OPERATING GAINS ACHIEVED BY A NEW GENERATION OF REMOTELY CONTROLLED MANIPULATORS

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ABSTRACT

A high performance remotely controlled mechanical master slave arm with direct transmission via cable and transmission rods has been converted to a new generation manipulator with electrical master slave arm and motion module with integrated software. The redesigned powered manipulator with software control improves efficiency and ergonomics while increasing operating field space.

The mechanical master arm has been replaced by an electrical robotic master arm using haptic technology. The movements initiated by the operator are transmitted in real time to the slave arm via the servomotors inside the motion module. The mechanical link between master and slave is eliminated and some mechanical constraints have been replaced by software applications. The operator benefits from an improved working position and vibration filtering plus full range high performance force feedback with reduced effort requirement.

1. Introduction

From an existing manipulator, the “MT200”, AREVA and the CEA (Commissariat à l’énergie atomique et aux energies alternatives) developed the prototype of the powerful telerobotic “MT200-TAO”. Industrialization and improvements were done by the manufacturer, Getinge-La Calhène. The TAO concept (“Télémanipulation Assistée par Ordinateur” or Computer Assisted Telemanipulation) and specific software were developed by the Interactive Robotics Unit of CEA LIST. AREVA, which utilizes hundreds of this particular type of manipulator on its La Hague site, included the project in its modernization program.

The updated system is designed to [1]

- Increase working volume allowing ceiling access
- Improve workstation ergonomics
- Allow the operator to work at a greater distance from the controlled zone thereby reducing dosimetry
- Improve safety
- Reduce operator fatigue
- Allow playback of some repetitive tasks not requiring force feedback (robotic mode)
- Guarantee similar performances to the high performance MT200

2. Upgrading the standard mechanical MT200 manipulator to a “new generation” MT200 TAO telerobotic system

2.1. The original MT200 mechanical system

In the 1980’s Getinge-La Calhène and the CEA developed the MT200 mechanical master slave system with a telescopic arm for work inside large hot cells (Fig.1). Using these systems, it is possible to run and maintain large hot cells in excellent conditions.

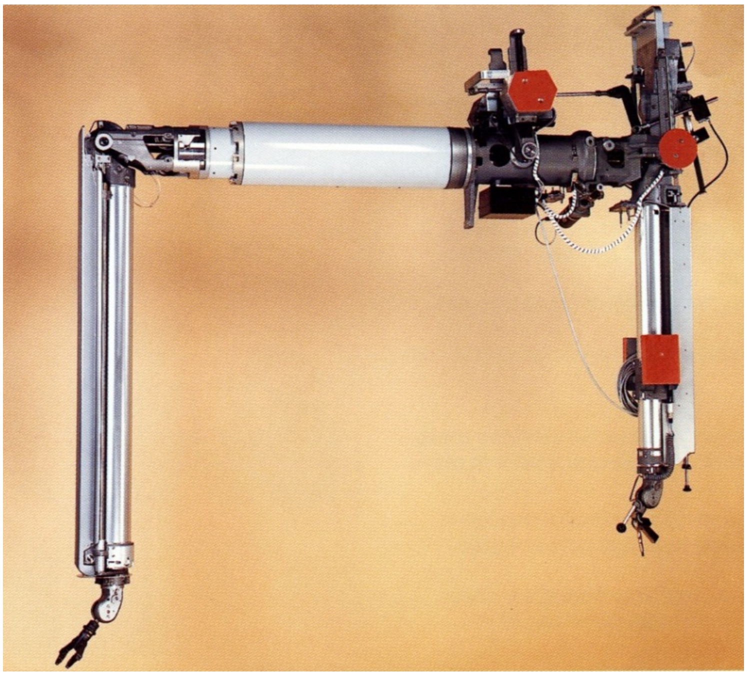

Fig.1. MT200 Mechanical Master Slave System

The MT200 has a 20 kg capacity in tongs, 80 kg capacity at hook and 4 m extension capacity.

Like other MSMs (Master Slave Manipulators) the MT200 system consists of

1. a slave arm situated inside the hot cell
2. a wall-through tube
3. a master arm situated in the “cold” working area.

The master arm’s movements controlled by the operator are retransmitted to the slave arm equipped with a grip. The transmission is carried out via the wall-through tube which is comprised of a set of bars.

