 50°C which correspond to the heating introduced by radiation.

New experiment has been scheduled with NE555 and TLC551, both from Texas-Instrument, with common characteristics. One of the advantages is the conversion of input voltage triggered with an external clock. As timing curves from figure 5, it should be possible, with a duty cycle upper 90 % for the clock signal, to convert an input voltage from 0 to 5 V in a pulse with width varying from 60 µs to 400 µs at clock frequency.

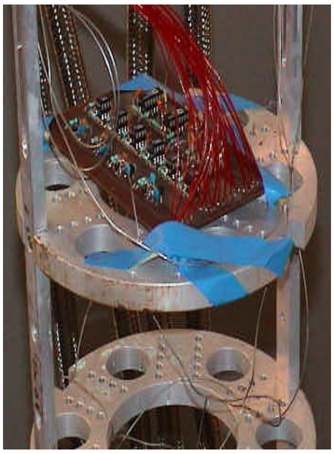

Figure 4 : Test card on bottle before irradiation

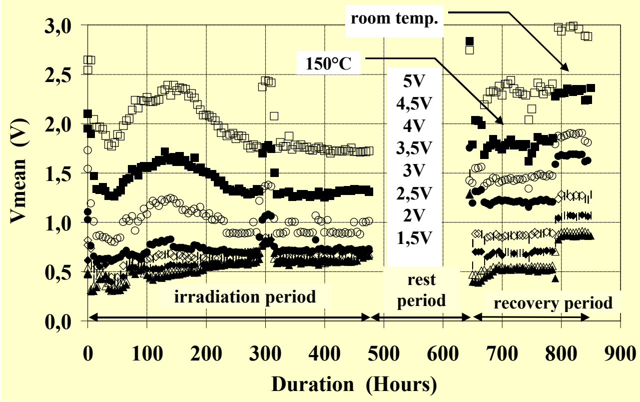

Figure 5 : Evolution of NE555 Vmean (irradiation and post irradiation)

At the end of the irradiation, the components were still alive and did not show lot dispersion for any of the converted voltage. Figure 5 represents behaviour of one of these components for input voltages from 5V to 1,5V by 0,5V step.

The rebound phenomenon observed during the first hundred hours has been already seen on previous experiments in the case of T252 developments.

Often, it is followed by a quasi-permanent state, balance between radiation effects and overheating due the important dose rate of Gamma rays.

A partial recovery has been taken place during the two weeks rest period. A heated week period at 150°C have achieved recovery and a plain dynamic of input voltage.

The next evaluation concerning this component was combined irradiation with temperature around 120°C. Once again, no failures were observed and results have shown curves in the same order than those of figure 5.

In any case, the components have passed with success these two particular tests.

An other function to be evaluated is the AD534 analog multiplier.

The test card (see figure 2) has been completed by two AD534 components.

Chronograms of parameters have been registered directly on oscilloscope 3,5’’ storage disk, after adapted triggering from PC (every six hours) in order to avoid overflow of memory disk. Control algorithm is very similar to those used during the previous evaluation campaign [4] in order to reach NEUROBOT working conditions.

An overview of results, given on [4] shows a continuous degradation of both AD534 components, leading to a probable lost of functionality. However, no fatal destruction seems to be arrived. The very similar comportments of the components during most of the irradiation let to think to a lack of lot dispersion.

Two failures caused by irradiation can be proposed: modifications of translinear electronic multiplier function or modification of the bias conditions mainly regulated by a zener diode.

Few days after end of the irradiation, a recovery period with heating at 150°C has allowed a quasi-full recovery of functionality after only one hour.

Survey concerning main embedded electronic functions for remote handling machines developed by CEA for ITER modules has been done [5].

The key interest is focused on a new concept of electronic network chaining elementary cells placed as near as possible actuators or sensors they drive, in order to reduce umbilical and achieved mechatronic goals.

An hybrid component has been developed to realise this function. Designed for low radiation level environment, the integration to ITER development needs to review main of the basic functions in order to respect radiation and temperature level. Most of the results issued of T252 experiments could be used. Complementary studies are going on, especially with logic components.

Finally, line drivers from LVDS latest technology have been experimented. Previous results, shown on [6] have given interesting results concerning the opportunity to use them at higher cumulated dose.

Three emitters typed LVDS31 and three receivers typed LVDS32 from both Texas-Instrument and Pericom manufacturers have been used. In order to evaluate lot dispersion, only one element of each sample has been evaluated.

Each hour, a clock signal at 100 kHz is sent to the embedded emitters in order to be converted on differential signals at LVDS level and transmitted out of irradiated area to reference receivers in control room.

Then, the same clock signal is sent to reference emitter in control room in order to be converted. The differential signals are sent to embedded receivers. The logic signal is transmitted out of irradiated area in order to be measured and compared to the clock signal. Figure 6 represents the electronic schematic of the implantation.

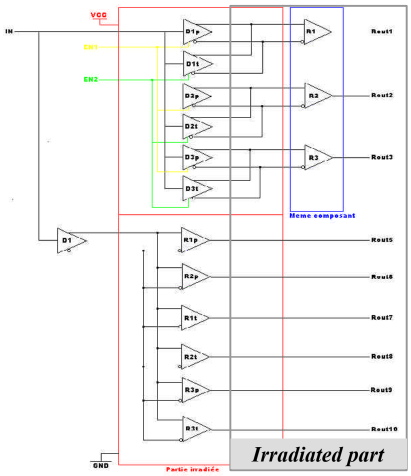

Figure 6 : Electronic schematic of embedded test functions

The parameters followed during the experiment are the mean value and the frequency of receivers, irradiated and reference.

During the irradiation at SCK facility, dose rate has been around 20 kGy/h for a temperature between 100 and 120°C (see figure 7).

Even if some difficulties have perturbed the expected values, mainly due to noise in wires and connecting boxes, deficiency of components from TI was clearly shown in the first hours of irradiation.

At the end of the campaign, most of Pericom components remained functional. It was notified that one of the emitters gave wrong mean value after 8,6 MGy.

The post irradiation control has confirmed the deficiency of TI components.

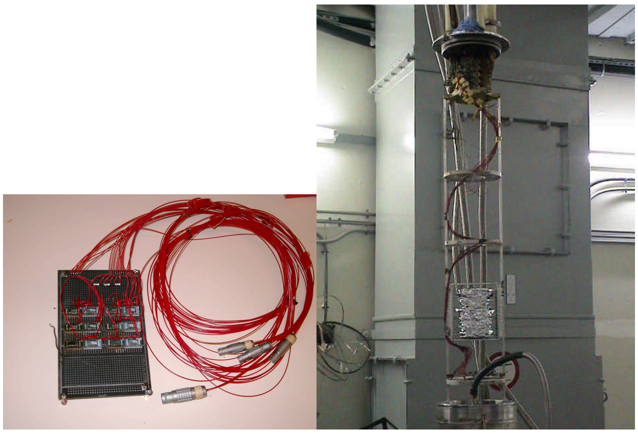

Figure 7 : Test card of LVDS components (SCK facility)

Concerning the Pericom emitters, the registered chronograms of figure 8 let to show the weakening of differential signals between left side at 0 Gy and right side at 12 MGy of total dose acceptance (less than 250 mV). Even if the post irradiation measures with a reference receiver have always allowed a correct conversion, it should be probably one of the reasons conducting to the deficiency observed during irradiation.

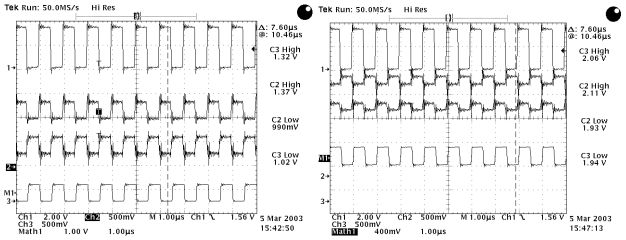

Figure 8 : Post-irradiation chronogram of Pericom LVDS31 emitters

Concerning the Pericom receivers, no failures have been observed on post irradiation measures with the reference emitter.

Nevertheless, sensitivity has been affected for a few of them. The three curves of figure 9 resume some of the converted signals coming from clock (upper 3,6 V square signal), through irradiated emitters (differential signals) to receivers (lower 3,6 V square signal). First curve shows a correct conversion while errors appear on the others. This point must be taken into account by end users in the design of their final applications in order to assume correct levels through connections (bifilar or optical) for differential received signals.

Last work engaged concerns a prototype of a serialise framer. The function has been designed with logic component able to replace shaft registers not available on CMOS recent technologies. Moreover, this component could be used to realise deframer. Couple of it is integrated on the testcard (see figure 10).

In the same time, couples of latches and flip-flop from both recent and oldest CMOS technologies have been implemented on the testcard.

