

**A New Modular Hydraulic Power Manipulator for  
Remote Handling Operations in High Radiation Environments**

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**Abstract**

A new hydraulic power manipulator is currently undergoing extensive trials for processing radioactive waste in a full scale test rig for a major UK nuclear facility. This manipulator can be also be used for a range of remote handling decommissioning and waste retrievals tasks. The key design objectives were to produce a reliable, high payload manipulator that could be deployed through ports or other narrow access points in a shield or containment wall and could accommodate a range of tooling to undertake decommissioning tasks with a high degree of dexterity. ModuMan 100 was the result of the development and is a, six degree of freedom (DOF) manipulator, with a 2.54 metre reach and a payload capacity of 100kg at full reach. The materials of construction have been selected for a harsh operating environment and the link lengths were specifically designed to allow optimum dexterity to navigate restricted environments.

The manipulator is modular and makes best use of “off-the-shelf” solutions to provide value-for money solutions in term of system and lifetime support costs. The system has been designed with “in-cell” (inaccessible area within harsh environment) and “out-cell” components. In-cell multiple hydraulic actuators power the joint motion and a dual servo motor arrangement drives the shoulder rotate. All the hydraulic sensors and drives are located out-cell to allow ease of maintenance and to effectively minimise any down-time. At the end of the arm a jaw is used to pick out debris or clamp and utilise tools such as a shears, drills and wash-down equipment to aid decommissioning. The manipulator uses reliable and proven technology notably conventional hydraulic actuators coupled with proven industrial instrumentation and control elements to ensure robustness and optimise maintainability.

This paper describes the design and control system of ModuMan and the functionality and features these provide and how they can support a wide range of remote handling challenges requiring a hydraulic power manipulator.

## Introduction

The ModuMan 100 manipulator, Figure 1, draws on James Fisher Nuclear's thirty years' experience of engineering dependable remote handling solutions and manipulators for the nuclear sector. It is the latest manipulator development and has been designed to meet the requirement of waste retrievals and/or decommissioning projects. The manipulator may also serve as a general purpose heavy duty manipulator which can be used for a range of tasks in the nuclear industry and any other industries with hazardous environments which prevent man entry and require a remote handling manipulator solution. JFN has undertaken all aspects of the ModuMan manipulator development and on going support in house, from the specification development, conceptual design, detailed design, through to manufacture, testing, commissioning and through life support.

The design is modular and uses standard engineering principles so the base ModuMan system can be efficiently modified to suit individual project requirements without the high costs associated with a truly bespoke manipulator. This modular approach to design has also been used during the development of the control system software. The addition of additional limbs and/or the reconfiguration of the existing joints can be provided without reworking the entire code.

ModuMan 100 delivers an optimum 100Kg handling capability throughout its 2.54 metre in cell reach. It also provides outstanding dexterity with six degrees of freedom under full telerobotic control and the rugged reliability that is essential when operating in hazardous environments. It can be deployed through existing through wall ports. The system can also be adapted to attach to remotely operated vehicles or mast mounted from cranes and offers a unique combination of heavy payload capacity and dexterity for hazardous environment applications.



**Figure 1 - Prototype ModuMan during Factory Acceptance Testing**

## Description

The ModuMan is a powerful 6 degree of freedom hydraulic manipulator, which delivers 100kg (220lb) handling capacity throughout its full range of motion at its maximum reach of 2.54 metre (100in).

The ModuMan 100 incorporates a simple hydraulic system that ensures high performance and optimum availability. It is designed around standard, conventional hydraulic actuators coupled with proven industrial instrumentation and control elements, including resolvers, actuators, valves and sensors that are integrated and driven by a sophisticated software control system to produce a power manipulator that is durable, cost-effective and extremely flexible.

