Experience in Remote-Operated Decommissioning with Electromechanical Equipment – 15354

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ABSTRACT

For the Reprocessing Plant (WAK) in Karlsruhe, Germany, Wälischmiller developed remote handling technologies and robotics used for dismantling of several high-activity radioactive storage buildings. The key component in this project is the Wälischmiller system TELBOT®.

The TELBOT® system has been successfully deployed in dozens of applications based on the customer's requirements and lessons learned. The objectives for this project were to deliver a reliable, high payload manipulator that is deployed on an excavator. The TELBOT® is a seven degree of freedom manipulator, with a 2.7 meter reach and a payload capacity of 100 kg at full reach. It is modular with selectable drives, arm lengths and joint modules. The motors and gears are located in a base behind the arm. Movements are effected by concentric tubes inside the arm links and concentric bevel gears inside the joints. Consequently, there is no wiring either inside or outside the arm and all axes can rotate freely. High-quality materials such as radiation-, acid- and corrosion-resistant materials and a final surface protective treatment are used in the manufacture of the TELBOT®.

This paper will describe the TELBOT® system used by the German decommissioning program at Karlsruhe.

INTRODUCTION

The *WAK Rückbau- und Entsorgungs- GmbH* (Decommissioning and Waste Management Company) pools all activities relating to the decommissioning of nuclear facilities and waste management at the premises of the former Research Center Karlsruhe, today´s KIT. Partner of WAK is the Federation-owned *Energiewerke Nord GmbH* (EWN). The company is financed by the Federal Ministry of Education and Research and the Baden-Württemberg State Ministry of Finance and Economics.

For the dismantling of the HLLW facilities, a TELBOT® system has been developed by Wälischmiller Engineering GmbH. Completion of vitrification operation was the prerequisite for the disassembly of the High Active Waste Concentrate (HAWC) storage tanks. These tanks are located in thick-walled concrete cells in the newer "LAVA" storage building and the older main waste store "HWL". Due to the high dose rates in the cells and on the tanks, remote-controlled tools and devices are applied exclusively.

DESCRIPTION OF PROJECT INCLUDING 3-D VIEW OF MAIN PROCESS BUILDING

Dismantling Activities – Overview

Decommissioning work in the first years focused on emptying the process building (Figure 1). After the decision to condition the HAWC on the site for later final disposal, construction and operation of the Karlsruhe Vitrification Facility (VEK) were included in the scope of activities.

In the meantime, the focus has shifted to the disassembly of the HAWC storage buildings. The VEK that was shut down after the completion of vitrification is being decommissioned. First peripheral systems are being dismantled manually at the moment.