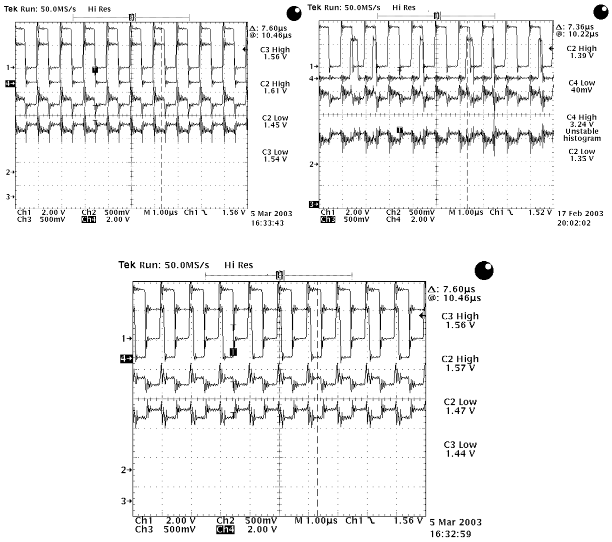

Figure 9 : Post-irradiation chronogram of Pericom LVDS31 receivers

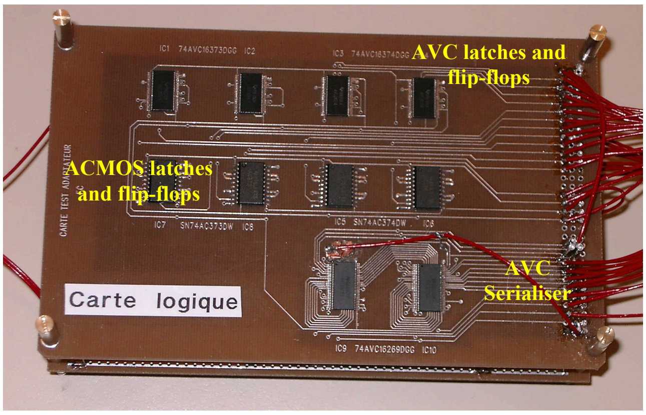

Figure 10 : Logic test card used for validation under ITER constraints

CONCLUSIONS

The full link designed and validated by the end of 2002 has allowed a direct reading of an analog data simulating a value given by a sensor. Combination of electronic and optoelectronic has been proved. An interpretation of the results must improve the adjustments necessary to reach the real sensor data. This could be done at room control by adaptive software. Concept of embedded network like NEUROBOT, even if today, dose acceptance is not achieved for elementary cells, should be kept for arm robotic developments.

Then, concerning recent LVDS data transmission protocol, it seems clear that important dispersion has been notified between manufacturers. Nevertheless, results obtained on Pericom family have kept functionality, even if a drift has limited differential voltage acceptance.

Work engaged on logic functions should normally lead to the availability of serialiser which is a main part of embedded multiplexer.

REPORTS AND PUBLICATIONS

[1] Fusion Technology Annual EURATOM/CEA Report 2001.

[2] Fusion Technology Annual EURATOM/CEA Report 2000.

[3] Fusion Technology Annual EURATOM/CEA Report 1999.

[4] Alain GIRAUD « RAD-TOL : intermediate report of June 2002 » DRT/LIST/DTSI/SLA/02-681/AG.

[5] A. BORG "RADTOL: definition of embedded electronic functions for remote handling" DRT/LIST/DTSI/SRSI/LEMS/02RT.028/Issue 0.

[6] Fusion Technology Annual Report 2000 Underline Task UT-RH4.

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CEFDA01-609

Task Title: LESSONS LEARNED FROM JET MAINTENANCE AND REMOTE HANDLING OPERATION

INTRODUCTION

JET is the only operating platform within fusion where RH techniques have been developed to a stage that allows in-vessel maintenance work to be carried out fully remotely. JET's RH team developed a methodology and a rational approach that helped them to succeed in the task.

However, this work also clearly shows that once one has a technical solution to a problem on paper, there is still a significant amount of work to be done before being able to say that you can perform RH operations in a safe and repeatable way. The gap between the first prototype and its upgrades to make it ready for operational use has a manpower cost which is often under-estimated.

ITER will be the next step fusion reactor. Remote Handling was defined by the ITER collaborators at the beginning of the project, as the nominal solution for the maintenance of the reactor.

The radiation levels expected inside the reactor during the latter stages of machine operation are such that maintenance work cannot be carried out by human intervention. There is also a wish to minimise radiation doses to personnel as much as possible during all phases of the reactor operation. The use of remote techniques will therefore be required for a large part of the maintenance programme.

The feedback provided by RH platforms developed for ITER within the L6 and L7 projects such as the Divertor Test Platform (DTP) at Brasimone (Italy) and the In Vessel Transporter (IVT) at Naka (Japan) is clearly a step further for the definition of ITER's RH in several fields. But one has to admit that significant evolution in the design of the machine due to the change from ITER'98 to ITER-FEAT has produced the need for a significant amount of re-working.

2002 ACTIVITIES

HANDS-ON VS. REMOTE OPERATIONS

According to JET's experience the choice between RH and hands-on maintenance is always based on a balance between expected personnel dose and cost. However, the application of self-imposed safety criteria and/or the application of ALARA often leads to the tendency to perform operations remotely in places where one could theoretically operate manually.

For in-vessel and hot cell maintenance in ITER, the requirement for remote vs. hand-on maintenance will generally be much more clearly cut, certainly in the latter years of operation.

However, for ex-vessel regions, particularly around port plugs, it would appear that the working conditions are likely to be similar to those experienced in-vessel at JET and as such, a general drift towards RH operations might be expected during the course of the project.

This tendency should be kept in mind when considering maintenance solutions for these "grey" areas of the ITER machine and the appropriate measures to allow for RH maintenance (e.g. sufficient space, component standardisation and captivation) be incorporated in the ITER design from the beginning.

RH CONSIDERATIONS

During the development of the RH equipment at JET, the design of the JET machine was expected to be continually evolving. Because of this, JET based its RH philosophy largely on a generic "man in the loop strategy" which maximised its adaptability to the environment and minimised the need for re-configuration of the equipment from one shutdown to the next. Minimising the interfaces between the reactor and the RH equipment was also essential in achieving this goal.

Although component replacement is the main activity during scheduled maintenance, in JET's experience, lots of additional tasks (e.g. inspection, cleaning, measurement) are always requested as part of the standard maintenance scheme and answers to these problems have to be provided. The adaptability of the JET system has lent itself well to these circumstances.

In contrast, a large proportion of the planned ITER RH equipment, in particular for divertor replacement is (arguably by necessity) heavily dependent on the machine design. The disadvantage of this has been illustrated by the knock-on effect of the new ITER-FEAT design which has resulted in a significant reconfiguration of the divertor handling equipment.

This in turn has dramatically shortened the useful life of existing test facilities, i.e. the Divertor Test Platform (DTP) which is based on ITER'98, and has lead to the requirement to create an alternative DTP-like facility to serve ITER in the run up to construction. Although this situation was probably unavoidable for the case of divertor handling, the lessons learned from the JET experience should be kept in mind for other less constrained situations e.g. use of the In-vessel transporter, port plug maintenance and hot cell work.

DEVELOPMENT LIFE-CYCLE

Experience at JET shows that a piece of RH equipment is not ready for operations at the end of its manufacturing phase, but it has to go through further stages of development known as its “life cycle”.

The “life cycle” can be defined as follows:

- Phase 1: Definition of the requirements & Design of the system.
- Phase 2: First version system.
- Phase 3: Development to maturity.
- Phase 4: RH operations.

This evolution will only be efficient if:

- interfaces between the RH equipment and the machine are frozen,
- R&D work is completed.

It is notable that no significant technological R&D was carried out, or in fact needed at JET, during the development of RH equipment.

In the particular case of JET, the complete development of the RH equipment involved approximately 260 man-years of effort before becoming completely operational and reliable. The work was distributed roughly as follows:

- Definition of the requirements and Design of the first systems: 45 % of the total work.
- Integration, upgrades and mock-up trials in order to become fully operational: 55 % of the total work.

However, experience showed that the development time can be significantly reduced for the new systems if similar design principles are applied.

The message for ITER contained in this experience is clear. Even having developed and successfully tested the first prototypes of an RH system, a great proportion of the effort still lays ahead.

RELIABILITY AND RESCUE

Estimations of the reliability of the JET RH systems using standard methods (based on the prediction of a Mean Time Before Failure) proved difficult because of the prototypical nature of the equipment. Instead the reliability of the RH systems was assessed and improved during long lasting endurance test campaigns in purpose built scale one mock-ups or test facilities. This was augmented by short periods of operation in the JET machine during an earlier shutdown when man-access was still possible.

Before starting a fully remote campaign at JET, measures were put in place to be able to remotely recover RH equipment from all in-vessel failures which were considered credible.

Nevertheless, it is important to note that, even at the highest levels of in-vessel activation, there was always the backup possibility for manual intervention in case remote recovery of failed equipment proved impossible.

For ITER, because at some point man-access will be completely impossible, the definition of the frontier between credible and non-credible failures will need to be more extreme. However, it does appear that during the first 7 years of operation, in-vessel radiation levels will remain low enough to allow man access. From an RH operational standpoint, it is important that this time is used to the full with regard to the development and tuning of the RH equipment.

CONTROL SYSTEM DEVELOPMENT

The JET experience has shown that control system standardisation can provide huge benefits in terms of quick response to failures and reduction of spares. The ability to adapt specific systems in-house, particularly in terms of software has also greatly reduced the time needed to respond to new task requests and develop new items of RH equipment. It also allows one to reduce the number of different man-machine-interfaces operators have to become familiar with. This in turn reduces training overheads.

