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A SOLUTION FOR REMOTE HANDLING IN ACCELERATOR INSTALLATIONS*

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Summary

This paper describes a remote handling system, designed for LAMPF, and versatile enough to be used in a variety of situations found around particle accelerators. The system consists of a bilateral (force-reflecting) servo-manipulator installed on an articulated hydraulic boom. The boom also carries the necessary tools and observation devices. The whole slave unit can be moved by crane or truck to the area of operation. A control cable connects the slave unit with the control station, located at a safe distance in a trailer. Various stages of development as well as some operating experience are discussed.

Introduction

LAMPF's design goal of 1 mA of 800 MeV protons makes it the most powerful Meson Facility built to date. From the earliest stages in the project designers have been concerned about the problem of handling equipment in residual radiation fields of several tens of thousands of Rem/hr. The first concept developed and actually built was "Merrimac",[1] basically a huge 200-ton, moveable hot-cell, which will probably be the ultimate answer to the most severe situations of radiation that may ever be encountered. Merrimac's access is limited to the main target cells, fitted with hydraulically operated shielding doors.[2] Not all situations will require the 75 cm thick iron shield it provides, particularly during intermediate beam current stages of the order of 100 μA. To cover these situations a faster and more versatile unit, Monitor,[3] was developed and built. It has already proven to be indispensible on several occasions. The most severe operation was the replacement of a beam exit window and collimator at the beam stop (Figure 1). Radiation levels were over 10,000 Rem/hr at the place of action and 1.5 Rem/hr at 6 m distance at the edge of the shielding cell.

Description

Basically the device consists of a hydraulic truck loader, that carries remote handling equipment, observation devices and tools at the end of an articulated and extendable boom. The truck loader is commercially available from a number of companies and comes with an option of remote control via cable. After the shielding has been removed from over a target cell, the end of the hydraulic boom can reach down 8 m from the edge of the shielding. The end of the boom carries two manipulator slave arms, and a remote control zoom, focus, pan and tilt C.C.T.V. camera and light. A second, light weight, extendable mast carries a similar camera and light unit, which can be moved around the scene of action as necessary. There are additional camera units at the "hinge" of the truck loader and at the edge of the shielding to provide an overall view. All equipment, other than the manipulator assembly, can be ordered from catalogues, needing only moderate adaptation.

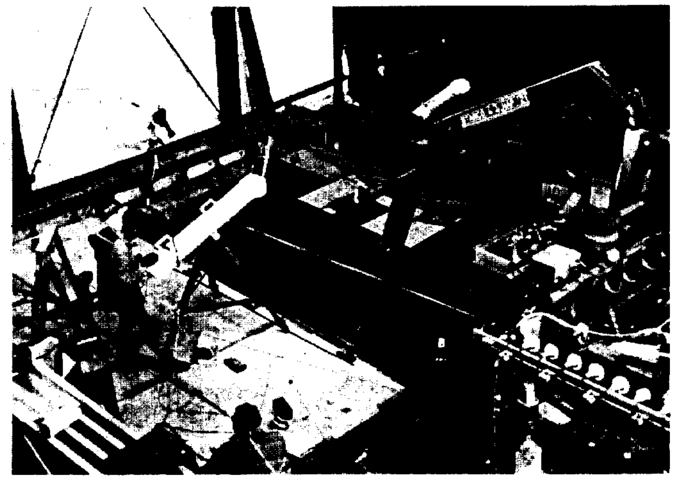

Fig. 1. Monitor operating in beamstop cell.

The pair of manipulator arms is suspended from the hydraulic boom via a levelling drive, which ensures that the shoulder is automatically kept horizontal, irrespective of the angle of the boom. The shoulder assembly with the two arms can also be rotated around its vertical axis to make the arms "face" the object.

The whole device can be moved by crane or truck to the desired location with the control station located in a trailer, at a safe distance of up to 100 m. Ultimately the equipment will be used in combination with a remotely controlled overhead crane, which has another camera/light unit looking down from below the cable drum.

