MANTIS 2

A NEW LONG RANGE REMOTE VEHICLE AND SERVO-MASTER-SLAVE MANIPULATOR

FOR THE CERN ACCELERATOR COMPLEX

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ABSTRACT

The ability to travel hundreds of metres independently, through narrow access routes, in order to carry out the maintenance, exchange, or deconstruction of equipment within the radioactive parts of CERN’s accelerator tunnel complex is the role of MANTIS 2, a new vehicle-based, long reach, servo-manipulator, now approaching completion. Controlled via a self-deploying fibre-optic cable, from a caravan stationed on the surface, the device is particularly suited to working in unprepared or experimental environments.

INTRODUCTION

There are currently more than 10 kilometres of tunnels and halls containing thousands of tons of magnets and associated vacuum, radio-frequency, and diagnostic equipment, operational in the CERN complex of accelerators. A further 27 kilometres will shortly be added when the LEP storage rings are complete.

Certain localities exist within the complex where induced radioactivity hampers shutdown maintenance work. These widely dispersed localities, which together represent only a small part of the total complex, typically contain targets, target monitors, magnetic horns, collimators, lithium lenses, beam dumps, and their local shielding, with which the incident beams of protons or other accelerated particles interact.

In some of the radioactive localities, where it was possible to predict maintenance requirements years in advance, and to make comprehensive preparations, “smart” cranes, plug-in replacement units and occasionally, industrial robots, are installed.

However, the evolution of accelerator techniques is extremely rapid, and the hardware frequently experimental in nature, so that predicting future remote operational demands is often impossible. This fact alone fully justifies the existence of versatile mobile remote handling equipment. A useful trend, becoming better organised, is to make certain minimal modifications to the design of potentially radioactive equipment, following guidelines 1, which speed up “hands on” maintenance while personnel access is permitted, but which also facilitate remote maintenance, using a MANTIS, when higher induced radioactivity levels dictate.

Thus when an intervention is requested, which is perhaps complicated or time consuming, and where real dextrous capability is required, with acute sensing and long reach, in distant or unprepared radioactive localities, then either MANTIS 1 or the new MANTIS 2, may be called for, together with other supporting remote devices.

SIMILARITIES

Certain basic concepts, well proven with MANTIS 1 during 2500 hours of operation, are retained with MANTIS 2.

Both have a very heavy low bed, 4 wheel drive base vehicle, one metre wide only, for narrow access routes, with fold-out stabiliser jacks (fig. 1).

Both are independently steered, back and front, with each pair of wheels able to track a white line.

Both have a pair of force-reflecting servo-manipulator arms, which are “flow” up to 8 metres from, and around, the base vehicle by an on-board hydraulic crane (fig. 2).
Fig. 1 - MANTIS 2 - First local control tests
Note: vehicle is 1-metre wide only with fold-out stabilisers.
Fig. 2 - 8 metre maximum crane reach
Note: fibre optic/power cable anchor box in foreground.
Both are controlled and powered through reliable self-deploying umbilical cables.

Both use TV and audio sensing, with "overview" and "third angle" view cameras "flown" out from the base-vehicle on furlable masts.

Both have an all up weight of around 7 tons.

DIFFERENCES

Experience has led to the development of some new features, which are reviewed below.

Whereas MANTIS 1 uses a standard commercial truckloader crane to position its slave manipulators, MANTIS 2 has a purpose built unit with an inclining column and with horizontal as well as vertical articulation. This means that the slave arms can be moved around obstacles, as well as moving over them, which is especially valid when headroom is limited. This also means that the slave arms can reach all parts of their own base-vehicle, which can be crucial for self assistance in distant or inaccessible zones, (e.g. freeing trapped cables, removing debris from wheels, fig. 3).
MANTIS 1 must deploy 1/4 ton of cables, arranged in a heavy flat band, from a separate winch-trailer, in order to move a maximum of 80 metres from a fixed anchor point. MANTIS 2, although smaller, carries an on-board automatic cable-winch, deploying a single cable, over 1/2 kilometre long, containing 3-phase power leads plus 8 fibre-optic channels. A novel mechanism, inside the cable drum, (fig. 4), compensates for the 250 drum revolutions required to lay the present cable, while carrying the optical fibres continuously through the system, with no breaks and no measurable losses. This feature allowed us to use a simple LED signal transmission system, instead of laser diodes, which the alternative, an expensive fibre-optic rotating joint, would have compelled us to use. The compensator can be extended to absorb 500 turns of the existing drum.

A digital data link transmits control signals to and from the master control station, which with its associated TV, audio, and recording gear, is housed in a "touring" style caravan.