The controllers for all the main pieces of RH equipment currently operational at JET (i.e. Boom, TCTF, TARM and Mascot) have effectively been "built to print". Prior to the adoption of this approach, the detailed design of control systems was carried out by external companies based on functional requirements with little or no specification of the hardware or software solutions to be used. Over the years, this resulted in difficulties for software development and bug fixing, the need for high levels of different spares and difficulty for a limited number of in-house engineers to be familiar with all the various systems. It is interesting to note that over recent years, similar problems have been reported in relation to the DTP. It therefore appears that, as well as being a topic for future consideration for ITER construction, there could be more immediate benefits in considering such an approach for the ITER prototype development program currently underway.

Regarding the way in which the operator is required to interact with the equipment, the ability to develop and, in many cases, simplify MMI's has allowed the JET development engineers to quickly tailor systems to suit the RH operators. Previously, it was found that many of the "advanced capabilities" of the RH equipment were heavily under used because it required a significant amount of background knowledge and technical understanding in order to exploit these features properly. As a result, significant effort has been made over recent years to simplify MMI's to a level at which operators feel comfortable.

Generally, the RH operators employed at JET have limited tertiary education and therefore concepts familiar to development engineers are not always obvious to operators. Within the framework of ITER R&D, recent experience with the Maestro servo-manipulator system at the DTP has highlighted similar problems.

TOOLING DEVELOPMENT

Maintenance tasks require tools and designing these to be remotely operable requires special measures to ensure 100% success during operations. One approach used at JET was to provide specific features to reduce the task complexity and transfer much of the responsibility for difficult aspects of the task (e.g. guidance of components within close limits) from the operator to the tool itself. A common feature of this technique is that remote tooling requires more space than would have been needed for manual tooling. This is, unfortunately, a necessity if one is to guarantee the best chances of success, a point often not appreciated by machine designers.

Although the number of tools can be minimised by standardisation, the large number of tools required during each shutdown at JET has created a significant overhead for tool repair, storage and contamination control. Although this has proved manageable by the development of a rational system to manage these processes, including the use of unique tool identification and databases, the man effort required has proved surprisingly high. This is an overhead that should not be overlooked for ITER.

VIEWING AND VIRTUAL REALITY

Preparation of the tasks procedures and feasibility trials at JET have been greatly assisted through the use of a Virtual Reality modelling of the torus and RH equipment. But because VR is unable to cope with unpredictable situations like machine damage, intensive use camera views remains central to the RH strategy employed at JET. As a result, final validation of tasks at JET still require the use of the in-vessel mock-up and of real time viewing systems. In fact some maintenance tasks that were clearly defined as routine work (e.g. inspection, cleaning) can never been made without a real-time high-quality viewing system. In addition, colour images, while not essential, have been found to help the operator's visual referencing, even in a supposedly “grey environment” like the inside of a tokamak. Special attention also has to be paid to the provision of good lighting conditions. For ITER, the topic of real-time viewing for RH operations seems not to be well defined, although recent predictions for radiation levels in the divertor region suggest that the use of standard radiation hard cameras should be possible. In addition the question of providing lighting in-vessel has yet to be addressed.

SUPPORT FOR RH OPERATIONS

It is easy to forget that the RH equipment operating inside an area needs a huge amount of external backup (e.g. cubicles, wiring, storage areas, maintenance and decommissioning areas) and this takes up a large amount of space outside the working zone. When RH is a necessity, it is not only essential to provide a RH-friendly design for the machine and its components, but also to provide the necessary support (access space, building space and management procedures) to allow for RH operation to be carried out in a safe and reliable way. This appears to be an over-riding message when talking to JET RH staff about their experiences and should clearly be taken on board in the preparations made for ITER.

CONCLUSION

JET has the unique experience of creating the only operational system for tokamak maintenance that has already successfully carried out long-lasting maintenance campaigns under fully remote conditions. It is clear that although some differences exist between ITER and JET RH environment, ITER could surely take advantage of the lessons learned throughout the years at JET to help it proceed in the development of its RH equipment and strategies.

REPORTS AND PUBLICATIONS

DTSI/SRSI/LPR/02RT.066 Operational experience feedback in JET. Collect of data. O. DAVID.

DTSI/SRSI/LPR/02RT.067 Operational experience feedback in JET. Final report. O. DAVID.

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UT-VIV/AM-Actuators

Task Title: REMOTE HANDLING TECHNIQUES
Advanced technologies for high performances actuators

INTRODUCTION

This task follows UT-RH3 Actuators.

Maintenance of fusion reactors requires high performances of Remote handling means. In addition to hazardous environment conditions, maintenance requires high performances for robotic devices. In fact, high load are required to be handled, and only narrow space is available for the motion.

Conventional design of robotic device reach its limit in such conditions. In order to build adequate handling or inspection RH device, R&D activity is required on this field.

State of the art actuator used to drive robotics devices need improvement in term of load capacity versus size of actuator.

PREVIOUS WORK

Actuators based on the thermal expansion of wax have shown exceptionally high ratio load capacity versus size and weight.

Their main drawback is a long response time but this is not dramatic in the context of maintenance tasks requirements delays.

We decided to make use of this technology to build a bore tool device suited for 2.5" pipe (Ø 63.5 mm) where conventional actuator reach their performances limits.

During the first design phase, tiny pieces made of ceramic have been used for insulation purpose. Limits due to mechanical behaviour have been shown (fragile).

But insulating-thermosetting trade-off has to be done to select the right material.

After acceptable results from thermosetting and indentation hardness tests, phenolic material (celoron) was selected as insulation component to perform tests on the future mock up.

2002 ACTIVITIES

During the year 2002, a new design of the clamping and aligning module for 2.5’’ diameter bore tools was achieved. It makes use of Eltek™ actuators mounted in insulating casts. The number of components was reduced and simplified.

Pieces were machined and the assembly was mounted. The general structure of the module has been validated. Improvements have to be done to reduce the friction in the synchronization system.

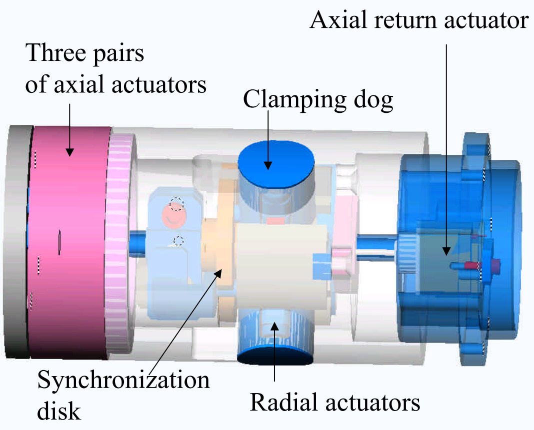

Figure 1 : Overall view of the new design

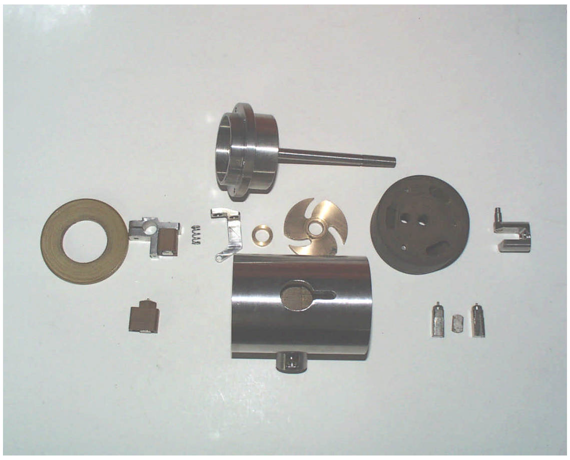

Figure 2 : Manufacture of the mock up

The wiring is achieved after the mechanical structure is mounted. Each pair of actuators must be connected by two wires, so far the whole module supports 16 wires for the actuators and 2 wires for each thermistors in a small volume. In order to save space, the connecting wires were welded directly on the actuators.

Specifications of the global tests campaign have been detailed. Very first tests were not acceptable to validate the wiring but the clamping operation was satisfying. Improvements are still required to overcome insulation issues.

