PROPOSED REMOTE HANDLING METHODS FOR A MODIFIED AGS*

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Introduction

Proposals to modify the Brookhaven AGS to run at beam intensities of 2×10^{13} protons per second imply, if implemented, high rates of induced radioactivity. Even after all precautions are taken to keep these activities at a minimum,[1] it is expected that radiation levels in substantial parts of the machine will, for a considerable period after shutdown, exceed tolerance by orders of magnitude, severely restricting or entirely precluding human access. Nevertheless it will be required to perform maintenance and any desired machine modifications. Furthermore, this remote maintaining of the machine should not require substantially more downtime than at present nor should experimental flexibility be unduly restricted.

Discussion of handling problems will be restricted to those associated with the components in the machine enclosure itself, even though the problem extends to beam transport equipment and target areas. The latter, however, can be handled by much the same techniques that apply to the machine without being subject to the same restrictions.

Adapting the Accelerator

Equipment Removal

Under present operating conditions about 5% of available AGS time is used for planned maintenance. If one tries to utilize the remote operating experience of hot laboratories, one finds that on the average one has to expect a factor of 10 to 20 increase in process time due to the fact that operations are remote. This should warn one that even if one had the required devices and techniques to convert straightforwardly to remote handling, the time factor makes this undesirable. Such an approach would in fact, assure that little, if any, machine running can occur, thereby reducing machine activation problems but otherwise missing the objective. Luckily there is an alternate solution. When the AGS was built, one was considering beam currents nearly 10^4 times lower than those mentioned in the present proposal. At this lower figure no reason existed to exclude from the tunnel auxiliary equipment which it was considered desirable to have near the machine. At the higher figure, considerable effort is justified to eliminate as many of these devices as possible, which, in fact, are now proposed to be moved to a superposed ring building above the machine tunnel.[2] By removing this equipment which consists, by and large, of electronics and controls, one finds that one has removed more than 80% of the required maintenance work from the roster of operations to be performed remotely. Furthermore, some of the congestion within the AGS tunnel enclosure is relieved sufficiently to allow the introduction of any required remote handling devices.

Remaining Machine is Modular

With all the auxiliary equipment removed, the modular nature of the AGS should become quite apparent. It will be recalled that the AGS consists of 240 magnet units separated by straight sections. The entire machine can be divided into 12 superperiods, which, with the possible exception of the detail content of the straight sections, are all identical. Each superperiod contains 20 magnet units separated by straight sections. In each superperiod there are two ten-ft long straight sections, six five-ft long straight sections and the remainder are two-ft long.

In Fig. 1, which shows a portion of a superperiod, dashed rectangles are drawn which represent a possible division of the machine into modules. As can be seen, the two-ft straight sections have been incorporated into the magnet module downstream of it. If one assumes all magnet modules, despite some subvariations, to be of one kind, one ends up with only three basic types of machine modules to contend with. Each of the modules of one type is standardized with respect to its external configuration and mode of connection to the machine. If a failure occurs in any one of the modules, rather than trying to repair it remotely in the machine, the faulty module is removed and replaced by a spare, thus reducing the bulk of the necessary remote operations in the tunnel to a few standardized, well-engineered and rehearsed procedures. The actual repair of the faulty module can then be performed at leisure, either after lengthy cool-off periods or, if urgent, in rather conventional hot cells without affecting machine running time.

Any of the continuously required machine modifications can be performed by designing, building and testing new modules (usually five or ten-ft straight section modules) which contain the new devices but otherwise correspond to the external standards established. At installation time the new module is exchanged with the one previously occupying the planned location. Such an approach does not require that for each particular module subvariety a spare exist, since in many cases of failure, one may decide that it is more economical to temporarily do without a particular machine feature. Only for the most basic and widely used equipment need complete spare units be available.

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* Work done under the auspices of the U.S. AEC.

Module Connections

Having cleared the tunnel and having arranged all remaining equipment into modules with standardized external connections, one comes to the main problem of module removal and replacement. Since the majority of "in tunnel" machine malfunctions and virtually all machine modifications call for a module exchange, one could expect five to ten such exchanges per year. It would, therefore, be desirable that any such exchange be accomplished within two working shifts and, if possible, a good deal faster. This has to be kept in mind as one analyzes the requirements of the intermodular connections, which must, in addition, be highly reliable and fail safe. The modules must also be capable of sufficient separation so that their removal or replacement by means of a remotely operated crane is possible.

