**TW5-TVR-AIA**

# Task Title: ARTICULATED INSPECTION ARM (AIA)

## 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 work performed under the EFDA-CSU Workprogramme includes the design, manufacture and testing of an articulated device demonstrator called Articulated Inspection Arm (AIA).

The AIA has to fulfil the following specifications:

- Elevation: +/- 45 ° range,
- Rotation: +/- 90 ° range,
- Robot total length: 7.4 meters,
- Admissible payload: 10 kg,
- Temperature: 200 °C during baking – 120 °C under working,
- Pressure: 9.7 $10^{-6}$ Pa – Ultra high vacuum.

Therefore a scale one full module with 2 degrees of freedom was manufactured and tested under Tore Supra (TS) requirements (temperature and pressure).

## 2005 ACTIVITIES

### PROTOTYPE MODULE ACTIVITIES SUMMARY

Manufacture of a vacuum and temperature module demonstrator was tested in a representative module of TS called ME60, under temperature and pressure constraints. Promising results were obtained in term of structural resistance of the system. The past year was dedicated to the segment upgrade and to cycling test campaign to validate all the robot components. The successful results enable to start the whole robot manufacture and procurement.

### UPGRADE

Following the ME60 test campaign, upgrade of the module was performed in order to improve its maintainability and to enhance its performances.

The main modifications are located on the rotation actuator box:

- Thickness increase, to allow leak detection and a better stiffness,
- Neurobot board integration with gold coating,
- Sealing is provided owing to aluminium joint whether welding.

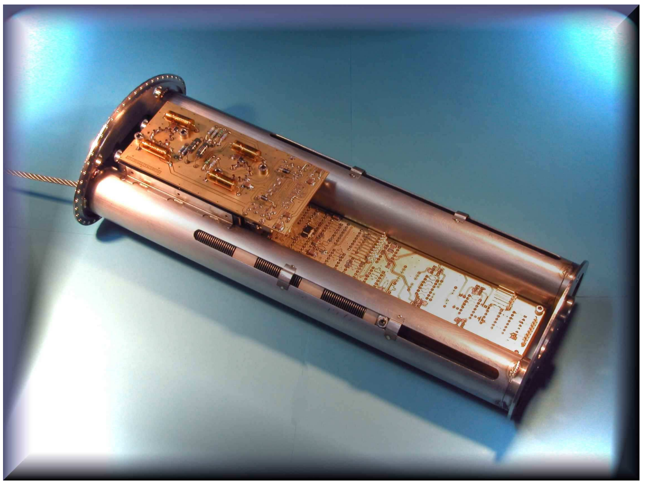


*Figure 1: Rotation actuator box*

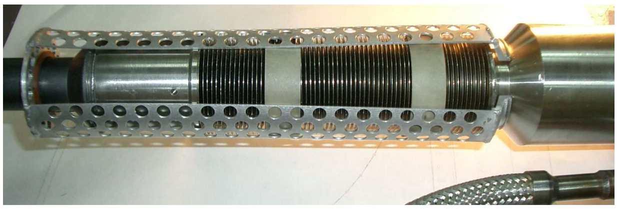


*Figure 2: New elevation jack*

A motor cooler was added to improve heat conduction. New rods are made in stainless steel plains bars.

*Figure 3: New rods and motor cooler*

A pumping tube, for the tightness tests, was added on the positions sensors.
A new locking key system was integrated to the module aiming to reduce the full torsion angle of the tube

**MANUFACTURE**

The manufacture of the final robot is under progress. The assembly is planned for the end of 2006. The AIA storage cask, the deployer and the electronic external bay will be delivered during 2006.
The integration of the whole robot on Tore Supra is foreseen for 2007.