These items are linked together by a set of mechanical transmissions so that the movements the operator gives to the master arm are transformed into homothetic movements of the gripper and slave arm with Force-Feedback (homothety of ratio 1 with a mechanical balancing function). Hence the operator feels the actual load that he is manipulating.

2.2. The “new generation” MT200 TAO system

AREVA launched a development program with CEA research team to develop a new system with less downtime and maintenance costs, better performances, safety and ergonomics.

The MT200 TAO system consists of

1. a slave arm situated inside the hot cell
2. a wall-through tube
3. a motion module (electric motorized unit)
4. a poly-articulated master arm
5. an operator workstation which can be located up to 150 m from the hot cell

Items 3 through 5 replace the original Master Arm.

Figure 2 : MT200 TAO system

The motion module is a fully electrical assembly composed of servo-motors with sensors for safety and operator comfort (see 2.3 and 3.4 and Figure 4 below). The module is an actuator of all the movements commanded by the master arm via the software.

The MT200 TAO motion module is compatible with the previous generation of fully mechanical MT200 wall-through tubes as well as those of the next generation TERMAN system (see 4 below). This major benefit of a completely interchangeable tool allows end-users to profit from the versatility of the system ; without any alterations to the hot cell wall, the advantages of the motion module features can be added or removed as required.

2.3. Upgrades

Figures 3 and 4 show the evolution towards a new system concept, patented by AREVA and CEA and manufactured by Getinge La Calhène. The mechanical link between the master arm and the slave arm is replaced by an electrical link. This strategy allows the operator to be freed of the constraints due to the system, and vice versa.

Hence the operator can work remotely on the master arm without being constrained by the drawbacks associated with the mechanical link such as balancing default and joint directional offset. Instead he benefits from advanced assistance functions thanks to the new software [1].

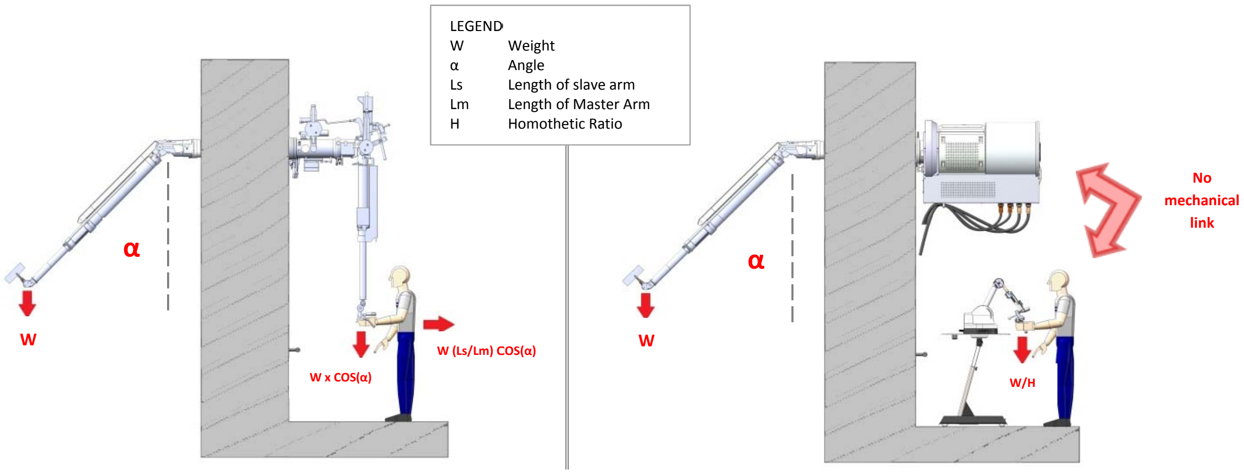

Fig.3: MT200 System

Fig.4: MT200-TAO System

At operator interface level, the main difference between the two systems lies in the master arm sub-system. The large historical master arm has been replaced by a polyarticulated small master arm manufactured by HAPTION (see Fig.5).

The operator still moves the handle in the direction of the required movement and the slave arm movement follows the same path (cartesian or articular modes), with respect to a homothetic ratio. The force feedback [1] [2] on both master and slave sides is transparent, i.e. the operator never feels the weight of the slave arm. This does not depend on the slave arm position as shown in Figure 4.