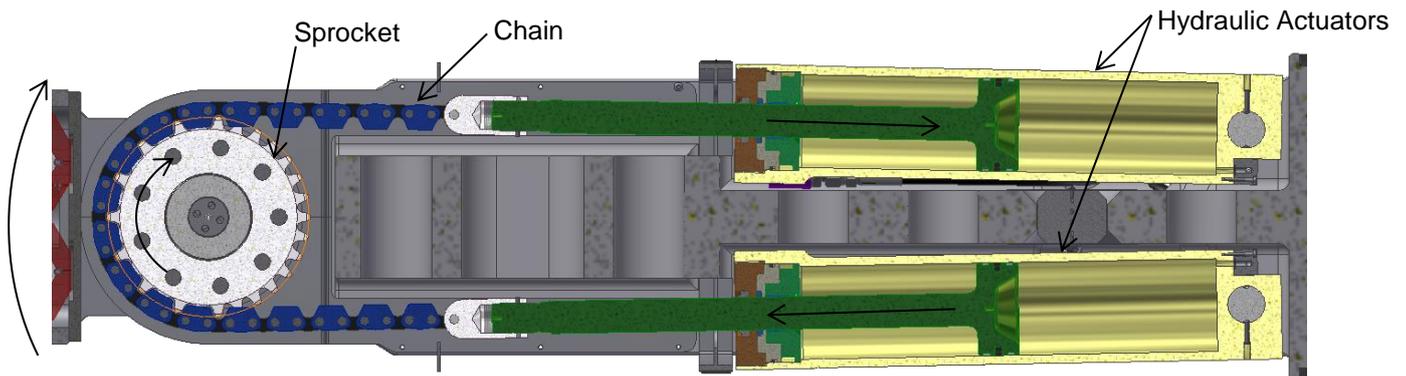
The manipulator system itself is supplied as three discreet sub assemblies:-

### 1. Manipulator Arm

This in-cell assembly comprises the structural members of the arm together with the actuators and required services to drive the arm functions.

The “through wall” portion of the structure contains a dynamic sealing element to maintain the in-cell containment against the installed liner.

The pitch joints, shoulder, elbow and wrist are actuated by a patented system comprising a simple pair of opposing hydraulic cylinders driving a heavy duty chain around a drive sprocket, as shown in Figure 2.



**Figure 2 – Typical Pitch Joint Drive Principle**

The wrist roll joint is powered by conventional hollow shaft hydraulic actuator and packaged accordingly.

The continuous tool rotate function is driven by a conventional low speed, high torque hydraulic motor.

The standard manipulator is supplied with a set of general use jaws that open up to 150mm and are hydraulically driven with a conventional actuator.

Each actuator is supplied by its own service hoses and its position monitored by a sealed radiation tolerant resolver.

The services are managed and routed down the manipulator arm to an interface plate at the end of the assembly. This component contains the individual hydraulic connectors for each function and also an electrical connector for all the resolver feedback signals.

## 2. Shoulder Roll / Valve Pack

The out-cell shoulder roll and valve assembly, shown in Figure 3, interfaces directly at the arm interface. Here the mechanical, hydraulic and electrical service connections are made to allow the arm to be driven.

The shoulder roll function is provided by a pair of servo motors driving a standard slewing bearing anchored to the out-cell structure.

This assembly also contains the servo, pressure relief and check valves required to drive and control the arm.

These control elements, being out-cell, are standard industrial devices which can be readily maintained and/or replaced without disturbing or removing the in-cell arm.

The out-cell hydraulic and electrical services to the assembly are managed in a simple cable chain allowing the rotation of the shoulder roll assembly.



Figure 3 - Out-Cell Shoulder Drive & Valve Pack

## 3. Control System

The control system is housed in two units, Figures 4 & 5.

A Control Console Unit, containing the Programmable Electrical System, feedback devices and power distribution. The unit also houses the servo drives for the shoulder rotate drive.

An Operator Control Unit, containing the physical components that make up the operator's workstation, including joy sticks and MMI. The unit also displays information from the CCU and can be used for diagnostics etc.