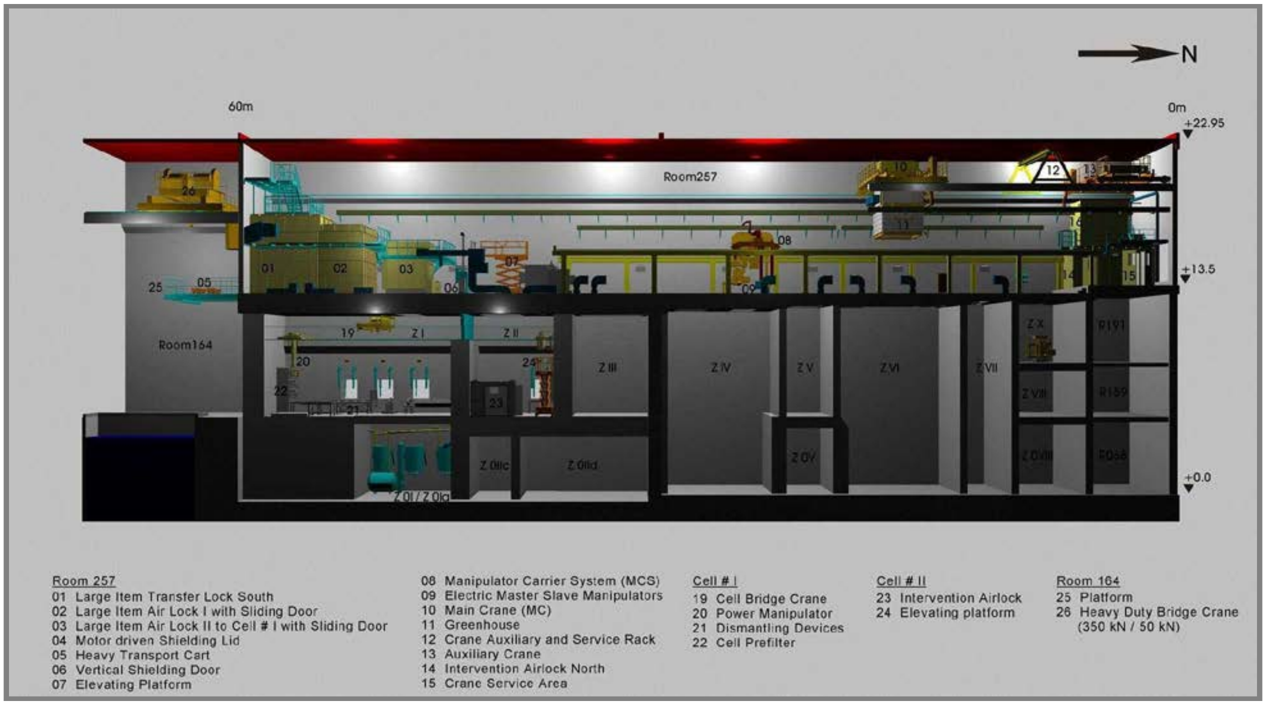

Fig. 1. Virtual 3D-View of the WAK Main Process Building

In the considered decommissioning section 5.4, the LAVA-cells as well as the HA laboratory and the sampling will be dismantled. The equipment is used to prevent contamination carrying, as well as handling, packaging and contamination-free lock out of decommissioned material. Then for the decommissioning section 5.4, a robotic system TELBOT® mounted on an excavator was selected.

Dismantling of the Storage Building LAVA

At the LAVA storage building, cells with HAWC process components are located above the storage tanks. These cells are provided with hatches to a crane hall above. Here, dismantling will be executed in vertical direction. The technology used in the process building will be developed further for this purpose. By a crane, the manipulator carrier system will be put down above the respective cell opening.
To the extent possible, the tanks in the cells will be removed undismantled. The associated handling processes were tested in a test rig. Based on these tests, the equipment was adapted. The results of the test operation phase completed in 2013 were directly incorporated into the detailed planning of LAVA cell dismantling. Work is planned to start in 2014 as well.

MAIN REQUIREMENTS OF THE WAK TO THE SYSTEM

For the decommissioning section 5.4 a complete manipulator system has been required: an arm and a control device based on a master arm control system.

General Information – Requirements

- The manipulator should be similar to the existing system, so that the authorization from the public authorities for the dismantling would be granted without difficulty.
- Withstand radiation (approximately 200Sv/h)
- Withstand loads
- Withstand remains of fluids from the pipes and decontamination fluids

Loads To Be Handled

- Maximum 100kg bearing load for min. 30 min handling/operation

Tools To Be Handled

- Electrical grinder
- Electrical nibbler
- Hydraulic cutter (d=50mm)
- Hydraulic cutter (d=90mm), weight approx. 70kg.
- Hydraulic nibbler, weight approx. 70 kg.
- Broom, shovel
- Screw wrench

The tools should be guided by the manipulator. The reactive forces from the tools should be taken up by the arm. The tools have to be held safely through a form fit (prismatic square – WAK specification). Vibrations and shocks generated by the tools must also be taken up by the arm, without a default of the mechanic or control system.

Technical Specification of the WAK to the manipulator

- Control system with control cabinet
- Control panel (with Joysticks and with pivoted lever)
- Adaption to coupling plate of the excavator
- 7 degrees of freedom
- Force feedback
- Compensation of loads (dead weight)
- Selectable force intensification (1:10 to 1:50) – reduced powers for the user
- Monitoring of contouring errors
- Emergency stop
- Monitoring of the temperature
- Cable length max. 160m
- Arm range 2.7 m (+5%)
- Emergency rescue procedure
- Remote handling connectors

Technical Specification of the WAK to the master arm

- Drive all axes
- Adjustable in height and revolvable
- Physical dimensions 70% of the slave

KEY DECISION POINTS IN EQUIPMENT SELECTION; POWER MANIPULATOR VS TELBOT®

Depending on the type of task, the power manipulator A1000 or the robotic system TELBOT® is more suitable for the work to be performed. Both devices have a high radiation resistance and durability. For that reason both systems have been offered for the decommissioning section 5.4.

General Description of the Power Manipulator A1000

The A1000 (Figure 2) is a power manipulator system for numerous applications, especially in areas unfit for human access or where heavy work is to be carried out, for example in the nuclear industry or chemical installations. Due to its comfortable remote control, its efficient movements and radiation resistance as well as its design as a self-contained unit with electric drives, the A 1000 is the optimum choice for heavy-weight operation in radioactive and hostile environments. The size and travel of bridge, carriage and telescope can be adapted to any environment. Due to its modular design, the application and exchange of tools as well as a comfortable maintenance are additional benefits of the A1000.

Typical for the A1000 arm is the soft and precise motion as well as the high handling capacity. Every axis can be adjusted in maximum force and speed. The motion is speed controlled and able to be done continuous from zero to maximum.

The A1000 is especially suitable for unrepeatability works and works over long distances.