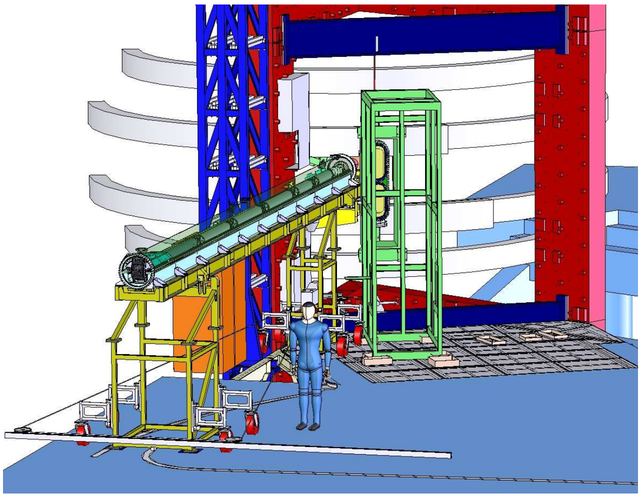


*Figure 4: AIA, deployer and storage cask on Tore Supra*

## CONCLUSIONS

Integration and tests of the deployer and storage cask are planned in the course of 2006, in CEA-Fontenay-aux Roses facilities.
Demonstration of the AIA intervention feasibility in real temperature and vacuum Tokamak environment is planned on Tore Supra for the next years.

## REFERENCES

- European Fusion Technology Programme - Task TW0-DTP/01.2, Task TW0-DTP/01.4, Task TW1-TVA/IVP, Task TW2-TVA/IVP, Task TW3-TVR/IVV, Task TW4-TVR/AIA.

## REPORTS AND PUBLICATIONS

CEA/DTSI/SCRI/LPR/ 5RT.068-Issue 0 Articulated Inspection Arm, Prototype module upgrade manufacture. V. BRUNO.

## TASK LEADER

Jean Pierre FRICONNEAU

DRT/DTSI/SRI
CEA-Fontenay-aux-Roses
18, route du Panorama- BP 6
F-92265 Fontenay-aux-Roses Cedex

Tel. : 33 1 46 54 89 66
Fax : 33 1 46 54 75 80

e-mail : jean-pierre.friconneau@cea.fr

# TW4-TVR-RADTOL
# TW5-TVR-RADTOL

## Task Title: RADIATION TOLERANCE ASSESSMENT OF STANDARD ELECTRONIC COMPONENTS FOR REMOTE HANDLING

## INTRODUCTION

The work engaged during the years 2004-2005 was a good synthesis to determine the availability of hardened electronic systems under severe environment. Two prototypes needed to digitalize the sensors analog measurements of sensors such resolvers and LVDT modules were developed and realized based on numerous results obtained from past years studies.
The irradiation campaigns done along 2005 led to partial significant results which up to now could not be enough to fully validate the conversions modules.

## 2005 ACTIVITIES

The functional block summarizes the added or redesigned developments all along 2005 (see figure 1).

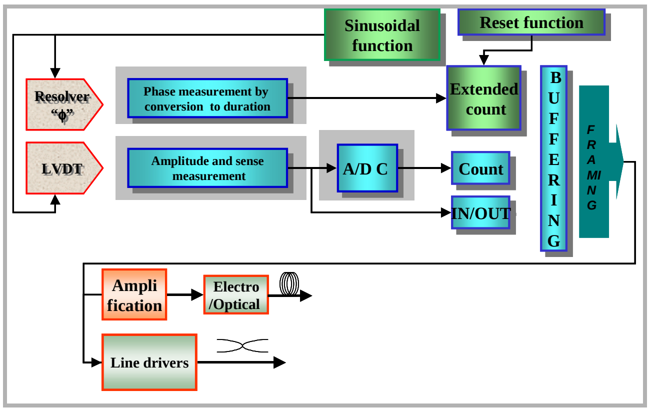



*Figure 1: Synoptic diagram of the electronic functions available on 2004*

**Resolver BRT or resolver "ϕ":**

The only resolver retained for the future multiplexor needs $A\sin(\omega t)$ and $A\cos(\omega t)$ as inputs and delivers a $A\sin(\omega t+/-\phi)$ as output.

The design of electronic functions and the global positive results of radiation campaigns of the mock-ups were detailed on previous reports [1], [2].

