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(CONF-77-313--3)

TITLE:

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SUBMITTED TO:

**1977 Particle Accelerator Conference, March 16-18,
Pick-Congress Hotel, Chicago, Illinois**

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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 the Los Alamos Clinton P. Anderson Meson Physics Facility (LAMPF), versatile enough to be used in a variety of situations found around particle accelerators. The system consists of a bilateral (force-reflecting) servomanipulator 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

The design beam of 1 mA of 800-MeV protons will make LAMPF 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 R/h. The first concept developed and actually built was Merrimac,¹ a 200-ton, movable hot cell, which may 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 tungsten shield it provides. Nor will Merrimac be able to operate in other potentially radioactive areas not previously prepared for remote handling. To cover these situations, a faster and more versatile unit, Monitor,³ was developed and built. It has already proved to be indispensable on several occasions. The most extensive operation was the replacement of a beam exit window and collimator at the beam stop (Fig. 1). Radiation levels were over 10,000 R/h in the working area and 1.5 R/h at 6 m distance at the edge of the target cell.

Description

Basically the device consists of a hydraulic truck loader that carries remote-handling equipment, viewing devices, and tools at the end of an articulated and extendable boom. The truck loader is commercially available and comes with a remote-control option. 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 remotely controlled zoom, focus, pan and tilt television camera and light. A second, light-weight, extendable mast carries a similar camera and light unit, which can be moved around the work area 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 catalogs, needing only moderate adaptation.

The pair of manipulator arms is suspended from the hydraulic boom via a leveling 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 while he is located at a safe distance. Therefore, dexterity is rated normally 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 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 (Fig. 2). Ultimately, Monitor II will have a two-arm bilateral servomanipulator. 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, BNL,⁴ CERN,⁵ and Fermilab⁶).

A bilateral servomanipulator is similar to the common master-slave manipulators used in hot cells, except that the master and slave can be separated by long distances, connected only by a cable. They also enable the operator to "feel" what he is doing. A servomanipulator has another advantage over a mechanical master-slave manipulator in that the force-reflection ratio can be varied so the operator feels only part of the load that is handled by the slave (Fig. 3).⁷

Because it would take well over a year to build the bilateral servomanipulator, a one-arm, unilateral (non-force-reflecting) servomanipulator was built for Monitor to overcome the lack of speed of the rate-controlled

Fig. 1. Monitor operating in beam-stop cell.

*Work performed under the auspices of the US ERDA.

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manipulator. This could be done in a few months, as it was possible to borrow an existing prototype slave arm (Fig. 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 with further development.

The eventual choice of a fully force-reflecting, two-arm servomanipulator was based on speed of manipulation. Operations in even the best equipped hot cells take at least eight times as long as when done manually. One may expect the same for a good servomanipulator. 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 tasks as well as on ease of viewing and skill of operators. At LAMPF we determined the time to complete two operations: attaching a sling to a lifting eye and installing a hexagonal bolt in a tapped hole. We used a mechanical master-slave manipulator (one and two arms) and an operator's bare hands. Observations were

averaged between an experienced and inexperienced operator. The comparative results are as follows:

System	Arbitrary Time Units ($\pm 50\%$)
Two-Arm Man	1
Two-Arm Mechanical Master-Slave Manipulator	9
One-Arm Mechanical Master-Slave Manipulator	16
One-Arm Electromechanical Rate-Controlled Manipulator	480

A servomanipulator without force feedback was not available at the time of the test, but its figure is approximately 40 time units, determined by practical experience with Monitor. During the recent remote-handling operation, it became clear that even the unilateral servomanipulator offered a speed and dexterity that made it the operator's choice for most operations. Another fact also became clear, the need for a 20-45 kg capacity dexterous manipulator to replace the slow rate-controlled manipulator. The present electromechanical manipulator was used for a number of operations because of its capacity and stability and, at least in LAMPF's case, that need will continue. We also learned that, due to the servomanipulator's much faster response, the lack of force reflection was a greater disadvantage than with the rate-controlled 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 "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 bilateral servomanipulator is achievable.

Fig. 2. Unilateral servomanipulator (L) and rate-controlled manipulator (R) with television cameras on Monitor.

Fig. 3. Bilateral servomanipulator for Monitor II.

Slave Unit

Master Station

Fig. 4. The Monitor II system.

The Bilateral Servomanipulator

The manipulators for the two-arm system are near completion. The master and slave arms are essentially identical and both are 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 feed-back loop. There are 7 degrees of freedom, 2 at the shoulder, 2 at the elbow, and 2 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 feed-back, 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, so most of the friction is from hysteresis in the motors. This is not expected to be a problem, but nearly all friction could be eliminated with a set of force transducers in the slave, which would produce a force in the master opposite to 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 farther, 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 servomanipulator a year later and has been used for actual remote handling since the fall of 1976. The first arm of the force-reflecting servomanipulator for Monitor II will be ready for installation shortly, with the second arm to follow in May 1977.

Acknowledgments

The authors are indebted to Dr. A. B. Rechnitzer, Department of the Navy, Pentagon, Washington, D.C., for his kind cooperation in arranging for the loan of the hydraulic servomanipulator arm. They also wish to acknowledge Dr. Louis Rosen, Director of LANPF, and Dr. Lewis Agnew, Associate Division Leader for Experimental Areas, for their continued interest and encouragement.

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