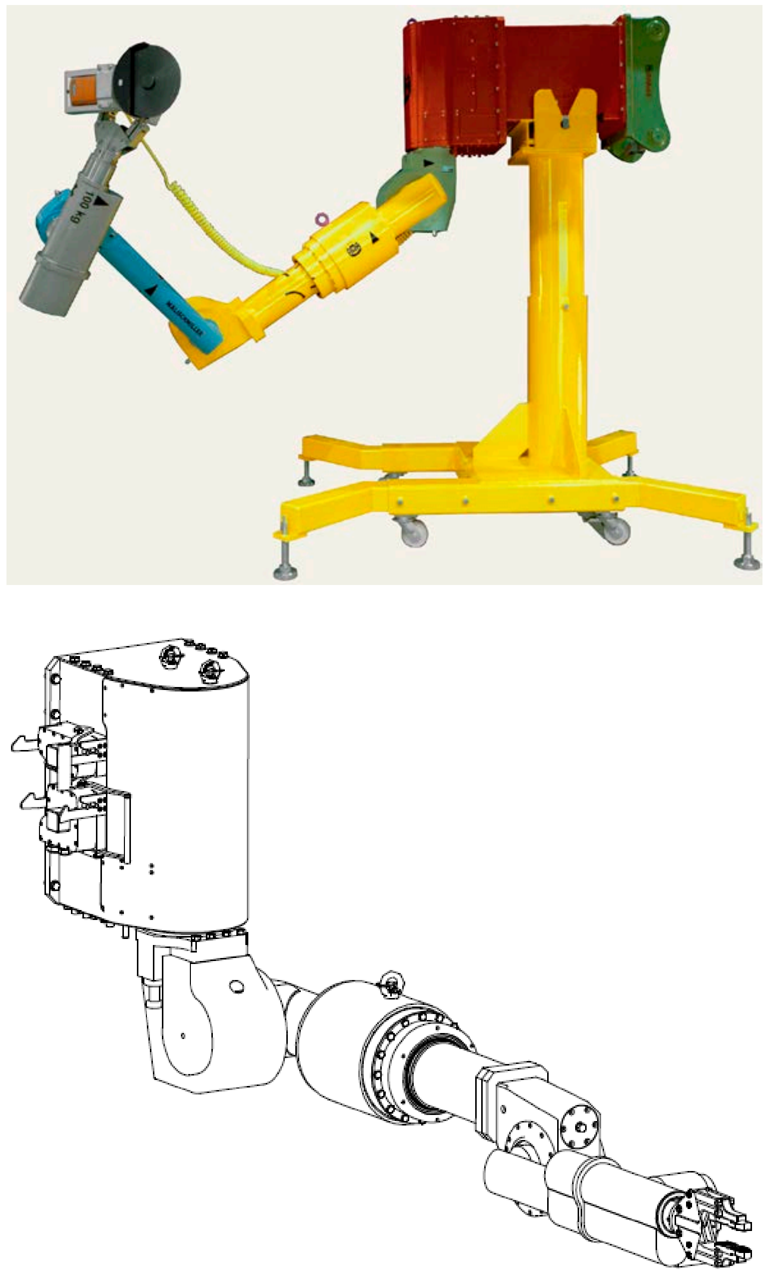

Fig. 2. Figures of the power manipulator A1000

General Description of the Robotic System TELBOT®

The TELBOT® is a modular robot with selectable drives, arm lengths and joint modules (Figure 3). Its modular design makes it a unique articulated manipulator arm with diverse applications.

The motors and gears are located in a base behind the arm. Movements are effected by concentric tubes inside the arm link and concentric bevel gears inside the joints. Consequently, there is no wiring either inside or outside the arm and all axes can rotate freely.

The components of the TELBOT® have been carefully selected to resist harsh environments such as those in the nuclear or chemical industries. The smooth and sealed arm parts facilitate decontamination of the manipulator.

Sleek construction and high dexterity enable the TELBOT® to access confined spaces. The precise arm movements and the intuitive and intelligent JOYARM II operating system deliver outstanding performance from an intuitive master-slave control system along with precise linear motion control and intelligent teaching-playback control.

Features
- Optimum link length and joint combination for each customer application.
- Wide working area with unlimited joint rotation.
- Long and slim structure offers excellent accessibility, e.g. long reach through narrow spaces.
- High repeat accuracy with zero back-lash.
- High resistance against hazardous environments: radiation, heat, dust, explosive gas.
- Easy maintenance, long life

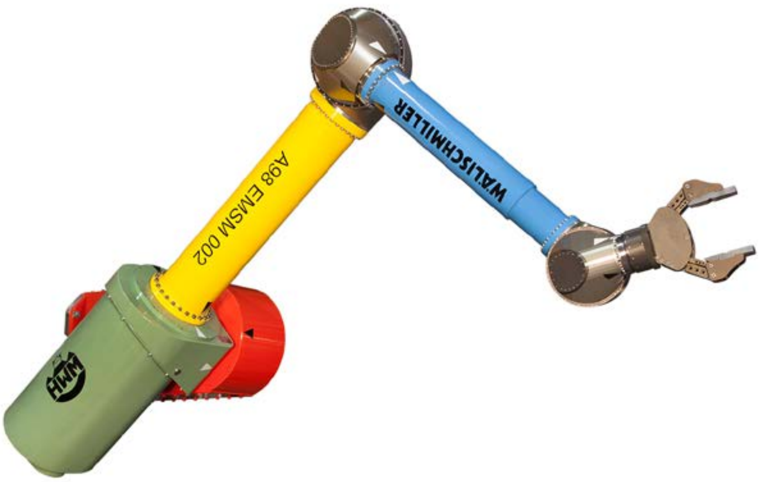

Fig. 3. Figure of the TELBOT®

A comparison between the A1000 and the TELBOT® is shown in Table I.