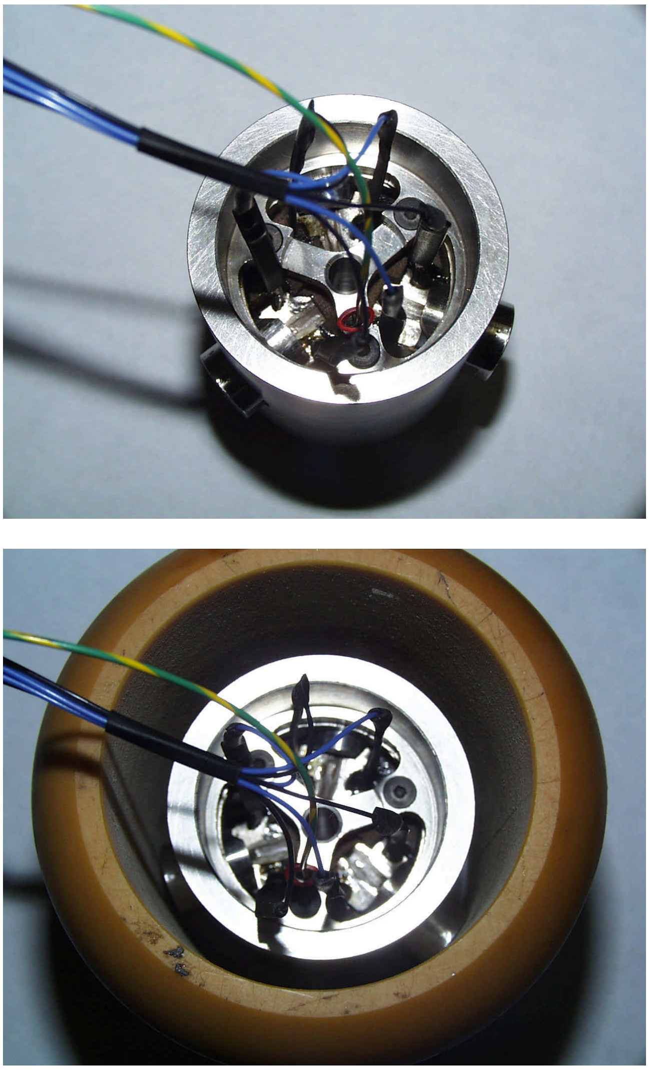

Figure 3 : Test of the clamping module

As the concepts are validated on the clamping module and on the high capacity of the thermal Eltek^{TM} actuators, future work should be carried on in order to test the whole module and solve the operating safety problems.

FUTURE WORK FOR YEAR 2003

- Improve the wiring and the connections.
- Perform the global tests campaign.

PUBLICATIONS

CEA/DTSI/SRSI/LPR/02RT.023/Issue.0 "New design and test planning of a clamping module".

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UT-VIV/AM-ECIr

Task Title: REMOTE HANDLING TECHNIQUES Radiation tolerance assessment of electronic components from specific industrial technologies for remote handling and process instrumentation

INTRODUCTION

Last year developments have allowed evaluation of submicronic CMOS technology (0,25 µm) HCMOS7 from STMicroelectronics [1]. The few drifts on most of the tested structures measured after high-level radiation have shown a significant dose acceptance. Nevertheless, it could not be possible to pursuit investigation on recent versions of this technology because no ASICs have been developed this year.

In any case, the size reduction of elementary CMOS transistors come with a lower supply voltage applied on the device. As designers convert functions such processors, ASICs, memories using the more recent technologies, they need low voltage logic components to connect them.

The need to operate at lower voltages is a challenge that many designers are faced today, extend battery life (or reduce size) on portable application, reduce heat dissipation in a constraint environment …

Texas-Instrument has developed and manufactured a CMOS Advanced Ultra Low Voltage, AUC, logic technology, optimised for 1.8 V.

Moreover, TI has added a new concept of packaging which saves space by limiting devices to single or dual AUC gates. This allows designers to place a particular gate function close to related circuitry, shortening and simplifying routes on a board.

Work started in 2002 takes into interest the evaluation of AUC logic technology under irradiative environment.

2002 ACTIVITIES

EXPERIMENTAL SETUP

With some regards, the experiment conducted here seems to be very similar to HCMOS7 experiment setup. Basic components like inverters and drivers have been selected on the list of AUC single gates SOT23 packages.

At the time of the experiment, very few logic functions existed. So, no real end users functions have been designed. Only NAND, NOR and OR single gates have been used.

Table 1 gives reference and functions of tested components. Two experiments have been scheduled. Main results of experiment 1 are presented in this paper.

Bias during irradiation: on-line experiment has been used to control this new technology (see figure 1). The orange part corresponds to the irradiated area with testbed card.

All the components have been supplied at Vcc = 1.8 V. Table 2 gives the bias conditions during irradiation.

In order to limit cables, only one of each component has been evaluated.

Table 1 : Reference of tested AUC components

AUC1G00	Nand Gate	Exp 2
AUC1G02	Nor Gate	Exp 1
AUC1G04	Inverter Gate	Exp 2
AUC1G06	Inverter Driver	Exp 2
AUC1G07	Non Inverter Driver	Exp 1
AUC1G17	Triggered Driver	Exp 1
AUC1G32	Or Gate	Exp 1
AUC1G125	Bus Driver Gate	Exp 1
AUC1G126	Bus Driver Gate	Exp 1
AUC1G240	Inverted Bus Driver Gate	Exp 1

Each hour, controls have been done by PC to polarise input and output enables of components in order to read the transfer function Vout = f(Vin) of the component.

Table 2 : Bias conditions for experimented components

AUC1G02	Inputs biased at 0V
AUC1G07	Input biased at 0V
AUC1G17	Input biased at 0V
AUC1G32	Inputs biased at 0V
AUC1G125	Input and output enable at Vcc
AUC1G126	Input and output enable at 0V
AUC1G240	Output enable at Vcc, input at 0V

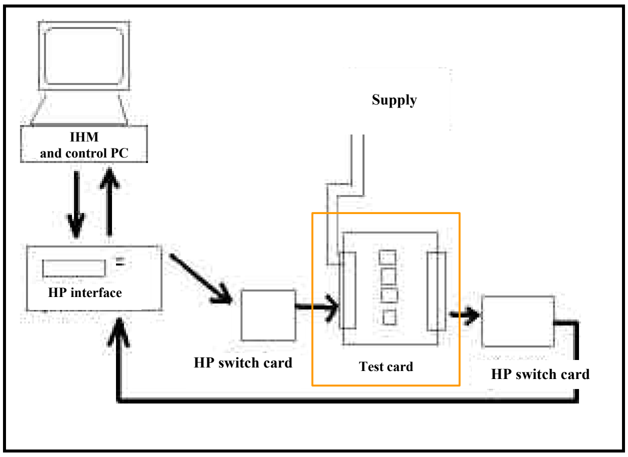

Figure 1 : Testbed of the experiment

Facilities: To perform the experiment, the Co^{60} facility IRMA from CEA/IPSN is used with an average dose rate of 40 Gy/H during four days followed by a 2,8 kGy/h.

The campaign has lasted fifteen days. Components temperature during irradiation was comprised between 30°C and 50°C.

Static electrical characteristics: The measurements of these parameters take place before and after irradiation at room temperature using an HP4145B analyser. No steps have been scheduled during irradiation period.

Three parameters are measured considering the next conditions:

- Output voltage function of input voltage Vout = f(Vin) for Vin varying from 0 to 1.8 V and reverse. This parameter shows the average threshold voltage (Vin for Vout = Vdd/2) evolution of the component during the irradiation and the availability to be kept for logic functions.

- Output voltage function of output current Vout = f(Iout) for Iout varying from 0 to -20 mA. Vin is polarized to the corresponding value in order to have Vout at high level when Iout = 0 mA. This parameter shows the load capacitance and the availability to be associated with others logic elements.

- Output voltage function of supply voltage Vout = f(Vcc) for Vcc varying from 1.8 V to 0V. Vin is polarised in order to have Vout at high level.

The supply voltage, Vcc, is fixed at 1.8 V.

RESULTS

The fifteen days of the campaign have allowed reaching a total dose of near 700 kGy.

At the end of the experiment, all the components kept their functionalities. No significant increase of current consumption has been notified.

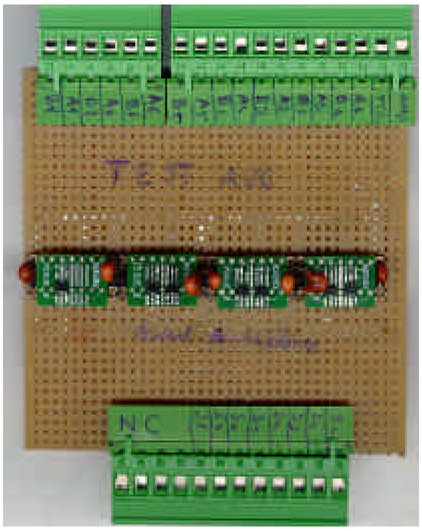

Figure 2 : Test card

No failures have been observed on most of the components (see upper figure 3).

Nevertheless, a sudden drift has affected the AUC32 “1” response (see lower figure 3). This phenomenon can be interpreted like the presence of leakage current inside probably one or more of the internal NMOS transistors.

This current coming from PMOS transistor increases the drain to source voltage and reduces output voltage Vout.

For open-drain output AUC07, the evolution of “1” state is very similar to those observed on basic MOS transistors [2][3][R1].

As shown on [R2], without the p-channel MOS transistor pull-up on the output structure, the entire output voltage drops across the n-channel MOS transistor.

Voltage is achieved on the test card through an external few kΩ pull-up resistor. Then, the evaluation under cumulated dose is usual.

The small variations on the curve correspond to a recovery period starting after each short stop of irradiation.

This drift often notified during high dose rate campaigns [3] was annealed when irradiation comes back.

The next figures represent pre and post irradiation controls of devices static electrical parameters. Curves for each figure are presented in the same order.

Concerning pre and post control of AUC1G126 device (see figure 4), an approximately 0.2V drift on threshold voltage (at Vout = Vcc/2) associated with a very narrow range is observable on post irradiation curve.

Load charge and Vcc min have a few diminished in respect, for such total dose, with nominal characteristics of AUC technology.