The problem of the detailed nature of intermodular connections is subject to a wide range of solutions. One could automate all module connections completely, so that any one of them would essentially be self-detaching or reattaching on command from the control room. If one had only two or three modules to worry about this might possibly be the easiest solution. But with several hundred modules to be taken into account, questions of cost, reliability and interlock complexity might preclude this solution.

An alternative solution calls for relatively simpler semi-automatic disconnects to be incorporated into the modules and to be augmented by relatively simple, jig like, special purpose manipulating devices. The problem here strongly depends on how "relatively simple" things can be kept and on the multitude of special purpose devices necessary to cover the range of required operations.

A third solution[3] would avoid using a multitude of special purpose manipulating devices and use instead the best possible and most dexterous general purpose manipulator units, minimizing as much as possible complex modifications to machine connections, and simplifying operational procedures. Such a system can be adapted with comparable ease to use with new accelerators. Also, much the same devices as are called for in this approach, will be required, even with complete machine automation, in order to handle the unplanned and unexpected operations which will inevitably arise. Therefore, some of the extensive work necessary to develop such devices would be required in any event.

It should be pointed out that these solutions are not mutually exclusive alternatives. Any number of intermediate compromises is possible. One can run through the entire spectrum of solutions as relative emphasis is shifted from automation built into the accelerator to complex devices introducible into the machine for the purpose of performing required functions.

To date, insufficient data on the relative merits of the suggested systems are available to allow one to make a clear-cut engineering decision as to what course to follow. Nevertheless, individuals will inevitably be led by their intuition to preferences of approach which will no doubt prevail until more conclusive data emerge. The author's preferences tend toward using general purpose manipulators with minimum machine modifications, and will, therefore, concentrate on describing work done in investigating this approach.

Remote Handling Devices

Accelerator Requirements

It is clear that any general purpose manipulating devices which one might want to use, in order to be effective, must be of the highest possible dexterity. This probably rules out the use of any of the unilateral electrical devices commercially available. One would hesitate to use these anyway since the lack of any force feedback to the operator combined with imperfect TV coverage would rather frequently cause forces of up to several hundred pounds to be unintentionally and unknowingly exerted on parts of the accelerator. For this reason comparison will be confined to master-slave manipulators which are both much more dexterous and safer.

One can try to regard the AGS tunnel as an outsized hot cell but one will find few points of similarity with conventional ones. Even the largest hot cells permit at least an overall view of the cell through shielding windows; both the shielding thickness and geometry of the AGS make this impossible. This rules out direct application of mechanically connected master-slave manipulators through shielding walls. On the other hand, such manipulators cannot be used in a biological shield unit which can be regarded as an inside-out hot cell requiring about 4" of lead shielding.[3] Such a unit must be 5 ft × 5 ft × 9½ ft minimum in outside dimensions to accommodate even light-duty manipulators capable of handling as little as 10 lbs and would therefore not fit into the AGS tunnel. Hence, existing and commercially available mechanically connected manipulators do not seem to be suitable for use for AGS remote handling.

It might be assumed that existing servo-controlled manipulators would be adaptable with greater ease. Of course, the choice of existing equipment is much more limited. Only four arms, all of the same Argonne National Laboratory design,[4] are operational today. This existing design is much too large and heavy to be mounted on a mobile remote-manipulating unit which could maneuver in the AGS tunnel. Much more than a simple scaling is required for adaptation to AGS needs. Furthermore, it is not clear that scaling existing designs is the best procedure. The existing ANL manipulators were designed for hot cell service in contaminating environment requiring gloved repair.[4] These service factors result in design restrictions which are not required in manipulators for accelerator use. Since all remote maintenance and handling will be done with the AGS beam off, there is no serious danger of contamination or activation of manipulators. Since manipulating units used at the AGS must be very mobile to cover the entire complex, the same mobility can be used to remove units from the ring before turning the beam on. Also, the induced activities predicted for the AGS, or for that matter those estimated for any accelerator likely to be built in the next decade, are sufficiently low to make it entirely possible to use organic materials and, to some extent, solid-state electronics at the slave end of the manipulator without appreciably shortening life expectancy due to radiation damage. In addition, contrary to many hot-lab conditions, no objections exist to the use of hydraulic systems, which are probably the most useful actuators for the dexterous servo manipulators.