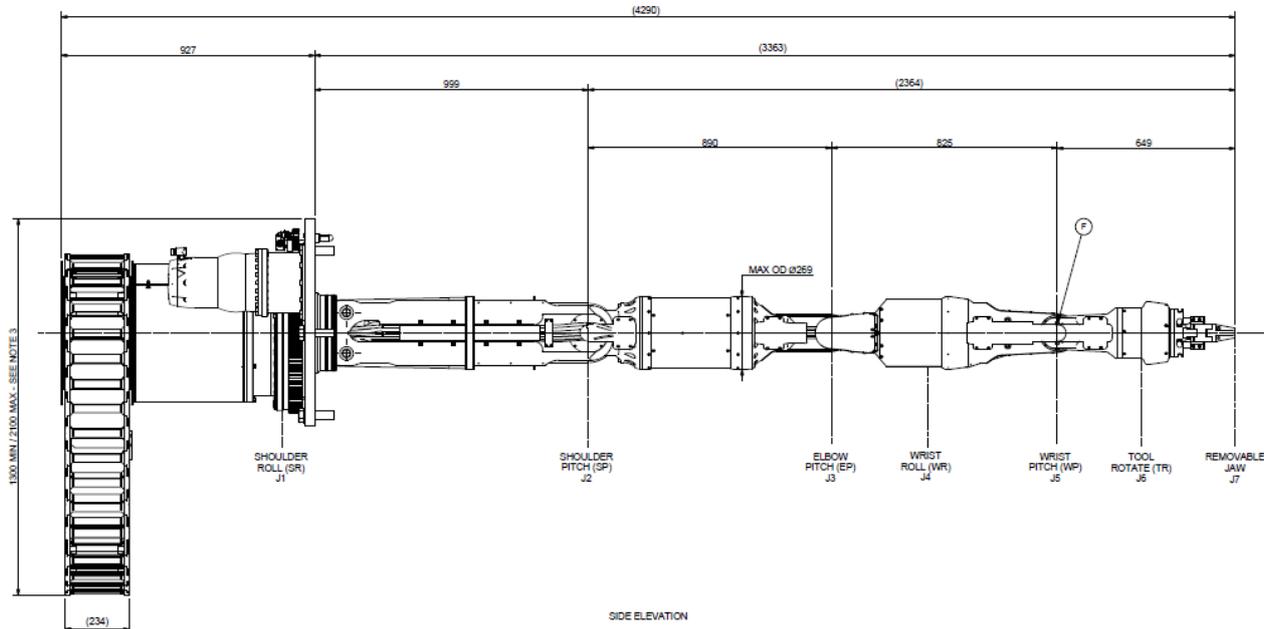
Figure 4 - Control Console Unit



Figure 5 - Operator Control Unit

## Configuration

The Standard Moduman 100 system, configured for a through wall application, is shown below in Figure 6.



**Figure 6 - Moduman 100 for Through Wall Application**

The specification of the manipulator in this typical through wall configuration is shown below:-

Shoulder Rotate	+/-130° Out-Cell Servo Motor
Shoulder Pitch	+/-90° Linear Hydraulic Actuators
Elbow Pitch	+/-130° Linear Hydraulic Actuators
Wrist Rotate	+/-130° Rotary Hydraulic Actuator
Wrist Pitch	+/-130° Linear Hydraulic Actuators
Tool Rotate	Continuous - Hydraulic Motor
Jaws	150mm Linear Hydraulic Actuator
Typical Reach	2540mm
Payload	100Kg Throughout whole range of motion
Jaw Grip Force	2500N
Tool Rotate Torque	250Nm
Typical Operating Fluid	Renolin PG32
Operating Pressure	210 Bar

The flexibility of the modular approach to this design allows James Fisher Nuclear to efficiently develop alternative arrangements to suit customer needs more precisely.

## End Effectors

The standard End Effector fitted to the manipulator is a general use set of jaws, shown in Figure 7. These jaws open up to 150mm and can be used to lift objects or clamp and utilise tools such as a shears, drills and wash-down equipment. The jaw profile contains an integral tee bar profile to assist with the acquisition and security of tooling fitted with typical manipulator "friendlies". The jaw module has an integrated quick disconnect mechanism which enables it to be replaced easily in cell or removed prior to export of the arm from the workplace. A variety of other tooling options and attachments could to be directly incorporated into this interface. This presents the Moduman system as an extremely flexible deployment mechanism for a whole range of equipment. Tooling such as shears, saws, torque wrenches, drills, hot cutting and surface treatment equipment can be

easily incorporated. This facility is also useful by allowing additional tooling to be developed and incorporated as new requirements are identified.