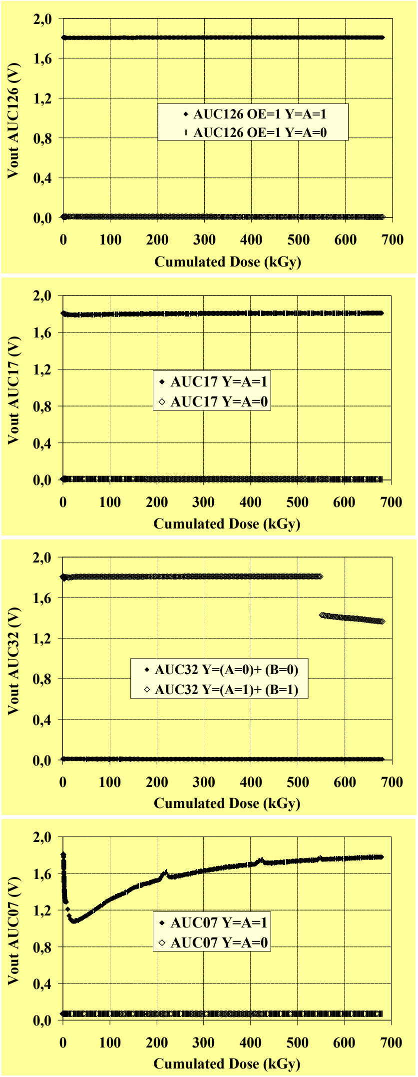

Figure 3 : Evolution of Vout during irradiation for some AUC components

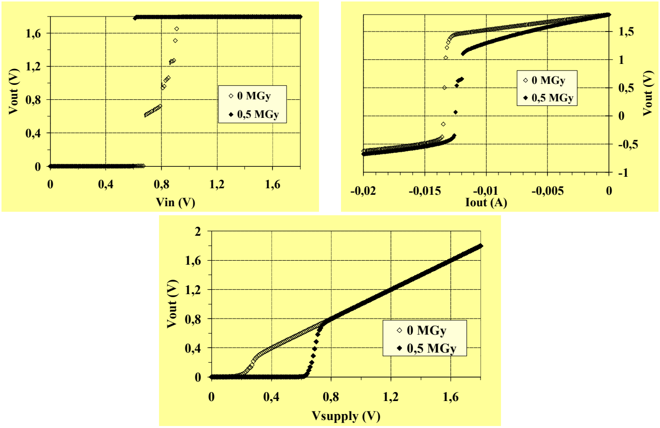

Figure 4 : Pre and post evaluation of AUC1G126

Concerning pre and post controls of AUC1G240 (see figure 5) the large range of commutation has been little reduced and duration of high and low level smoothly changed. Load drifts stay into recommended operating conditions (-8 mA at 1.2 V for Vcc = 1.8 V). It is the same for minimal supply voltage.

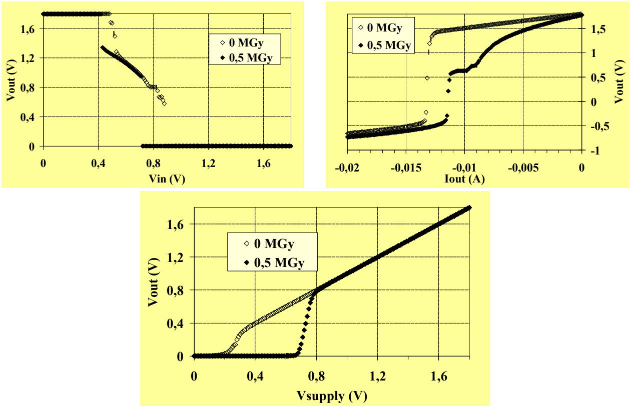

Figure 5 : Pre and post evaluation of AUC1G240

Concerning pre and post controls of AUC1G02 (see figure 6), drifts on threshold voltage comes over 400 mV at Vin = 0.4 V. Noise immunity could be affected.

Load is significantly affected by the radiations. The value of –8 mA could be reach with an output signal less than 1 V.

Minimal supply voltage has increased to 1.2 V. This comportment could be awkward if the drift continues to grow again with more radiation, and on the contrary; tolerated if it is stabilised.

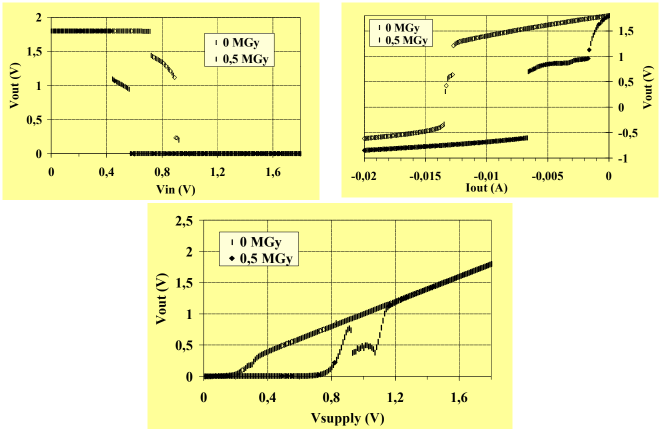

Figure 6 : Pre and post evaluation of AUC1G02

The post irradiation measures concerning AUC1G32 (see figure 7) confirm the “1” state level at 1.4V shown during on-line investigations.

Threshold voltage is not so affected while either load or minimal supply voltage is deficient.

Even with a lack of irradiated samples and functions, it appears that basic logic functions have a greater sensitivity to radiation than elementary components.

The bias configuration retained during this experiment (input at 0 V) which is always referenced as the best case for elementary components, can however turn out to be limited due to the unknown design of the function on the die.

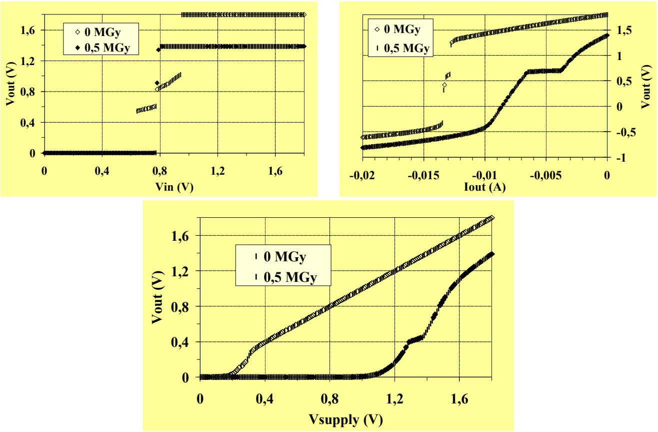

Figure 7 : Pre and post evaluation of AUC1G32

SiGe TECHNOLOGY

The very important difficulty to find elementary SiGe transistors has introduced an important delay in the evaluation on constraints environment. This technology has been originally designed for high-speed data communication in order to replace or complement Gas family. That is why it is often used as drivers for optoelectronic links. This application has a direct interest for data communication for remote handling ITER engines. Finally, five transistors from SiGe Semiconductor have been packaged (figure 8).

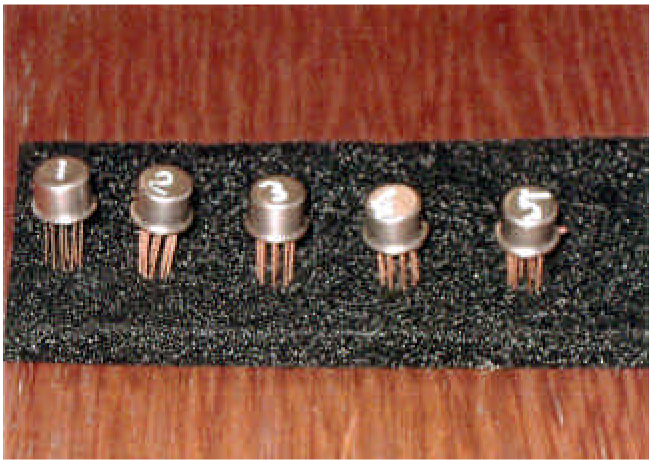

Figure 8 : Tested SiGe transistors

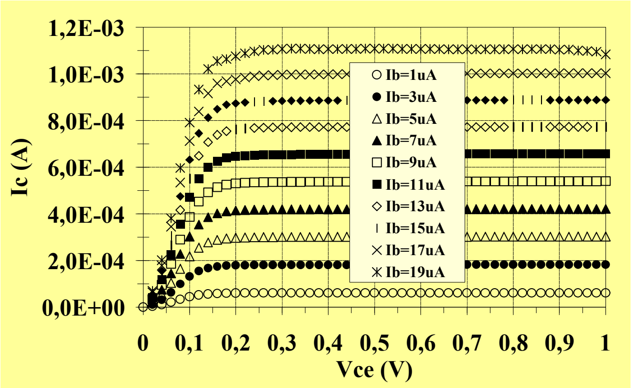

Figure 9 : Transfer function Ic = f(Vce)

Parametric measures have also been done. They are very closed of usual bipolar transistor.