According to the above analysis it was deemed desirable to study the development problems of servo manipulators. As a first goal it was desired to maintain dexterity and capacity of the best manipulators available, while achieving a considerable reduction in size and weight. A second step would concern the study of parameters and factors which seem to influence dexterity. Toward that end the prototypes resulting from the first study phase should be of value.

Feasibility Study Results

For the purpose of the first study phase it was decided to maintain the seven degrees of freedom (three translational, three rotational and terminal device) and their relative arrangement of conventional master-slave manipulators, and concentrate entirely on trying to achieve nearly an order of magnitude in volume and weight reduction over ANL Model 3. It was also decided to study electric rather than electrohydraulic devices first as it was hoped that with the limited manpower available, initial hardware might be available sooner.

Advantage was taken of the compactness possible with dc servo components. For the desired service and performance, the smallest and lightest package seemed to result with permanent magnet dc torque motors for actuators and single-turn film potentiometers as position transducers. The first breadboard consisted essentially of identical master and slave assemblies, each containing a motor, transducer and a lever, all mounted on the same shaft. These were connected as shown schematically in Fig. 2. This scheme is essentially the same as used for the ANL devices.[4] The figure shows only the basic position sensors without explicitly pointing out that velocity feedback is obtained from the differentiated position signal. The direct acting breadboard worked very successfully and smoothly. It had excellent frequency response and sensitivity, but of course lacked handling capacity. To rectify this, a breadboard incorporating gear trains of approximately the desired overall ratio was built (see Fig. 3). One will note that in this breadboard master and slave are not identical. The reasons for this are to be found in the fact that operator control of the master becomes difficult for input forces approaching about 15 lbs, so that for high force levels some de-emphasis of force feedback is desirable while full feedback is required for low levels. For this reason, the master is designed for a 10 lb capacity and the slave for 30 lb capacity. The master-slave force ratio is intended to be varied continuously as a function of input force, from unity at zero input to 1/3 at maximum input. This breadboard also worked quite successfully but it was realized that the effect of motor friction had been underestimated. This increase in friction is the price one has to pay for size reduction. A manipulator built along the lines of this breadboard would end up with about 8 to 10 ounces of friction at the master, which is about twice the basic value of the ANL models. Such values of starting friction are barely tolerable and result in reduced sensitivity and increased operator fatigue. Since there seems to be little chance of substantially reducing the friction components with the above scheme, some alternate was desired.

An alternate servo system also initially suggested by the ANL group[5] but never really implemented is shown in Fig. 4. This system has the interesting property that any friction or inertia forces originating from either master or slave on the motor side of the force transducer are not reflected at the master handle. Thus friction levels can be reduced drastically subject only to force transducer limitations. While this system looks promising its investigation and breadboarding is not yet completed.

Parallel to the above activity, a study of the possible mechanical manipulator configurations containing the components used in the breadboards was undertaken. It soon became apparent that due to the substantial size reduction possible with these components the servo packages could be fitted into the manipulator arms themselves rather than having to be placed in the shoulder of the manipulator body. This enabled further size reductions since upper and lower arm dimensions were not dictated any more by shoulder and body size. It also allowed direct coupling of servo packages to manipulator motions, doing away with motion transfer cables whose transmission characteristics tend to restrict frequency response of the entire arm, giving it a very spongy feel. The absence of these cables also does away with the complex cable guide linkages. Furthermore, complete articulation through some 300° of arc of both the upper and lower arm is possible as is continuous wrist rotation, both features which should improve overall dexterity. The absence of cables also reduces the interdependence of the various degrees of freedom, thereby simplifying design and development work.

The net result of the study showed that an order of magnitude of size and weight reduction of servo manipulators seem possible with only slight capacity reduction. More specifically, the slave end of a 30 lb capacity arm will weigh about 30 lb rather than several hundred. In addition, some bonus features like continuous wrist rotation, better articulation, reduced complexity and cost and possibly very low friction values can be realized.

Future Plans

Once the first manipulator design is completed, the resulting prototypes will be used for further study. It is hoped that a set of empirical tests for dexterity can be developed so that the influence of various manipulator parameters on overall dexterity can be examined. Some of the parameters to be examined are: force sensitivity, frequency response, terminal device articulation and configuration, additional arm articulation and, if possible, tactual feel.