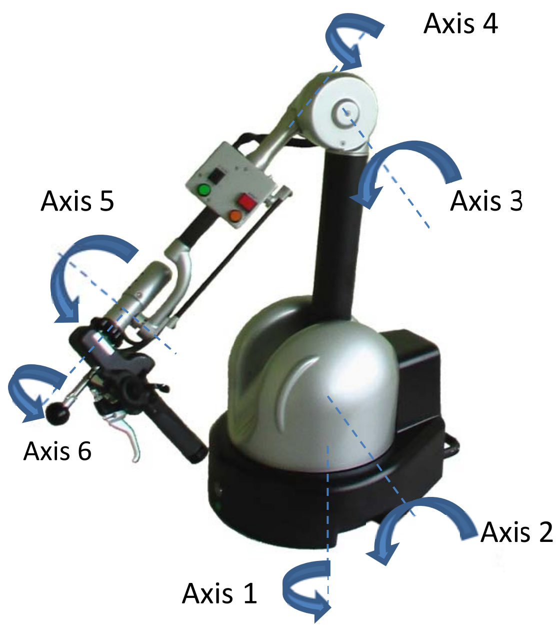

Fig.5: Haptic Master Arm

The offset function has been greatly simplified by integration into the haptic master arm. The operator can always be correctly positioned with respect to the ongoing task. In order to simplify operations, internal movements such as the electrical telescopic motion are automatically driven.

The operator may be positioned anywhere within 100 m of the hot cell, with direct vision or camera vision, thanks to the electrical link between the master and slave arm (see Fig. 6). This major benefit is not affected by operational constraints, such as correlation between hand motion and visualisation of this motion, thanks to the operating software. The camera inside the hot cell is automatically enslaved onto the grip position.

In Cartesian mode the software calculates the slave arm position with respect to a reference point and the master arm position. Operational assistance is provided by special algorithms e.g. partial or total load compensation, claw safety, claw rotation, and virtual axes lock-on[1] [2]. Operator effort is multiplied by a homothetic coefficient in the slave arm, thereby reducing the physical effort required to lift and move loads.

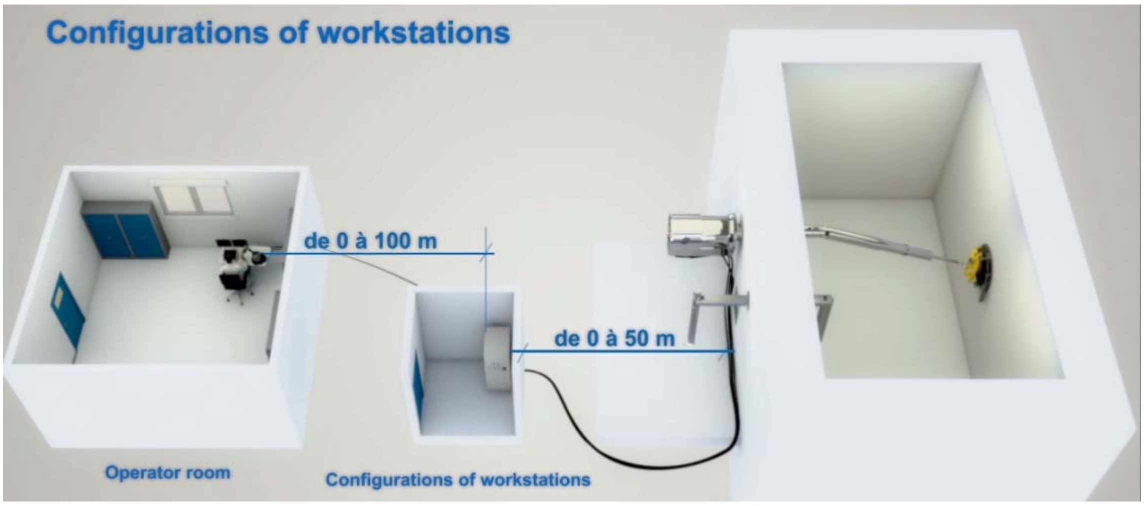

Fig.6: Configurations of workstations

A highly sophisticated HMI (Human Machine Interface) was developed specifically for this application to offer more options and better ergonomics to the system. CYXPro software from Cybernetix presents the following characteristics:

- Virtual reality: off-line used to create, simulate and train.
- Personalized HMI for greater user-friendliness.
- Real time display and importing of the 3D environment during execution.
- Advanced functions e.g. passive anti-collision, management of force feedback, etc.