To increase the precision of the analog measurement of the rotation angle, the conversion was done by a clearable 12 bits high speed counter (20 MHz). Recent enhanced AUC components allowed such developments [3]. Other functions as AGC oscillators and framers were added to limit numbers of wires. Digital data was sent simultaneously to a bifilar twisted wires using LVDS line drivers protocol and to an optical driver to be converted into light (optical link).
An early irradiation campaign was realized at IRMA, IRSN facility at Saclay, commonly with SCK team, to validate the mock-up of the resolver multiplexor. The mean received dose by this important test-bed was close to 4.5 MGy.
The very short time dedicated to the adaptation of our modules to the test-bed did not enable easy pre-irradiation and later on-line controls of our boards.

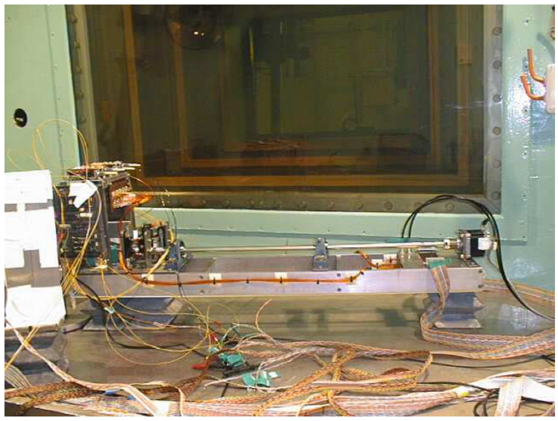


*Figure 2: Mechanical test-bed used for full validation of the multiplexer*

Some failures occurred during the campaign mainly for the intermediate state of the printed board and the association of different modules coming from previous experiments.
Most of them were compensated by direct investigations, voltage adjustments and easy recovery. The recorded frames of figure 3 taken during a break inside the cell on test points were obtained after at least 3 MGy. They gave good signals which at least validate the principle of high speed clocks.

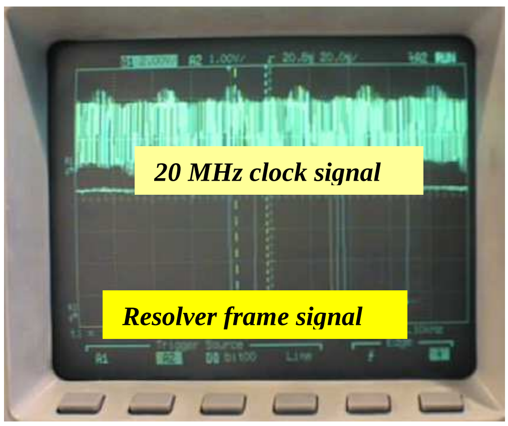



*Figure 3: Inside cell measurements*

Some post-irradiation controls after about 4.5 MGy of cumulated dose and shown on figure 4 confirm the operational state of most of the elements of the mock-up.

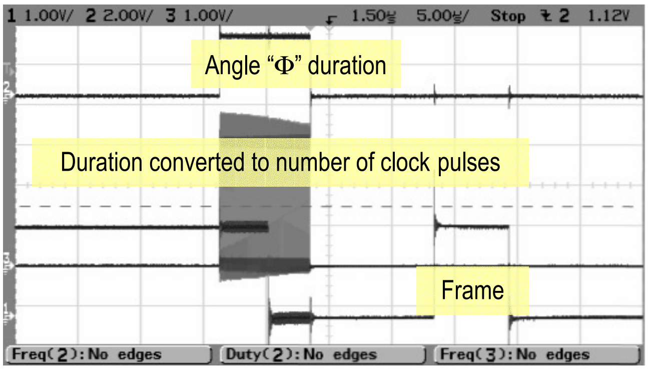



*Figure 4: Effective signals after radiations*

The critical parameters as sinusoidal oscillators, 10 MHz clock generator were always available that confirms the tolerance of the selected components under radiation.