Choice of Manipulator

The basic philosophy of this approach to remote handling is to replace the technician in the radiation area by a mechanical slave that promptly duplicates his manipulations resulting from his observations while he is located at a safe distance. Therefore, dexterity is rated more important than power. A man will use power tools and cranes and so can the slave. The slave should also have two arms, as does the man.

Initially Monitor was equipped with a one-arm surplus rate-controlled manipulator. These are readily available off-shelf items, but they are slow, as each degree of freedom is controlled by a separate, two-way lever switch (Figure 2). Ultimately Telearms, its successor, will have a two-arm bi-lateral servo-manipulator. Originally complex and bulky, these devices have reached a high degree of sophistication. Accelerator laboratories have provided considerable impetus to their development and deployment (for example at Brookhaven[4], CERN[5] and Fermilab[6].)

A bi-lateral servo-manipulator has force reflection. In many respects it is similar to the common master-slave manipulators used in hot-cells, except that the master and slave can be separated by a long distance, connected only by a cable. They enable the operator to "feel" what he is doing. A servo-manipulator has another advantage over a mechanical

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master-slave manipulator: the force reflection ratio can be varied, so the operator feels only part of the load that is handled by the slave[7] (Figure 3).

As it would take well over a year to build the bi-lateral servo-manipulator, a one-arm uni-lateral (non-force-reflecting) servo-manipulator was built for Monitor to overcome the lack of speed of the rate-control manipulator. This could be done in a few months, as it was possible to borrow an existing prototype slave arm (Figure 2). This arm is of compact design and uses hydraulic cylinders as actuators.[8] The master has the same joint-to-joint dimensions as the slave, but carries no actuators, only position sensing potentiometers. Hence there is no force reflection, although this could be added in principle.

The eventual choice of a fully force-reflecting two-arm servo-manipulator was based on speed of manipulation. Operations in even the best equipped hot-cell take at least eight times as long as done manually. One may expect the same for a good servo-manipulator. Anything less than that will be much slower. Several studies have been made to evaluate manipulators in terms of time to do certain operations.[9,10] Such evaluation depends a great deal on the choice of particular manipulations as well as on ease of viewing and

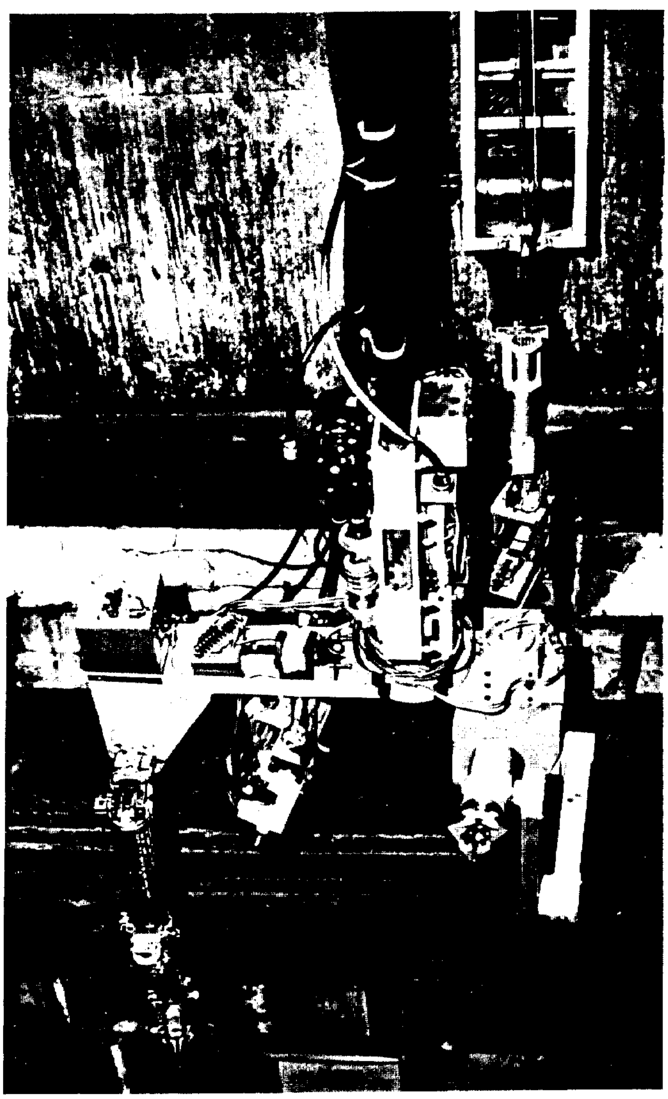


Fig. 2. Uni-lateral Servo-manipulator (L) and Rate Control Manipulator (R) with T.V. Cameras on Monitor.