3. Gains

The development project aimed to achieve the following major operating gains:

- Higher availability rate
- Lower maintenance cost
- Lower exposure to dose for operators
- Better performances (load and work area)
- Safer use, improved ergonomics

3.1. Better productivity, performances and higher availability rate

A testing campaign carried out by AREVA/NC in a cold cell at La Hague plant demonstrated that the MT200 TAO system brings a 60 to 65% productivity gain. This is due to the fact that the system is easier and lighter to use, so the operators can therefore work more quickly over longer periods of time. Additionally, master and slave arm motions are more precise using the MT200 TAO system. It was shown that this particular precision brings a productivity gain of 20% [2]. Downtime is shorter because less maintenance is required.

3.2. Longer life of slave arms and lower maintenance cost

In order to gain knowledge on the operability of the system, AREVA launched a "lessons learned" program based on normal operations in a cold testing hall at La Hague plant with active benchmark testing in a hot cell.

The program, which lasted for 40 weeks in 2010 – 2011, checked operational performance of the new system in the cold cell with input by an ergonomist and a group of trained operators. After training in the cold cell, experienced operators worked in the hot cell, dismantling and decontaminating glass fusion crucibles, a job selected to maximize lessons learned on the new system. A total of 530 hours were worked with the MT200-TAO system.

Results were drawn from 3 sources: operator feedback with back-up from medical services, system feedback with software history and log books and productivity measurements.

The test results showed that the MT200 MTBF (Mean Time Between Failures) is linked to loads lifted and stress applied on the system. Thanks to the TAO computer assistance, load saturation is possible (7 kg, 11 kg, 15 kg) giving the MT200 TAO slave arm a MTBF up to 10 times longer than that of a standard mechanical MT200 system in identical duties [2].

During the testing campaign, no maintenance at all was required on the operator side of the system. On the hot-cell side, the amount of maintenance necessary was much less than expected, with resultant significant reductions in time, cost and waste [2].

3.3. Human factor benefits and improved ergonomics

A 90% satisfaction level was noted in operator feedback after AREVA's "lessons learned" program. Physical strain was lessened thanks to better body positioning, load compensation, vibration filtering and lighter force feedback, this last advantage thanks to the homothetic coefficient which reduces load by a factor of up to 10. Operators experienced less mental strain thanks to constant indirect vision via cameras whereas the previous system forced them to adapt to "mirror" or upside down motion [2].

Operator security is improved since the remote workstation reduces irradiation dose.

3.4. Safety

Among new safety features included during industrialization are the sprockets which have replaced the belts used on the prototype, for greater safety and less maintenance. Sensors located inside the motion module to detect correct slave arm locking and its type/length automatically, also contribute to safety and ease of use.

3.5. Robotic gains

Robotic mode provides optimal precision and speed for repetitive tasks. Operations are first done in virtual reality then applied in real time, which limits friction and promotes efficiency since recurrent manipulations inside the hot cell are repeated with the same precision every time.

4. Gains for the motion module

The MT200 TAO motion module offers improved versatility. It has been designed to be combined with other future products from Getinge La Calhène including the TERMAN. This latest manipulator, under development in Getinge La Calhène plant, is a robust cable-less slave arm operated by drive shafts and gears which greatly improve precision and rigidity. Infinite rotation at the grip end speeds up some manipulations, e.g. screwdriving [4].

5. Conclusion

The study carried out by AREVA/NC prior to industrialization shows that operators quickly learn to use this new type of computer-assisted manipulator arm. Not only does it improve the reliability and efficiency of operations inside hot cells, it also lowers costs, reduces waste and brings tangible benefits to users. Improved ergonomics means that working with manipulators can be opened up to a wider group of operators whose physical resilience is not mandatory.

The versatility of this tool can benefit workers in many different nuclear fields including maintenance and decommissioning of nuclear power plants.

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Index Terms—Telerobotics, force feedback, computer-assisted Teleoperation, hot-cells, workstation, field test, productivity, ergonomic.