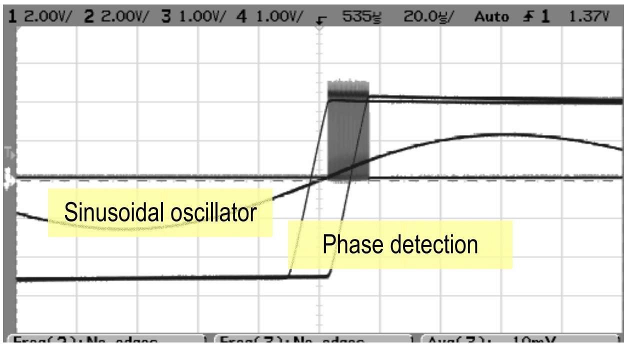



*Figure 5: Phase detection after irradiation*

After up-grating the electronic schema of the resolver multiplexor, it was decided to perform developments with the design of a fully printed card prototype.
Unfortunately, the printed card manufactured outside our lab was not significantly usable. In order to keep in time radiation investigation (scheduled on mid-december 2005), we spent time to debug the module with very limited success. Some functions were recovered.
Nevertheless, card was submitted to about 2 MGy, total dose. Due to the very limited possibility of the card, the data were only reported to the control room and recorded (see. figure 6).

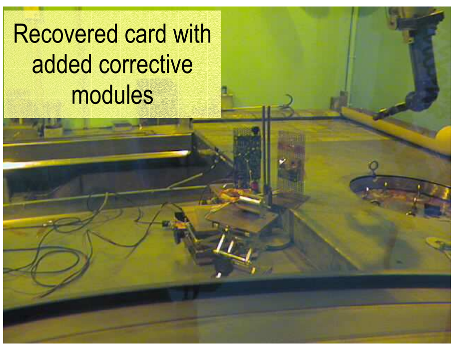



*Figure 6: Resolver card during december 2005 experiment*

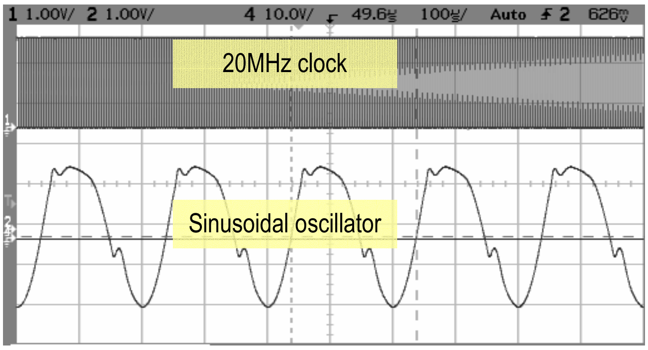



*Figure 7: Some measurements during december 2005 experiments*

Once again, most of the critical modules kept their functionalities.

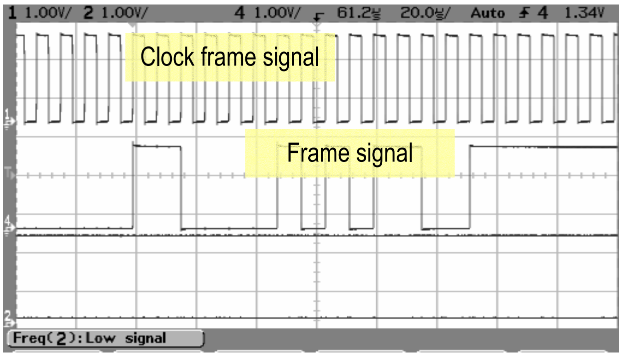



*Figure 8: Clock frame and frame signals during december experiment*

To conclude resolver experiment during end of year 2004 and year 2005, most of the results shown by all the recorded data validate the multiplexer principle with its main critical modules. To assume the final representative experiment in order to determine the accuracy of the resolver measure (stability for a define position of the angle, repetitively measurements, answer to a step variation), the prototype will be rebuilt with new design rules.

**LVDT developments**

The integration of a floating ground supply as well as an useful anolog to digital converter based on track loop control were used to designed a first prototype [2]. The interesting results obtained during first experiment in SCK facility at MOL and reported on [3] allowed a new design with an inside sinusoidal oscillator with the same principle of the one of resolver multiplexor. Frame transfer is scheduled by period of ADC conversion which allows a low rate exchange but enough for such measurements.

The supply module, which can be used for both LDVT and resolver modules, was designed as a separate module and easy added as a mezzanine card (see figure 10).