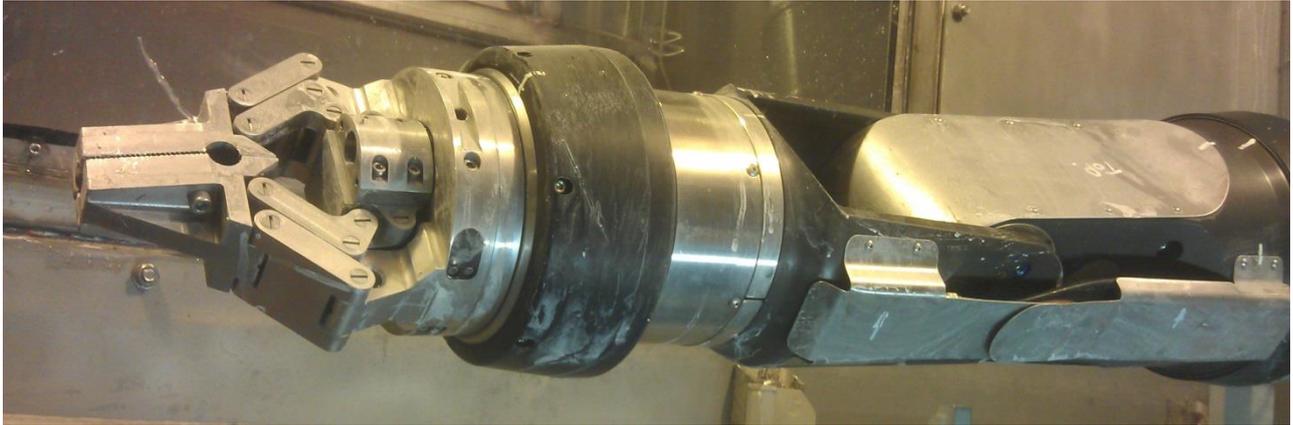


Figure 7 - Moduman Jaws

### Power

The through wall Moduman described above has been configured to operate from a hydraulic supply to the following specification:-

Recommended Hydraulic Fluid	Renolin PG 32
Minimum Required Flow Rate	10 litres per minute
Recommended Supply Pressure	207 bar
Maximum Supply Pressure	250 bar
Recommended ISO 4407 Cleanliness Code of Hydraulic Fluid	15/15/12 or better

The electrical supply for this system requires a 32 A 3-phase 400 VAC power supply (50-60 Hz) supplied by an industrial 32 A 3-phase + neutral + earth socket.

Obviously some of these power and hydraulic system requirements can be adjusted and tailored to suit specific environments and/or existing installations.

### Operator Controls

Standard, commercial rugged and reliable hardware and software platforms are at the heart of the ModuMan control system.

Operator control is via a Windows based touch screen and twin 3 axis joysticks, as shown in Figure 8. The control hardware can be desk-mounted, or incorporated into a portable desk system.



Figure 8 - Control Joy Sticks and Touch Screen Interface

The touch panel is used by the operator to select which mode to control the arm with, as shown in Figure 9. The touch panel also presents data such as current joint angles, their software limits, the end effector position and orientation, fault analysis, and the teach and repeat interface.

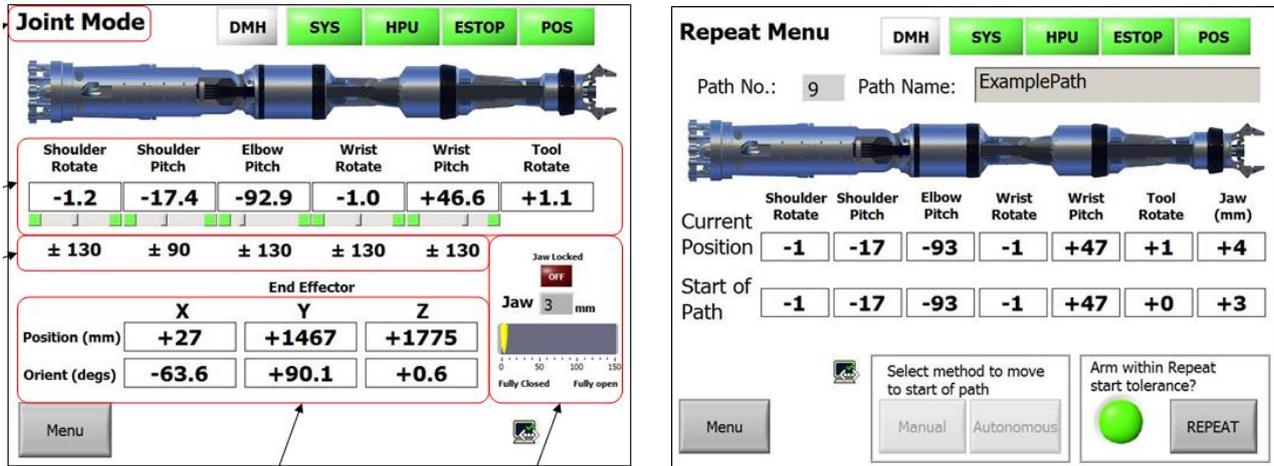


Figure 9 – Screens from the Moduman MMI

The manipulator can be manually driven in three standard operating modes:

**Joint mode:** where the individual control of each manipulator joint is directly driven by movement of the appropriate axis on the relevant joy stick.