TABLE I. Comparison between specifications, power manipulator A1000 and TELBOT®

Specifications	**Power manipulator A1000**	**Robot System TELBOT®**
Control system with control cabinet	✓	✓
Control panel (with Joysticks and with pivoted lever)	✓	✓
Adaption to coupling plate of the excavator	✓	✓
7 degrees of freedom	✓	✓
Compensation of loads (dead weight)	✓	✓
Selectable force intensification (1:10 to 1:50) – reduced powers for the user	✓	✓
Monitoring of contouring errors	✓	✓
Monitoring of the temperature	✓	✓
Emergency stop	✓	✓
Cable length max. 160m	✓	✓
Arm range 2.7 m (+5%)	✓	✓
Weight	500 kg	327 kg
Emergency rescue procedure	✓	✓
Remote handling connectors	✓	✓
Force feedback	×	✓
Coordinate drive	× (not available at this time)	✓
Virtual reality	× (not available at this time)	✓
Max. load capacity	100 kg	100 kg
Speed of the TCP	0,3 m/sec	1 m/sec
Speed of the arm joints	0 – 1,5 min^{-1}	0 – 10 min^{-1}

Final Choice: The TELBOT® System

In this case, the TELBOT® was selected for example for the automatic tool change paths, which can be programmed to shorten this procedure. Furthermore, the TELBOT® can be used with intuitive input devices, which make long works easier and are better tailored to the health and ergonomic needs of the operator. The work is also easier with the possible use of the force feedback and increases the working precision. Force Feedback compensates partly the missing view, as cameras are limited in the working area. The A1000 is limited by its mechanical structure in its motion. The TELBOT® offers the possibility of infinite rotation of all wrists. Due to its 7 degrees of freedom, it is possible to reach any point in various ways. This function is called as elbow control.

It can be concluded that both the A1000 and the TELBOT® for coarse and fine work are suitable. Wherein the TELBOT® significantly increases the working comfort by the use of different input devices.

Description of the TELBOT® System for the WAK

As modular System, the TELBOT® is especially designed for the need of our customers. For the WAK, it is installed on a manipulator carrier system. It consists of an electric hydraulic powered 3-joint dredger of the 8 tons class, manufactured by toptec/Germany. It is remote controlled by wire and radio. It has a maximal horizontal reach of 5 m by 1.2 tons payload at the end effector.

TABLE II contains an overview of the technical data of the whole system: TELBOT® and excavator. The Fig. 4. is a photograph of the system and helps to get a representation of it.

TABLE II. Technical data of the whole system

Designation	Data
Operating weight	8.0 to
Allowed payload	1.2 to
Min. height	1.9 m
Min. width	1.5 m
Max. range	7.0 m (including PM)
Drive	electro-hydraulic 400-420 V / 63 A
Operating pressure	250 bar
Delivery volume	Till 50 l/min
Control	Cable or radio

Fig. 4. Photograph of the robotic system TELBOT® and the excavator

The TELBOT® was selected because of its capabilities as multi-functional, modular and automatic system which includes unlimited rotation in all axes, no wiring inside or outside the TELBOT® arm, and unlimited fast and precise movement. Depending on the configuration, the TELBOT® has six to seven degrees of freedom (D.O.F.) + Gripper. The TELBOT® has a Payload of 100kg and an arm length of 2700 mm. The construction weight without suspension bracket and pivot joint is 327 kg. The radiation resistance is 1 MGy.

WhileTABLE II on the previous page presents the whole system, TABLE III and Figure 5 below is focused on details on this particular deployment of the robotic System TELBOT®.

TABLE III. Technical data of the TELBOT® system

Parts	Designation	Data
TELBOT®	Max. load capacity	100 kg
	Max. length of manipulator	2 700 mm
	Weight (without suspension)	327 kg
	Radiation resistance (max. accumulated dose)	Gy 10^6
	Radiation resistance (max. dose rate)	Gy/h 10^3
Pivot drive	Length between interface plate and pivot joint	620 mm
	Upper arm pivot angle (A1)	+/- 135°
Upper arm	Length between pivot points	1 280 mm

	Rotation angle (A2)	continuous
Lower arm	Length between pivot points	1 050 mm
	Pivot angle (A3)	continuous
	Rotation angle (A4)	continuous
Wrist	Length incuding gripper	370 mm
	Pivot angle (A5)	continuous
	Rotation angle (A6)	continuous
Gripper	Max. force between jaws	2 000 N
	Opening width mm (A7)	150 mm

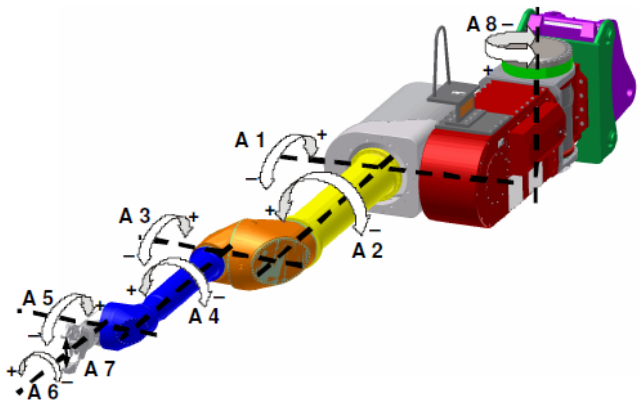

Fig. 5. Possible movements of the TELBOT®

DECISION POINTS FOR CONTROL SYSTEM; JOYARM VS MASTERARM

Selection of the Control Input Device

Depending on the tasks, the equipment must be operated efficiently and easily. The selection procedure can be represented in the Figure 6 below and is choice between compact and/or economical input devices or more intuitive ones.