The availability of this new design was validated in room conditions previously to any irradiation campains.. No damage in the order of those of resolver card was observed. A simple test bed was defined to receive all the frames

coming from the LVDT drivers for both bifilar and optical link (a card containing SiGe driver was added as first stage of optical link). The LVDT sensor was positioned inside the cell but protected against radiation (see figures 9 and 11).
The prototype was irradiated up to 2 MGy at IRMA facility.

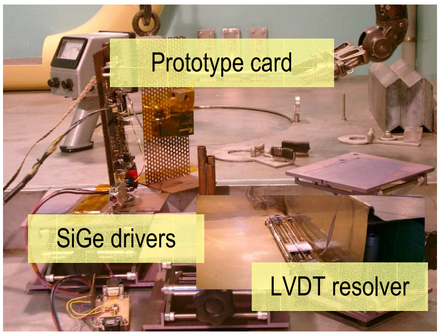



*Figure 9: LVDT prototype under radiation*

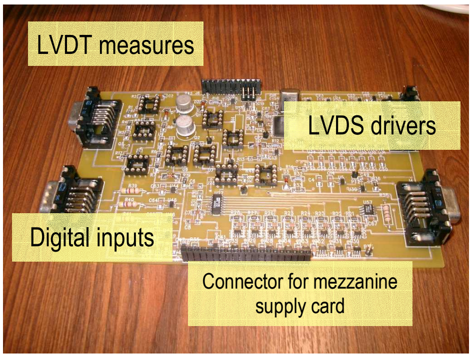



*Figure 10: New prototype of LVDT multiplexor*

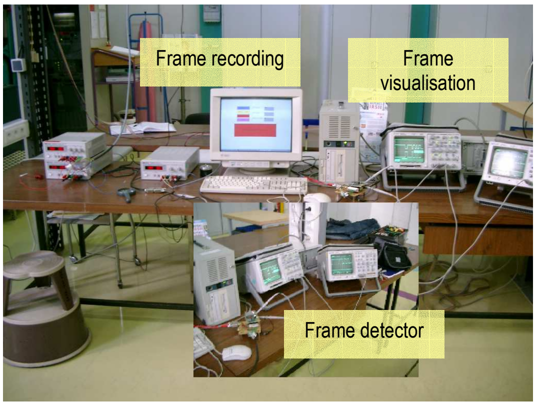



*Figure 11: Test bed for LVDT measurements*

The frame signal corresponding to the position of the LVDT sensor was continuously reported on the oscilloscopes. No evolution was related at the end of the irradiation. Corresponding frames on the chronograms of figure 12 for both LDVS and SiGe drivers, shown a regular signal.
No lost of bit conversion were visible on the analog ramp used for ADC conversion (see figure 13) while high and low state of LVDT signal for the position were always efficient (see figure 14).