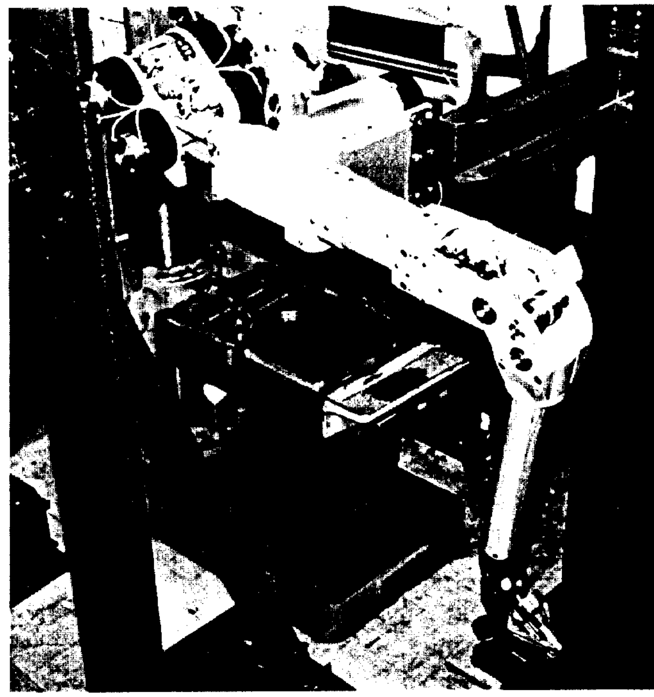


Fig. 3. Bi-lateral Servo-manipulator for Telearms.

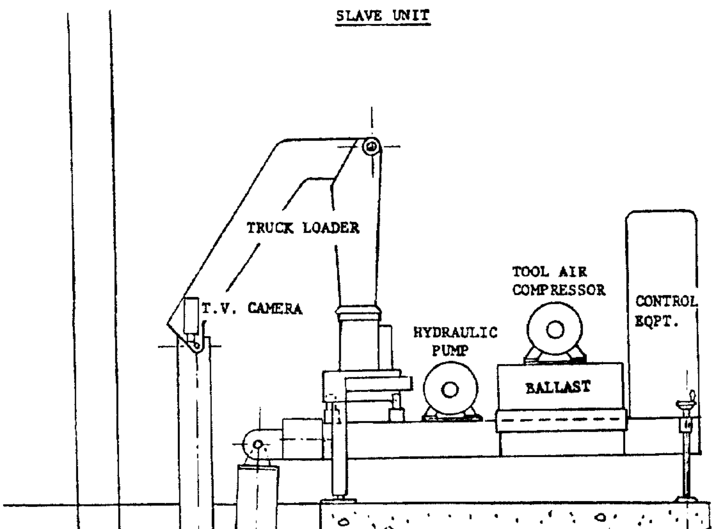
skill of the operators. At LAMPF we timed the elapsed time to complete two operations: attaching a sling to a lifting lug and inserting a ½-inch hexagonal bolt in to a tapped hole. We used a mechanical master slave manipulator (one and two arms) and the operators' bare hands. Observations were averaged between an experienced and an inexperienced operator.