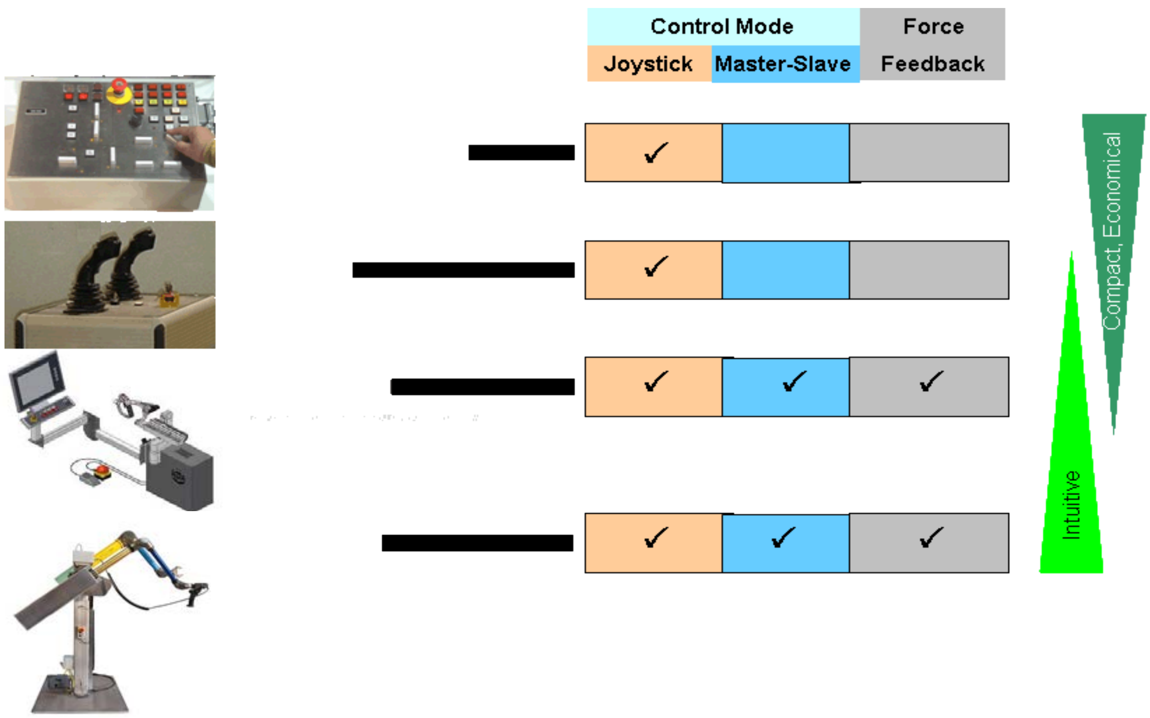

Fig. 6. Selection of Control Input Device

Description of the JOYARM II (Combination Between Joystick and Masterarm)

TELBOT® control function controlled by JOYARM II

- Joystick mode: joint / robot / tool / user-defined coordinate control
- Bilateral master-slave control: position offset and scaling, force / stiffness scaling
- GoTo mode: quick teaching-playback mode with multiple user-defined trajectories.
- 7DOF control: elbow position control
- Max force limit, stiffness control
- 3D robot simulation and collision avoidance
- Network communication

JOYARM II is an innovative universal operating device for all kinds of multi-axis robots (Figure 7). In the past, many kinds of remote operating devices for robots have been developed worldwide: joysticks, master-arms, haptic devices, etc. Operators sometimes need intuitive, more precise control, and other times rough but very quick positioning. What counts in real-life applications is a low level of stress and fatigue resulting from operation. JOYARM II has been developed to solve these problems.

JOYARM II was designed to provide ideal ergonomics for operators in order to minimize fatigue, independent from the slave-manipulator structure. To improve the functionality, JOYARM II has a feature that combines the advantages of conventional joysticks and bilateral master-arms. The name JOYARM II comes from Joystick and master-arm. With one device, operators can realize precise motion control such as that provided by a joystick and then switch to the intuitive quick positioning offered by master-slave control systems. JOYARM II sends commands with 6 D.O.F. for position/rotation and receives 6 D.O.F. force/torque feedback in a Cartesian coordinate frame. JOYARM II also offers numerous possible applications as a haptic device.

JOYARM II Technical Data

Number of axes	6 axes (X, Y, Z, θx, θy, θz) + gripper
Signal output/input	6 encoders, 1 analogue, 7 switches / 4 lamps, 1 buzzer
Force feedback	6 axes (Fx, Fy, Fz, Tx, Ty, Tz)
Maximum force	Fxyz: 20N, Txyz: 150Ncm at center of wrist

Fig. 7. Joyarm

Description of the Masterarm

The new HWM Masterarm is a new operating element for manipulators (Figure 8). It has force feedback on its seven degrees of freedom. The advantage is that you can sense feedback on the Masterarm from what is happening on the manipulator.