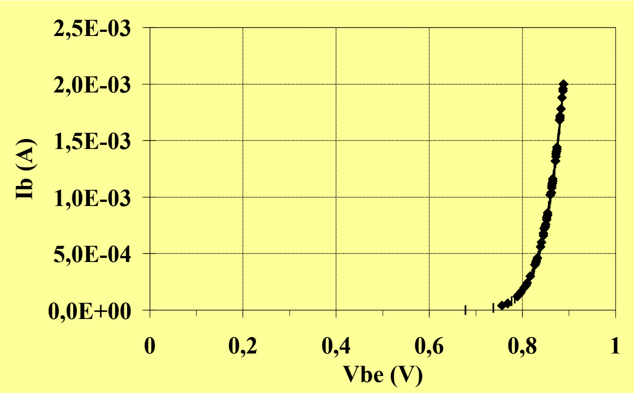

Figure 10 : Ib = f(Vbe)

CONCLUSIONS

Since the end of this first experiment, numerous components, mainly basic functions of AUC Little Logic Technology are now commercially available. Market seems to be more important than for older intermediate TI technologies (ALVC and AVC). More, AUC Little Logic is alternate sourced by other manufacturers.

It clearly seems that AUC represents a technological jump leading to a necessary redesign of oldest applications using bipolar to CMOS 5V (3.3V ?) technologies.

So, the reasonable results obtained on first investigations to very constraint environments (thermal, radioactive) must go in order to increase compartmental knowledge on that technology.

It seems also important to appreciate increase of reliability and availability for remote handling engines in nuclear applications when space is saved due to low power and low supply electronic modules.

Finally, for small market production, the easy use of tiny logic components (Ball Size Array packaging) for tests could be more interesting than ASIC dedicated technology. SiGe studies are to be completed.

REFERENCES

[R1] “Study of Dose Effects on IGBT-Type Devices Subjected to Gamma Irradiation”, M. Marceau, TNS December 1999 pp1680-1685.

[R2] “Application of the TI AUC Sub-1V Little Logic Devices”, Application Report SCEA027A September 2002 Texas-Instrument.

REPORTS AND PUBLICATIONS

[1] Fusion Technology Annual report 2001 UT-VIV/AM/Eclr.

[2] Fusion Technology Annual Report 1999.

[3] Fusion Technology Annual Report 2000.

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UT-VIV/AM-HMI

Task Title: REMOTE HANDLING TECHNIQUES Graphical programming for remote handling techniques

INTRODUCTION

Hands-on assisted operations and/or remote interventions will have to be thought about when planning a maintenance or repair scenario inside a Fusion Tokamak reactor.

Due to radiations involved in such environment ($\sim 10^4$ Gy/hr considering ITER in-Vessel), the dose exposure must be taken into account when designing the scenario, especially to comply with ALARA principle.

Hence, we reflect and develop in UT-VIV-AM-HMI task an intervention simulation tool, based on appropriate algorithms and virtual reality technologies, able to bring the user interactive dose rate evaluations during any simulation, meeting Fusion requirements.

Such a tool will prove useful to foresee best intervention scenario, prepare operators and check procedures.

During 2001 year activities, one reflected about the most relevant algorithms, methods and software architecture to be retained to answer the needs.

Especially, the numerical method for dose rate evaluations (dose equivalents for a human being, doses for hardened materials) was much investigated, and led to focus on the straight line attenuation method with build-up factors, potentially able to answer interactivity requirements.

One then developed a former mock-up, linking the numerical calculation to *Igrip* robotic CAD software (where the scene can be described), *reaching real-time and on-line simulation of doses, for point-like γ radiation sources.*

2002 ACTIVITIES

Considering a radiative source as a single emitting point perfectly warrants on-line and real-time features of the simulation tool, but can be not accurate enough to depict realistic sources, required to answer potential configurations of Fusion issues.

We thus intended in current 2002 year to improve the simulation tool to *surfacic* (2D) and *volumic* (3D) sources.

When one ray comes out of the source for a single emitting point, a continuous envelope of rays comes out for 2D/3D emitting sources, which hugely increases the volume of elementary calculations.

REFLECTIONS UPON NUMERICAL APPROACHES TO MANAGE VOLUMIC SOURCES

We first looked at the numerical approaches based on the simplified straight line attenuation method already retained, in order to perform volumic sources:

- a deterministic approach, lying on an integration of the dose, upon appropriate partitions of the entire source volume, though advantageous for its accuracy, brings the major drawback of quickly enlarging the amount of calculations, as soon as the configurations turn more complex (several screens, complicated shapes …),
- a statistic (Monte-Carlo) approach, as the one of *Mercure* code (developed by CEA DEN/DM2S/SERMA teams in Saclay, and based on the retained method), proves more relevant for our needs. It consists in approximating the integral, for a given geometry, by pertinent averages, of the function to integrate, on dedicated points drawn in the volume of the source.

Evaluating the effect of a volumic source then sums up to compute the impact of many points parted in a 3D network of meshes in the source, according to laws of contribution of each mesh. Each random point contributes to the global dose thanks to the classical straight line method with build-up factors. Consequently, the management of a volumic source induces an immense amount of elementary point-like calculations. Succeeding in performing the calculations in reasonable times requires drastic optimisations and improvements in the global method and process of calculation.

PRELIMINARY STATISTICS ON COMPUTATION TIMES

Some evaluations upon most consuming parts with the former mock-up designed under *Igrip* software revealed that:

- the way to find the distances of interaction between one ray and one screen had to be much improved:
  - * the use of a native *Igrip* function to perform such distances revealed inadequate, as much too costly;
  - * that single part represented a great ratio upon the global geometric calculations (80%), supposing many checks between the ray and the screen geometry (thus much affected by the kind of description of the geometry),
- the sole geometric computations take more time than all other calculations involved in the method (build-up factors, Kitazume formula, …).

ALGORITHMIC AND SOFTWARE OPTIMISATIONS

One made some first restrictive choices, to focus on the drastic optimisations required : the sources are *homogeneous* and *isotropic*, their meshes are *uniform* and *cartesian* (based on an oriented bounding box). These choices do not bring major restrictions, as they do not suppress scientific point locks. Taking heterogeneity, anisotropy or mesh stands will just bring some more reorganizations and further developments in the code.

Besides, we suppose that all geometries are described as triangle polyhedrons, which brings several advantages:

- most of CAD tools give exports of native geometries as polyhedrons,
- all objects in a scene can be taken into account, whatever their complexity,
- a single algorithm can be involved to perform the distances or interaction with any of the objects in the scene (as they are geometrically expressed the same way).

Seeing a screen in the scene as a polyhedron restricts the research of potential intersections with one ray to the research between numerous triangles and a segment. Therefore, we reflected and implemented three major optimisations :

- As all rays coming out of one source up to the calculation point are housed in a 1, 2 or 3 pyramids envelope, one can first perform preliminary checks upon the potential intersected screens (left view - picture 1). By extending the separating axis theorem (demonstrated by S.Gottschalk at University of North Carolina for geometric collision detection algorithms) to the check between a pyramid and an oriented box bounding each screen, one can sort a restrictive list of screens to be looked at (for potential intersections with the rays), *which largely lowers the global calculation times*.

- Looking for the potential points of intersection between one ray and all the triangles of a screen, keeps too costly. Using a hierarchical tree grouping the triangles of a polyhedron inside fitting oriented bounding boxes (known as OBB Tree) *brings new impressive benefits* (a link to the RAPID OBBTree library turned the geometric routines up to 9 times faster).

- Last, looking for the potential intersection point between a ray and a given subset of triangles can still be improved (right view – picture 1):

  * by parting the check of effective intersection to the evaluation of the point. We inspired form recent *Segura* algorithm, based on subtle cross and dot products between vectors built with the segment and the triangle points, to quickly answer the question: intersection or not,

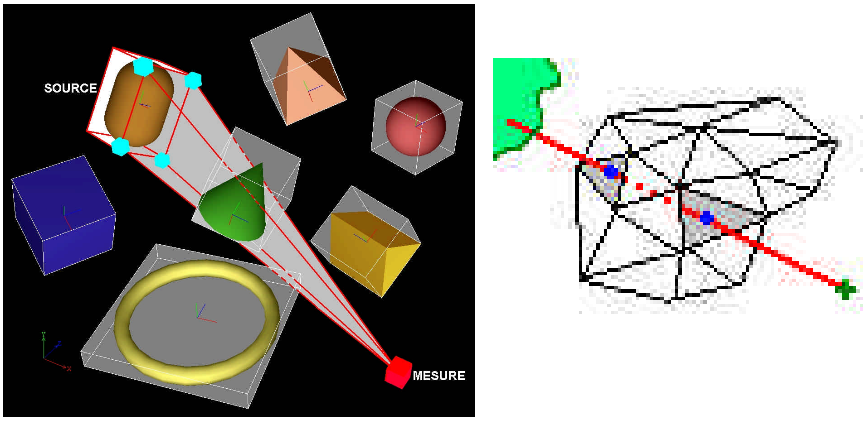
  * by not evaluating the intersection point but the distance λ_k , that expresses the intersection point in its [PQ] ray coordinates ($\underline{PM_k} = \lambda_k \underline{PQ}$). The distances we are interested in then just come from ($\lambda_{k+1}-\lambda_k$).