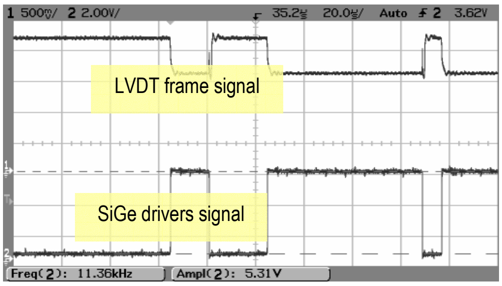



*Figure 12: Frame delivered by both LVDS and SIGe drivers*

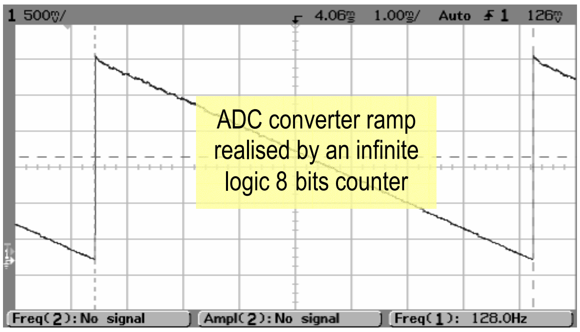



*Figure 13: Digital ramp used to ADC conversion*

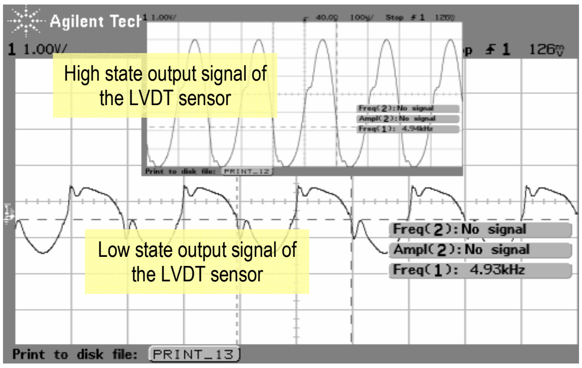



*Figure 14: High and low state of LVDT signal*

The accuracy of the LVDT converted signal was yet not done.

## CONCLUSIONS

Works done from end of 2004 to end of 2005 led us to unexpected results. Most of the modules designed and realized as part of functional blocks of figure 1 gave partial interesting results. Moreover, we expected from industrial printed cards enough quality from signals to validate with a good accuracy the conversion of measures coming from both resolver and LVDT sensors. Unforeseen events during the manufacturing affected the normal use of the cards. Debugging and recovering of the main functions and radiation scheduling became no so easy to drive.

A new resolver card, now realized and validated, is ready for further experiment. The final testbed has also to be

realized in order to give some accuracy to the converted resolver measures.
LVDT experiments could be extended with accuracy determination.

## REPORTS AND PUBLICATIONS

[1] TW3-TVR-RADTOL june report
DRT/LIST/DTSI/SARC/03-813/AG

[2] TW3-TVR-RADTOL december report
DRT/LIST/DTSI/SARC/04-042/AG

[3] Fusion Technology Annual Report 2004
EURATOM TW4-TVR-RADTOL

## TASK LEADER

Alain GIRAUD

DRT/DTSI/SARC/LCSD
CEA-Saclay
F-91191 Gif-sur-Yvette Cedex

Tel. : 33 1 69 08 64 30
Fax : 33 1 69 08 20 82

e-mail : alain.giraud@cea.fr

**TW4-TVR-WHMAN**
**TW5-TVR-WHMAN**

# Task Title: DEVELOPMENT OF A WATER HYDRAULIC MANIPULATOR

## INTRODUCTION

Hydraulic technology can provide powerful actuators in small volumes. For that reason hydraulics becomes an interesting technology to build heavy duty manipulators for maintenance operations in space constrained areas.
Due to potential leaks, oil hydraulic can not be used for maintenance operations in ITER. Pure water hydraulics proposes a good alternative to oil and today's developments are focusing on that direction.
Previous work focused on the test preparation of a SAMM oil hydraulic vane actuator that was adapted to operate with water. Materials were changed and new coatings were used to check their compatibility with water. A test rig was designed and built and performances of the joint were assessed. Analyses of the test results and actuator's mechanical state were made.

### TEST RIG

The test rig (see figure 1) is composed of an actuator mounted on a manifold providing pressurized water through a D633 direct drive valve manufactured by Moog.