Freedom of movement provides operational comfort
- balanced ergonomics thanks to weight compensation in the arm elements
- frictionless components
- ergonomic handle
- effortless operation
- adjustable working height
- can be operated from both seated and standing position
- can be controlled by both left- and right-handed operators

Intuitive operation
- completely user-friendly
- controlled synchronisation with the manipulator
- infinite rotation of the swivelling and rotational axes (axes 2 to 6)
- easy positioning of the manipulator with Masterarm in many varied and complex situations
- extended working area
- control system with absolute encoder

- Immediate availability of the Masterarm after it has been switched on and synchronized with the manipulator
- precise simultaneous transmission of movements to the manipulator
- Masterarm movements copied 1:1 to the manipulator via a real time control system

Applications
- training with simulator thanks to autonomous control cabinet
- operates in combination with the TELBOT® (optimally with TB300)
- also as Masterarm for manipulator arms on bushing

Fig. 8. Masteram

Difference between JOYARM II and Masterarm

Operation of the Masterarm is more intuitive as the JOYARM because the TELBOT® 1: 2 is represented. Any movements in 3-D space are accurately transferred to the "big" arm and are executed. Due to the possible height adjustment of the pedestal, an ergonomic work for the operating personnel is possible.

TESTING RIG, TESTING PHASE AND MOCK-UP BY HWM

Test To Reduce the Coefficient of Friction on the JOYARM

During the first cold operation the focus was on the control device.The operators were able to run all tests by the use of the Joyarm. The works that have to be done by visual control and additional information from the force feedback were less successful than works that need movements in a coordinate system, like straight cuts with a cutting disk. The movements free in a room, operated like a mechanical master-slave-manipulator are easier and quicker to be solved by the use of a Masterarm. The Masterarm has a wider working range, so the precision control is sometimes better. Control by a simple joystick panel is much slower, as it is only in speed control. For simple tasks it is a good solution, but most of the work was preferable done by Masterarm or Joyarm.

To validate the requirements of the WAK, HWM conducted several tests in a test rig. Several tests were also conducted by the company IABG – a leading European technology and science service provider in Munich. Furthermore HWM did measurements of the gears and the coefficient of the friction. A new technology was developed to reduce the friction in the gears and reduce the friction coefficient from the sealing.

HWM performed a concentric running test for the drives of the Joyarm II (Figure 9).

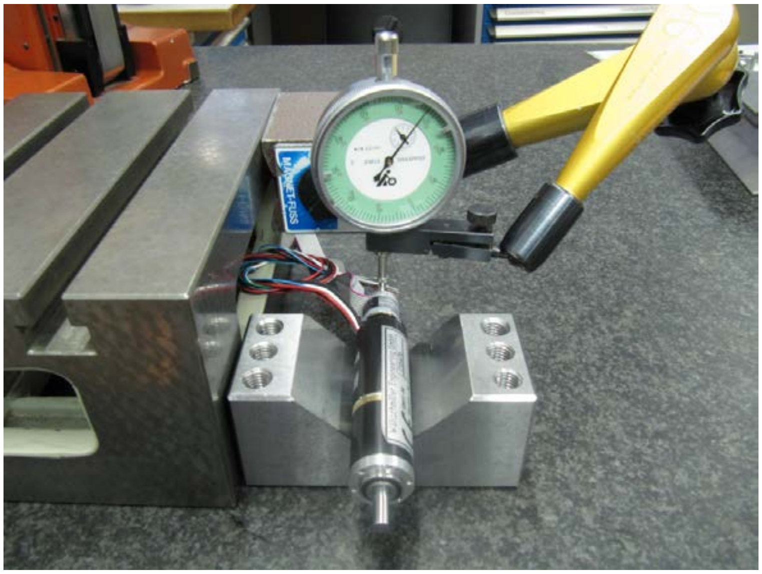

Fig. 9. Concentric running test for the Joyarm II drives

The drives for the TELBOT® were also all measured, torque (Figure 10).

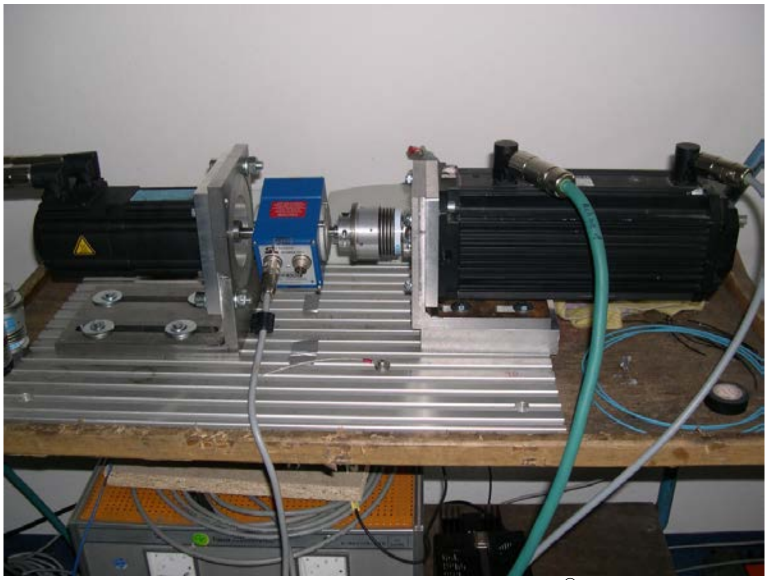

Fig. 10. Measurement of the TELBOT® drives

Tests to Measure the Recoil of the Tools in Collaboration with IABG

The objectives of these tests are the measuring of the reactive forces of the tools, in Figures 11 andd 12 the hydraulic cutter.