**World mode:** allows the operator to translate and orientate the end effector in X, Y & Z axes without focussing on the individual movements of the joints. The base coordinate system defining the axes is fixed in line with the through wall mounting.

**Tool mode:** also allows the operator to translate and orientate the end effector in X, Y & Z axes. In tool mode the base coordinate system defining the axes is fixed in line with the axes of the end effector, therefore it moves with it.

Skilled operators prefer to use a combination of operating modes whilst performing remote handling tasks. The flexibility of the Moduman control system efficiently provides this feature.

Another important feature of ModuMan control system is the optional “**Teach and Repeat**” facility. Operators can record and store the motions of the manipulator and replay them at any time. This facility is essential for regular routine in-cell operations and greatly simplifies some of the more repetitive tasks that this type of system is often asked to perform.

The ModuMan system also features an optional **training module** that enables customers to test the equipment's capability in a virtual environment that can be modelled on their own particular application and requirements. The training module also allows operators to gain experience of ModuMan remote handling interface.

A full diagnostic and fault reporting function in the control system provides interrogation of the arm's performance and fault history.

The flexibility of the ModuMan control system facilitates enhancements to the standard system. Additional functionality can quickly be added to the controller to provide new features, such as collision avoidance. This functionality also allows updates to be made as a result of unplanned changes to the remote working environment.

**Safety** is a critical design aspect of the entire system. The arm can lock out the hydraulic feeds and electric motors to instantaneously stop all motion. All communication paths feature watchdogs checking the status of each part of the system. Any issues or loss of communication in the control system will stop the manipulator in a safe state and alert the user.

## Performance

A through wall Moduman 100 has been supplied to a client who required the system to be tested in a representative development rig. The validation trials were designed to simulate real plant conditions and prove the functionality and reliability of the system and its interfaces with the plant and tooling. The trials programme was developed to test the system for 1 year's simulated operations as part of the waste retrieval equipment in a major UK decommissioning project. The duration of these trials required that a dedicated team of operators was employed to drive the manipulator, both manually and with taught paths, performing simulated waste retrieval, size reduction and cleaning activities for 16 hours a day, 7 days a week.

The 1 year simulated operations milestone was reached in December 2013 and the client has decided to maintain the testing regime in an attempt to establish what the actual working life of the system could be in his particular application and environment.

## Deployment

The initial deployment for the Moduman system has been a typical "through wall" type. The arm is simply inserted into the installed through wall liner and mated with its out cell components to complete the installation. This arrangement maintains the gas tight seal and is also provided with interstitial seal test points to confirm the sealing integrity of the installation.

The system has been designed to fit through a standard Master Slave Manipulator (MSM) port allowing it to be inserted into existing hot cells with minimal modification. This provides operators of the cell with an additional handling device with much higher payload capacity as well as the additional benefits offered by a telerobotic system of this type.

The Moduman system can easily be modified to suit a variety of alternative mounting arrangements. The manipulator can also be mounted vertically to suit through roof applications. Mast mounting and deployment on Remotely Operated Vehicles is also readily achievable.

## Conclusion

Standard but Engineered to individual customer specifications

Moduman100 is designed as a powerful manipulator workhorse for the nuclear industry. It delivers an optimum 100kg lifting capability throughout its operating envelope, offering outstanding dexterity with full resolved motion control, and the rugged reliability that is essential when operating in hazardous environments. It is particularly suited for use in nuclear decommissioning environments and in confined spaces.

ModuMan 100 incorporates a simple hydraulic system that ensures high performance and optimum availability. It employs proven industrial elements including resolvers, actuators, valves and sensors that are integrated and driven by a sophisticated software control based on a commercial platform to produce a power manipulator that is durable, cost-effective and extremely flexible. The high performance structural integrity of the arm is enhanced by the use of radiation tolerant materials.

ModuMan 100 is a standard manipulator but can be engineered to meet the individual customer's specifications across a wide range of project types. This is due to the modular and configurable nature of the system design. JFN's experience in providing complete remote handling solutions for a wide range of difficult projects in the nuclear industry over several decades is also key to fulfilling this requirement.