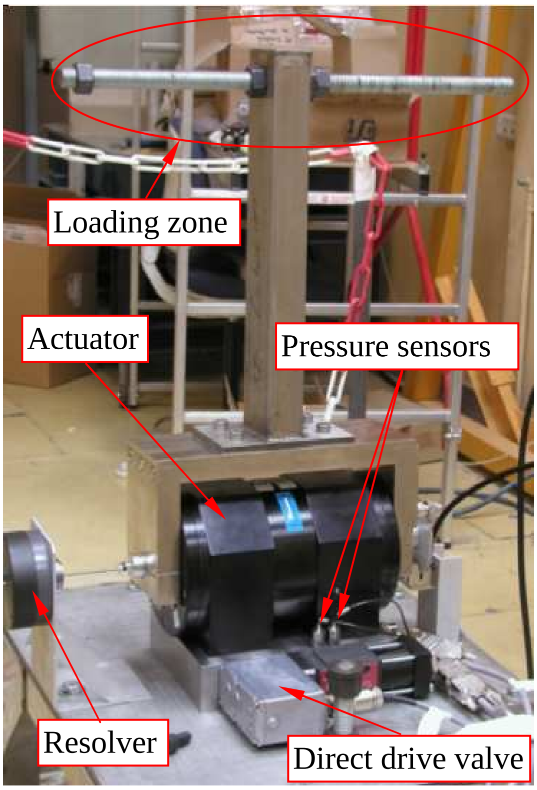



*Figure 1: Test rig*

Pressure is measured with EPXT pressure sensors of the manufacturer Entran. These are the pressure sensors used in the Maestro. 3 of them are used to measure:
- The supply pressure
- Pressure at outlets 1 & 2 of the Direct Drive Valve.

Position is measured with a resolver Litton SSH 30B4.

Fluid power is supplied by a Danfoss Nessie power unit. Maximum supply pressure is 210 bar with a maximal flow of 45 l/min.

### PRELIMINARY TESTS

Qualification tests of the direct drive valve were made in order to assess its performances. Tests made on close ports show that:
- Pressure raises until 210 bar on both outlets when full power is provided to the direct drive valve
- Internal leakage of the direct drive valve is close to 0.2 l/min at full power.

Preliminary tests on position control loop were performed. Position of the joint was set on a reference triangular signal with amplitude of 1.5 rad and a frequency of 0.1 Hz.

Zero position of the joint was defined when the load bar is vertical. We see on figure 2 that without any compensation the position error remains acceptable. When the position goes from -1.6 towards 1.6 rad displacement of the joint is obtained when a torque step is reached (see figure 2). This is in agreement with friction behaviour and the slope following the step is due to the inertia of the arm. The error signal is repeatable. It means that compensation of friction and inertia would increase the accuracy.

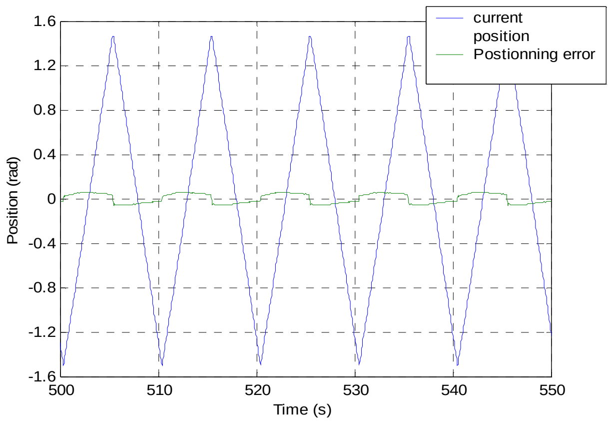



*Figure 2: Position and positioning error*

Compared to similar oil hydraulic vane actuator like Maestro, the friction torque is very high (three times higher).

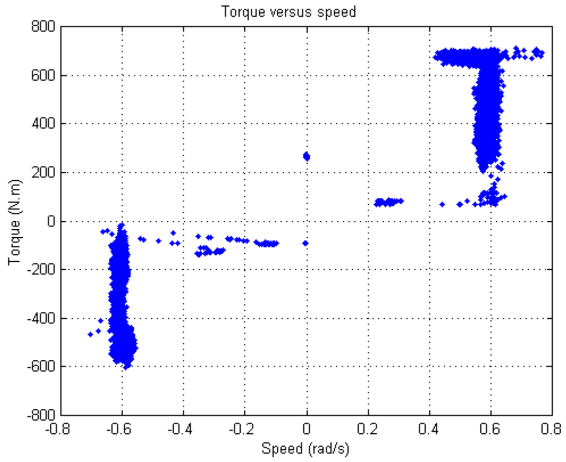



*Figure 3: Estimation of the dry friction torque*

According to the set signal (triangular shape) variations of the torque at stabilized speed (see figure 3) should remain in the range of the gravity torque applied on the joint by all elements of the actuator in movement. This gravity torque is less or equal to 34 N.m according to the own weights of all elements. And we see that for 0.6 rad/s speed the torque range is close to 500 N.m. For speeds between 0 and 0.6 rad/s the torque is approximately constant and equal to the dry friction torque. This figure shows that energy has to be supplied to something that has nothing to deal with the movement.