Fig. 11. Measuring the back lash of the tools

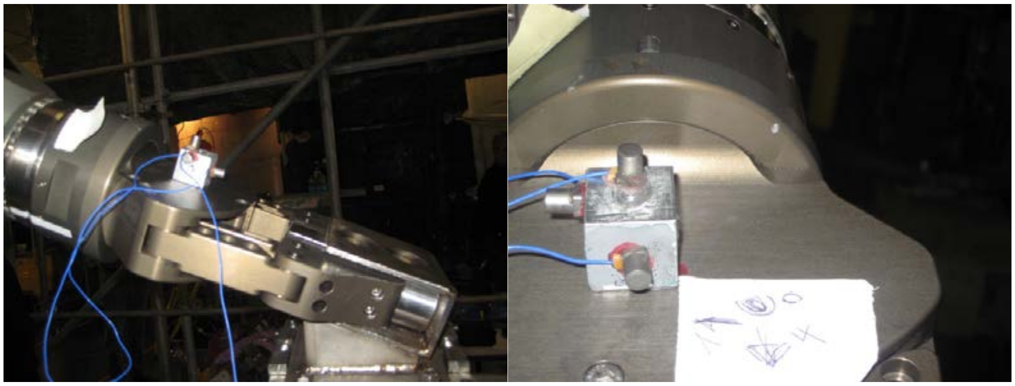

Fig. 12. Measuring the back lash of the tools

The results of the measurements can be seen in Figure 13. (Extract of the measurement report) The accelerometer was on the gripper in X, Y and Z directions. On the Figure 14 X corresponds to K3, Y to K0 and Z to K1.