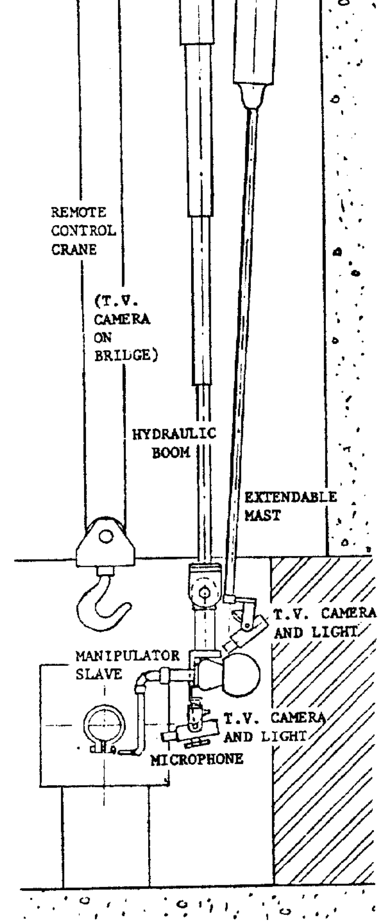
The comparative results are as follows:

System	Arbitrary time units (±50%)
Two-arm man	1
Two-arm mechanical master slave manipulator	8
One-arm mechanical master slave manipulator	16
One-arm electro-mechanical rate control manipulator	480

A servo-manipulator without force-feedback was not available at the time of the test but its figure is in the neighbourhood of 80 time units, as indicated by practical experience with Monitor. During actual service it was also apparent, that while the rate control manipulator was actually more readily available during actual service than the uni-lateral servo-manipulator, which suffered from some teething troubles, it was invariably preferred by the operators and used to do the job in the end. We also learned that, due to the servo-manipulator's much faster response, the lack of force reflection was a greater disadvantage than with the rate control manipulator. There is one particular application where the rate control manipulator is faster: once it has found the tapped hole, it can screw in a bolt faster, because it has continuous wrist rotation. One can expect a bi-lateral servo-manipulator to perform about as well as a mechanical master slave manipulator.

A word of caution is appropriate with respect to the interpretation of above performance data. They are based on rather simple laboratory tests and do not take into account the time it takes to move the manipulator to the job. Real life remote handling proved to be very slow indeed, indicating that only the best equipment available is good enough. However, with the system as shown in Fig. 4, we feel that we have reduced the job of





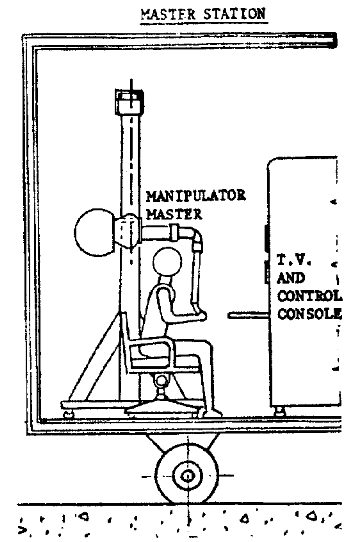


Fig. 4

The Telearms System

"getting there" to a minimum and that with some further development of viewing systems and manipulator adapted tools a figure of 8 time units for a bi-lateral servo-manipulator is achievable.

The Bi-lateral Servo-Manipulator

The two-arm system is presently being commissioned. The master and slave arms are essentially identical and both driven by low-speed, low-inertia motors, so as to minimize gear ratio and inertia resulting from rotating parts. The motors in the master provide the feed-back force via a position-error feedback loop. There are seven degrees of freedom, two at the shoulder, two at the elbow and two at the wrist, plus the grip movement. All motors are located at the shoulder, thus minimizing size and inertia of the various members. Because of the force-feedback the arms need to be balanced, so the operator does not have to carry the weight of both master and slave. Mechanical friction is extremely low, but most of the friction is determined by hysteresis in the motors. This is not expected to be a problem, but if necessary nearly all friction could be eliminated with a set of force-transducers in the master, which produce a force in the master in the direction of motion.

The manipulator is capable of following virtually all movements of a man's arms when his body remains stationary. To reach out further there is also provision for indexing.

Status

Construction of Monitor was started by the middle of 1975. It was put in service with its rate control and servo-manipulator, a year later and has been used for actual remote handling since the fall of 1976. The first arm of the force-reflecting servo-manipulator for Telearms is ready for installation with the second arm to follow in May.

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