Development of a new mock-up

We finally developed a completely new mock-up (example in picture 2), based on :

- a completely new rebuilt C++ version of the numerical engine (evaluation of dose rate), autonomous, and integrating the optimisations mentioned above,
- a link to *Virtools* software, a rendering and behaviour engine tool, where one can import CAD models, and build scenario, thanks to a graphical blocks language,
- some MMI (man machine interface) functionalities, based on *QT* library abilities, to help the user describing the relevant attributes of the scene (activity of the sources, composition of the screens), then graphically display the results.

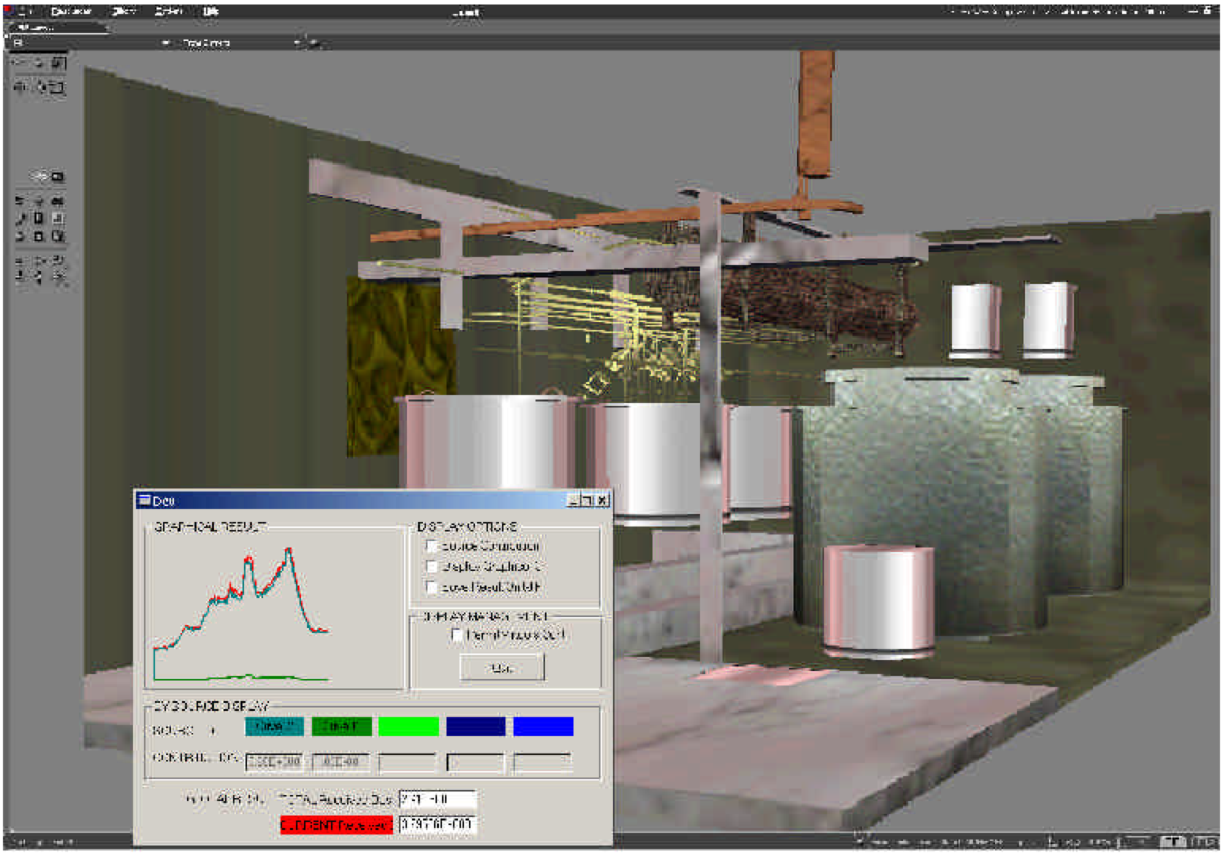
All implementations have been validated by comparing the calculation results to the ones got with *Mercure* code, for equivalent configurations (example in table 1).



Picture 1 : Geometric optimizations used to perform intersection distances between rays and screens

Table 1 : Study-case validation - volumic cubic source – one LEAD screen

mesh	draws	MERCURE WITH BU	NMU with BU	ratio	NMU BU + AIR	ratio
8 (2 x 2 x 2)	100	3855,948	3852,010	*0,102 %*	3850,360	*0,145 %*
8	1000	3851,218	3856,074	*0,126 %*	3854,423	*0,083 %*
125 (5 x 5 x 5)	1000	3851,412	3854,119	*0,070 %*	3852,470	*0,027 %*
125	5000	3851,619	3852,817	*0,031 %*	3851,167	*0,012 %*
1000 (10 x 10 x 10)	5000	3851,333	3852,764	*0,037 %*	3851,113	*0,006 %*
1000	20000	3851,301	3852,729	*0,037 %*	3851,079	*0,006 %*



Picture 2 : Example of simulation with the new mock-up

CONCLUSION

We now can take advantage of a new mock-up for the simulation of dose rate, capable of managing more realistic cases, which will better answer Fusion requirements.

Thanks to drastically optimised algorithms and methods, to a new architecture and to new dedicated tools, one can quickly get back a CAD model of an environment, design a scenario (repair, maintenance, involving human beings and/or remote handling systems), and *perform evaluation of doses induced by realistic sources* (surfacic or volumic ones), interactively as a scenario is played. Such on-line information will help planning the best scenario according to technical or environmental terms.

REPORTS AND PUBLICATIONS

CEA/DTSI/SRSI/LCI/02RT.053/ Issue 0. Laurent Chodorge. Analyses for the management of homogeneous volumic sources. Architecture of the developments.

CEA/DTSI/SRSI/LCI/03RT.013/ Issue 0. Laurent Chodorge. Developments and validations for the management of volumic sources. Statistics on computation times and research of potential complementary optimizations.

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UT-VIV/AM-Hydro

Task Title: REMOTE HANDLING TECHNIQUES
Technologies 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 disqualified for precise manipulation and are dangerous for the environment and themselves in case of unexpected collision. CEA, in collaboration with CYBERNETIX and IFREMER has developed the advanced hydraulic robot MAESTRO (see figure 1). Force and hybrid control has been developed in order to avoid the previous problems.

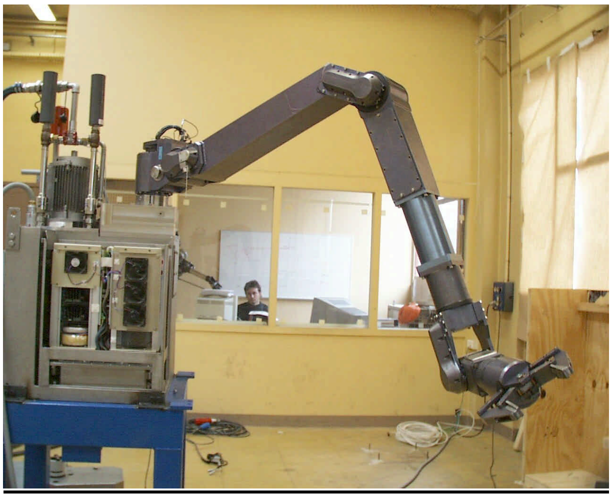
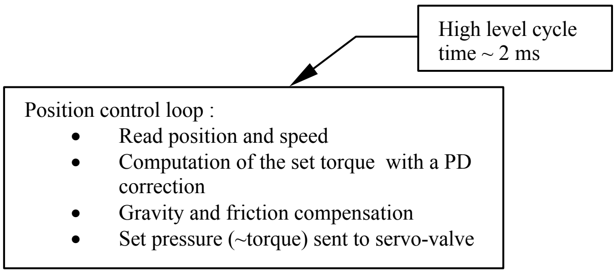


Figure 1 : Maestro on its embedded power unit

Using «pressure» control servo-valve instead of the standard «flow» control servo-valve makes a real simplification of the control loop (see figure 2 and figure 3).



High level cycle time ~ 2 ms

Position control loop :
- Read position and speed
- Computation of the set torque with a PD correction
- Gravity and friction compensation
- Set pressure (~torque) sent to servo-valve

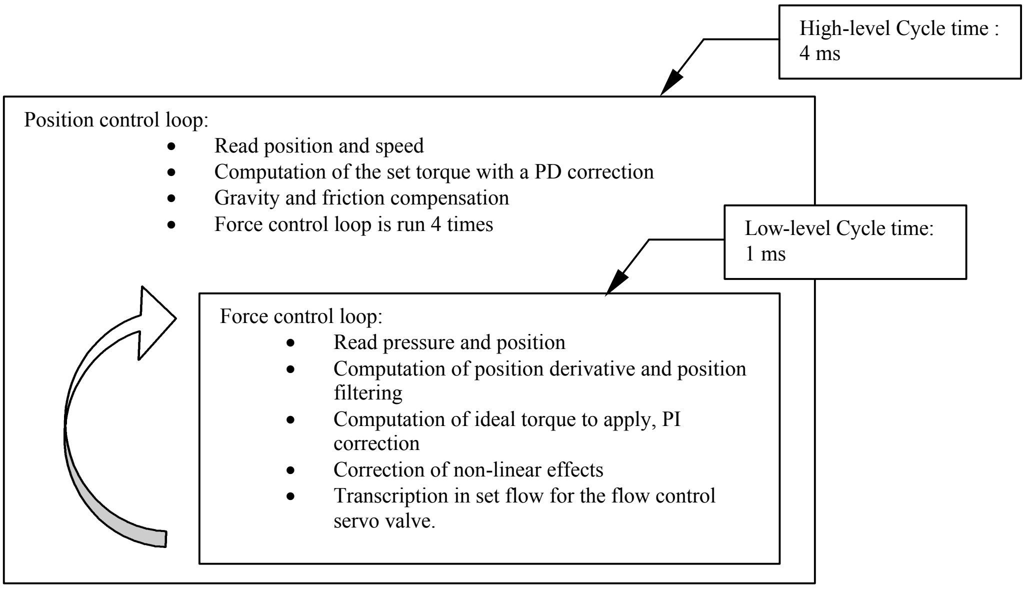
Figure 2 : Control scheme used with pressure control servo-valve

The French company IN-LHC, designed and manufactured a prototype of servo-valve that fits the performances and space constraints of the Maestro arm.