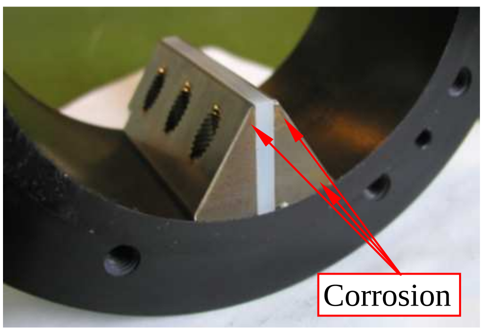
Internal leak rates of 10 liters/min were observed during the tests. It was identified as the origin of the torque excess of figure 3.

Seal shape, material and arrangement were modified to reduce these leaks without success.

Bad manufacturing quality seems to be the main reason of these leaks. Leak modeling according to Poiseuille's law show that 2.5 1/100$^{th}$ of a millimeter in the region of the vane are enough to produce a 10 liters/min leak.

### JOINT MECHANICAL EVALUATION

Several corrosion spots were noticed (see figure 4) during first disassemblies of the vane actuator.
The nickel coating used for the screws of both vanes of the actuator proved to be inefficient. Replacement of all screws by APX4 stainless steel screws and replacement of all centering pins solved the problem.



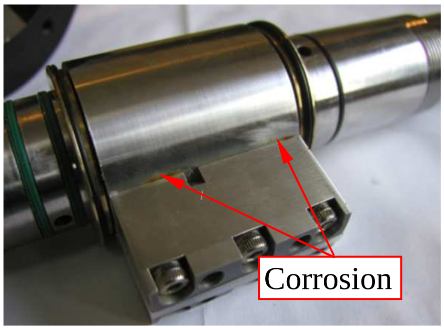




*Figure 4: Corrosion spots*

## CONCLUSIONS

Due to significant internal leaks in the actuator, performance evaluation was difficult. Dry friction torque was found very high compared to oil actuators of the Maestro arm but results on position control loop showed little and stable error. Real improvements could be expected with a friction and inertia compensation model implemented in the control loop. Unfortunately the internal leaks were too high to perform the same test with significant payload and for the same reason it was not possible to try force control modes.

New seal designs and arrangements were tested to limit the amount of leaks. No significant improvements were noticed during the trials.

Leak estimations with help of Poiseuille's law and dimensions measurements of the main parts of the actuator pointed out the poor manufacturing quality as the responsible of these leaks. Although clearances in the SAMM vane actuator would have been correct for oil, the 30 times factor between viscosity of water and oil severely affected the water tests.

Although performances didn't give the expected results and leaks were high, no real corrosion problems were noticed, meaning that the material choice was correct at least for simple testing. Wear analysis after endurance test would be necessary to confirm the option of all selected coatings during the design phase.

It seems difficult to define the exact values of the clearances required in the joint to reach the expected performances. Today (cost problem excepted) among other vane actuators, the Maestro joint seems to be in best position to reach ITER's requirements.

Next test phase will therefore concentrate on a performance analysis of a reconditioned Maestro joint to define a start point without making any modifications of the existing design. In a second phase, an analysis of the results and proposals to modify the design will be made.

## REPORTS AND PUBLICATIONS

- DTSI/SCRI/LPR/05RT006 Water hydraulic manipulator. Definition of a single axis water hydraulic mock-up.
- DTSI/SRI/LTC/06RT006 Water hydraulic manipulator. Preliminary tests on a water hydraulic manipulator.doc

## TASK LEADER

Jean Pierre FRICONNEAU

DRT/DTSI/SRI
CEA-Fontenay-aux-Roses
18, rue du Panorama - BP 6
F-92265 Fontenay-aux-Roses Cedex

Tel. : 33 1 46 54 89 66
Fax : 33 1 46 54 75 80

e-mail : jean-pierre.friconneau@cea.fr