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Fig. 4 - 8-channel, 260 turn, fibre-optic drum rotation compensator.
Fig. 5 - Hydraulic servo-manipulator arms with covers removed, supported at jib end by articulating link.
NEW MANIPULATOR

A very significant feature of MANTIS 2 is the new hydraulic servo master-slave manipulator (Fig. 5), which has transducer force feedback, and whose development aims were dictated by operational experience with the venerable, 16 year old, MASCOT electric servo-manipulator, used on MANTIS 1 .

A first requisite was increased power, while avoiding the problems we had experienced with fully loaded electric motors running at low or zero speed (e.g. frequent cutting-out, and constant fan noise picked up by the audio system).

A second requisite was improved force and position resolution, permitting the operator to distinguish greater touch detail.

Thirdly, we wished to reduce the size of the slave shoulder unit, to give us access to smaller localities.

These ideas led us to develop a hydraulic servo actuator, giving abundant power, with no backlash, and with integral braking and overload provisions. A torsion bar force transducer, with Hall-effect pick-up, is mounted coaxially within the actuator hub, and transmits torque directly to an output pulley or chainwheel. The unit also has Hall effect position sensing. Force and position resolution between master and slave actuators is around 0.1%.

Seven actuators, in three sizes, power each of the arms, which for the time being, retain classic low-inertia kinematics, based on Walischmiller A 200 forearms.

The complete arm is lighter and more compact than our old MASCOT arms, and the "X", "Y" and "Z" movement ranges are doubled.

MANIPULATOR CONTROLS

The control loops of the master-slave manipulator are based on the principle of bilateral position regulation. They have also to provide backdriveability for the hydraulic master and slave actuators, and force reflection. After comparative studies of different loop configurations, the version shown in Fig. 6 was adopted.

![](image)

Fig. 6 - Control loops of the MANTIS 2 hydraulic servo master-slave manipulator.
A high gain position loop helps to solve several of the problems of hydraulic manipulators. It eliminates the effect of servo-valve non-linearity and drift, damps mechanical oscillations, and provides a stiff coupling between master and slave.

Force-feedback for both master and slave is essential, to provide backdriveability and force reflection. A force loop with high gain (at frequencies below about 10 Hz) will give good backdriveability, but leads to a system with poor damping and an elastic coupling of master and slave. Non-linear force feedback was found to be very efficient in solving this conflict.

The force and position regulators are robust (parameter insensitive) PD regulators, with correcting networks. Extensive measurement and computer simulation were necessary to determine the structure and parameters of the regulators. The hydraulic manipulator, seen as a dynamic system, is non-linear (because of the valve hysteresis), and time-variant (because of the variable load). The position and force loops are interdependent, i.e. a modification of the position regulation influences the force system, as seen by the force regulators, and vice versa.

Additional functions of the regulators are the adjustment of the force reflection ratio (gain factor Q), and electronic load-counterbalancing. When the latter is selected by the operator, the control signal of the master force regulation, U_m, is stored, and progressively applied to the summation point of master force and position regulator, (fig. 6). This will, for a particular load, maintain the manipulator in equilibrium, with a zero force sensed by the master force transducer.

The force transducer voltages of master and slave are monitored by individually adjustable comparators. If a selected force threshold is exceeded, the hydraulic brake of the master or slave, or both, will be tripped.

At the time or writing – Oct. '86 – a prototype regulator has been tested on each of the motions of the manipulator, with encouraging results. The coupling stiffness between master and slave actuators is much better than the stiffness of the steel cables which transmit actuator movement to the manipulator wrist functions. The backdriveability is comparable with that of the MASCOT electric manipulator, used on MANTIS 1. Force reflection performance is also within the design goals, if we consider the transmission properties of the servo regulation, without the mechanical losses in the arm mechanisms. The smallest transmitted force is about 25 grammes, and the force reflection bandwidth is about 50 Hz, for signals above the minimum force threshold.

FUTURE DEVELOPMENTS

There is no significant contamination in the CERN complex, so that MANTIS 2, like its predecessor, can return directly to the development shop between operations. The construction team is also responsible for operation and maintenance, so that evolution is continuous, but firmly based on operational realities.

We will continue to work toward "crisper" touch, vision, and audio, together with more efficient hybrid sensors e.g. for line tracking, navigation and proximity. The fibre-optic system, which has has dramatically improved video stability, will be carefully monitored for signs of degradation, and radiation-resistant versions will be researched.

The full exploitation of the geometric possibilities of the new crane may lead us toward computer-aided operation, e.g. "return crane to parked position with minimum swept volume". We will also continue to improve deployment response time, and tooling versatility.

REFERENCES