In 2001, a characterization of this new product was made on a mock-up and a set of these prototypes integrated in the Maestro slave-arm.

A comparison between the two actuating technologies was made and showed that the performances of the pressure servo-valves make it applicable to general application.

The first characterization was made with a basic mechanical model of the pressure servo-valve and an upgrade of this model was necessary in order to provide the best possible results.



High-level Cycle time : 4 ms

Position control loop:
- Read position and speed
- Computation of the set torque with a PD correction
- Gravity and friction compensation
- Force control loop is run 4 times

Low-level Cycle time: 1 ms

Force control loop:
- Read pressure and position
- Computation of position derivative and position filtering
- Computation of ideal torque to apply, PI correction
- Correction of non-linear effects
- Transcription in set flow for the flow control servo valve.

Figure 3 : Control scheme used with flow control servo valves

Two phenomenon were identified as main possible improvements for the whole actuator model:

- the pressure loss at the outlets of the servo-valve for high flow rates,
- the dry friction compensation used in the mechanical model of the joint.

IMPROVEMENTS TO THE MECHANICAL MODEL

Each Maestro joint follows the mechanical equation:

$$J\ddot{e} = Cd - Cf - Cp$$

With: J inertia of the system with payload, $\ddot{e}$ angular acceleration of the system, Cd driving torque, Cf friction torque, Cp additional torque due to payload.

Cd is directly proportional to the pressure in the two joint's chambers and Cp varies with the position of the arm when moving.

The sensitivity of the force feedback in force control applications is highly correlated to the accuracy of each model used to build the torque that will feed the control loop. Although compensation of the gravity is easy and can be made with a true compensation model, definition of the friction compensation is often problematic.

The friction torque can be resolved in the following components:

$$Cf = Cfd . \mathrm{sign}(\dot{e}) + Cfv . \dot{e}$$

With : Cfd dry friction torque (in bars), Cfv viscous friction torque (in bars.s) and $\dot{e}$ angular speed of the joint (rad/s)

Improvements of the model was expected after the introduction of a hyperbolic tangent in the friction definition (see red curve figure 4) in order to take into account the decrease of the dry friction coefficient that can be observed at low speeds (known as the Stribeck effect). Continuity of the friction torque is then available for all speed values.

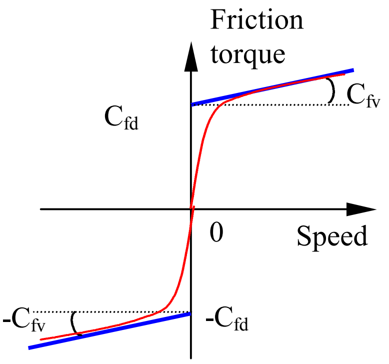


Figure 4 : Evolution of the friction coefficient with speed

According to the oil flow coming out of the pressure servo-valve, a pressure drop can be experienced compared to the set value.

The following graph (see figure 5) gives a linear approximation of the pressure drop and its bounding values.

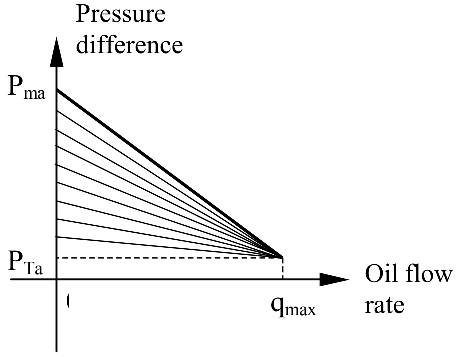


Figure 5 : Pressure loss in the servo-valve

The available pressure at the outlet can therefore be written:

$$Pa = Pset\left(1 - \frac{q}{qmax}\right).$$

Successive models for pressure loss were tested. Best results were obtained with a pressure loss following the correction law (where v_a is the angular speed of the joint):

$$Pa = Pset\sqrt{\left(1 - \frac{va^2}{vamax^2}\right)}$$

Correction of the pressure drop should provide a quicker response of the joint to the operator's solicitations by providing a drifting behaviour of the joint.

The figure 6 and figure 7 show the results of the torque identification. The rebuilt torque is composed of : an inertial term, a viscous friction term, a dry friction term, an offset correction, terms coming from gravity compensation and a last term coming from the pressure drop at the outlet of the servo valve. It is compared to the set torque.

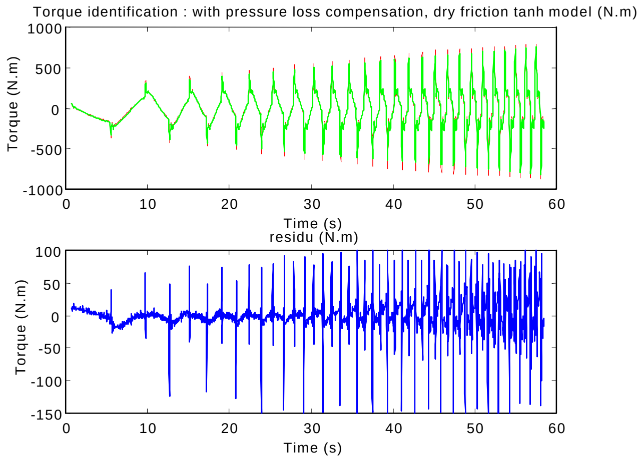


Figure 6 : Triangular signal:
with pressure loss compensation.
Red : set torque. Green : rebuilt torque. Blue : error

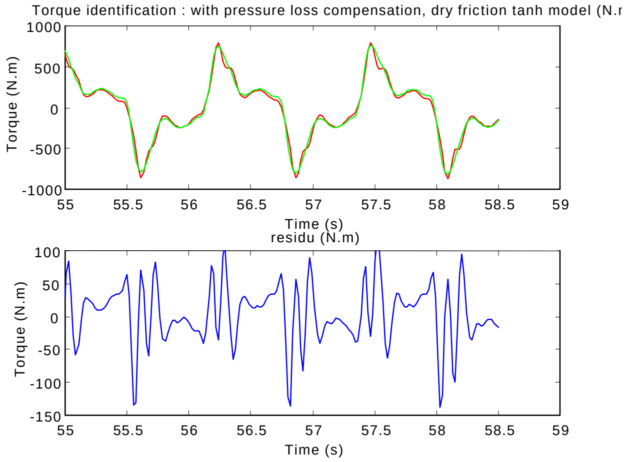


Figure 7 : Triangular signal zoom 55-59 s:
with pressure loss compensation.
Red : set torque. Green : rebuilt torque. Blue : error

Good performances were achieved with a friction model based on a composition of a bi-linear model with a hyperbolic tangent while the compensation of pressure non-linearity (essentially pressure drop at the outlet of the actuator) seems to give results that can be discussed. The effect of such a correction (minor correction) cannot be shown easily on a real model. The uncertainty of the evaluation of other parameters (major effects, such as friction parameters, payload…), noise on speed measurement, … are too important compared to the correction itself. Using force control on a maestro arm controlled by 6 pressure servos should help the tele-operator to move the maestro arm at high speed more easily.

The identification procedure was made with a non-linear multi-argument function using a status vector minimizing the error between the set torque and the rebuilt torque.

The good agreement of the parameters of the model with the reality is evaluated by the operator.

Such identification routines are providing easy and reliable ways to perform identification of the parameters of real–time models of the actuator and will be extended to the remaining actuators of the Maestro slave arm.

REPORTS AND PUBLICATIONS

STR/00RT.024 "IN-LHC Servovalve 1900687 Spécification d'une servovalve pression 4 voies" F. LOUVEAU -28 septembre 2000.

DPSA/STR/LTO/00RT.096 Rev 0. "Design and launch manufacture of the pressure valves" F. LOUVEAU –5 jan 2001.

DTSI/SRSI/LPR/01RT.043 Results on qualification of a pressure servo-valve for force feedback applications. Y. Measson, O. David.

DTSI/SRSI/LPR/02RT.008 Qualification of a Maestro arm equipped with pressure servo-valves. Y. Measson, O. David.

DTSI/SRSI/LPR/02RT.071 Upgrade of the torque model used in the control of hydraulic manipulators Y. Measson, O. David.

Y. Measson, O. David, F. Louveau, J.P. Friconneau . technology and control for hydraulic manipulators. 22th SOFT conference. September 2002. Helsinki. Finland.

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