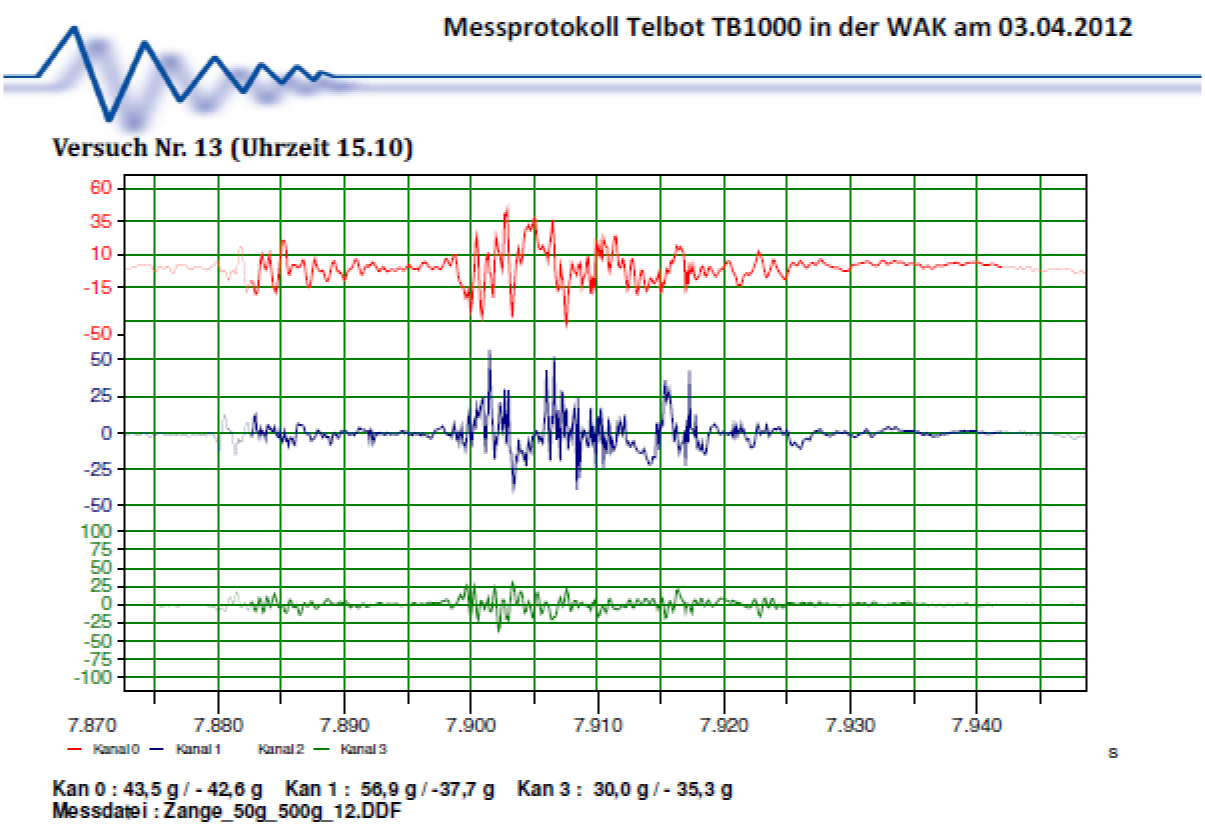

Fig. 13. Measurement report

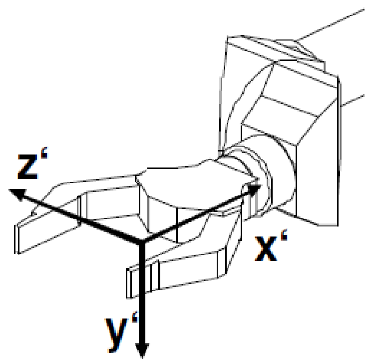

Fig. 14. X, Y and Z directions

The acceleration in the hand of the manipulator have been 50g and more. Such high values would reduce the lifetime of the manipulator. So there had to be modifications also on the tools.

As the TELBOT® system is equipped with safety clutches to prevent damages due to overload from outside the system, these clutches opened sometimes and the operators had to restart the system. As a result of these measurements the safety clutch was modified and the compliance control was further optimized. The requirements were fulfilled.

Special Test Rigs for Step 5.3 and 5.4

The TELBOT® at WAK has to operate in step 5.3 on a vehicle and on step 5.4 on a telescopic mast system. Therefore we needed to have a test rig that simulates the interface to a standard excavator, (oilquick-coupling). As the hydraulic arm of the excavator can bring the coupling to any position, we had to simulate also overhead working positions. The manipulator can principally work in any position. For the gravity compensation this is another challenge, as the hydraulic arm has no position detecting system.

For the tests at HWM for RB 5.4 the blue hall was used for the test rig, since this TELBOT® was mounted on a Telescope. Due to the long telescopic travel, it was an advantage to open the test pond for testing the stiffness of this special telescopic mast. The shown test sequence (Figures 15 and 16) is part of the camera test. The camera has to be placed remotely. The manipulator has to hold objects that stable for the camera makes it possible to read the text on it.

Fig. 15. Tests of the camera – special application - with cameras for RB 5.4

Fig. 16. Mock-Up for testing overhead working positions

Improvement of the Swivel Axis

During the first tests with the excavator, the operators noticed the difference in precise motion between hydraulic and electric drives. As a result we supplied an electric swivel joint as axis 8 to the system (Figure

17). This made it possible to put all the cabling into the joint and we also replaced the automatic hydraulic coupling by electric connectors. So it is possible to connect the manipulator to the excavator very easy. To complete the smart design of the system, the excavator was modified and all the cables and hoses were put fix on the arm. These modifications reduce the risk of damage significant.

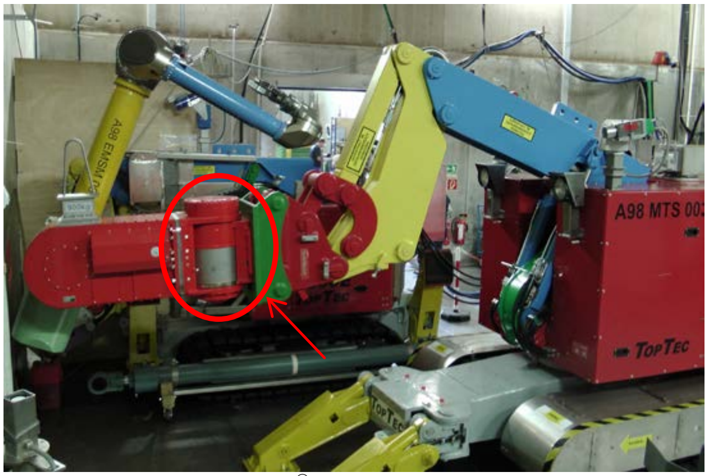

Fig. 17. TELBOT® with electrical swivel axis

The supply project RB 5.3 started in September 2009 and ended 2013, all together 8 TELBOT® arms, 5 for step 5.3 and 3 for step 5.4.

For the first TELBOT® a test phase of 8 weeks was calculated before the FAT. After the deliverance in February 2011 HWM and WAK collaborated, also with IABG to develop the TELBOT® further. This process was ongoing until the end of 2012.

CONLCUSIONS

Application of TELBOT® For High-Radiation Decommissioning is shown in Figure 18.

Fig. 18. Test time with mock-up

During the test time two main points became clear:

- The use of different input devices have been helpful to decommission the mock-up. For that reason, the TELBOT® system was equipped with following input devices:
  - Control panel with switches
  - Joysticks
  - Joyarm II
  - Masterarm
- The use of an electrical swivel joint as axis 8 is useful.

The Joysticks were used for simple tasks. The JOYARM with force feedback had the advantage particular for works overhead. The master arm with force feedback was used because of the intuitive work.

The test operation was so successful that the remote handling equipment is placed in the hot area with support from HWM to start the decommissioning.

REFERENCES

www.ewn-gmbh.de

ACKNOWLEDGEMENTS

With the friendly support of the WAK GmbH