Beside these studies toward improving dexterity, first attempts to incorporate manipulators into manipulating units will be possible. This requires study of some viewing, transportation and communications problems. Since biological shield units primarily use direct viewing through leaded glass windows and need only simple communications they will be tried first despite their limited mobility. These trials will include work on mockups of machine modules for the purpose of studying module interconnections. After some work on TV observation similar studies will be extended to completely remote units which can be either self-propelled or crane transportable. For control links a variety of possible cable schemes will be investigated. Figure 5 shows an artist's concept of an early version self-propelled unit and its remote control center. The manipulator dimensions were drawn according to the results of the configuration studies. The prime purpose of the illustration is to show that a small unit capable of maneuvering in the AGS tunnel can result. The inset shows the terminal tongs and their connections to the rest of the arm. These were drawn from nearly finalized designs and therefore closely approximate the expected hardware. For scale comparison, the lower arm is three inches in diameter, so that the complete servo package driving the tongs will easily fit into an average sized palm.

Parallel to the development of more dexterous manipulators a better understanding of the dependence of overall unit effectiveness on mobility and communication links will emerge. With such understanding it will be possible to decide whether improved mobility or introduction of radio control links will be required as part of the complete AGS remote handling system.

Acknowledgement

The author is much indebted to J.G. Cottingham for his work on electronic and servo problems, to R.E. Meyer for assistance with manipulator configuration studies, and to other members of the Accelerator Department, too numerous to mention, who offered helpful suggestions.

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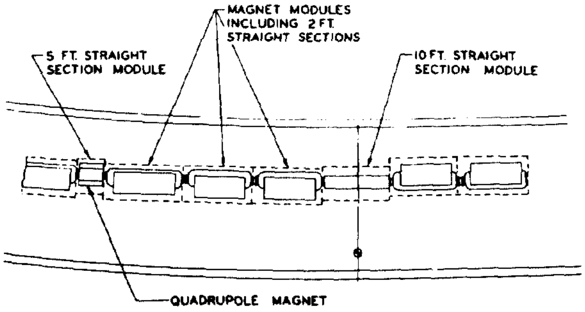

Fig. 1. Portion of AGS Ring showing modular arrangement.

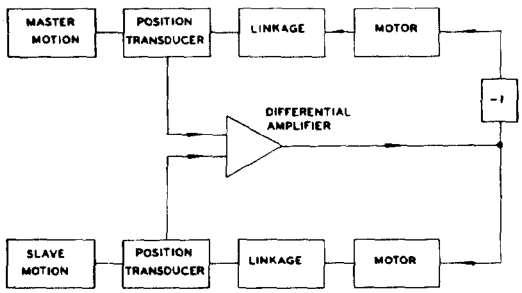

Fig. 2. Position sensing bilateral servo.

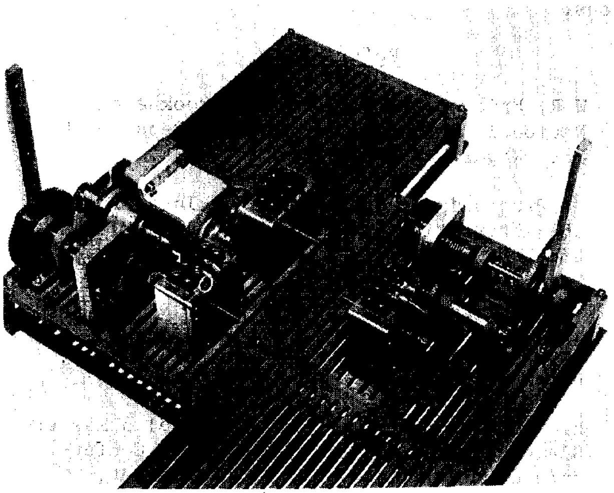

Fig. 3. Typical force reflecting bilateral servo breadboard.

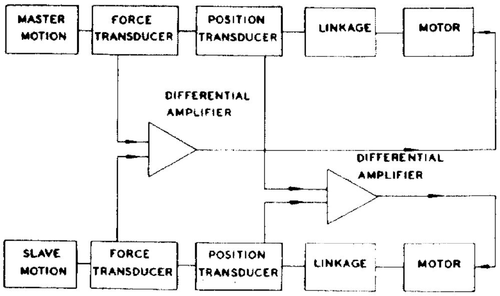

Fig. 4. Position and force sensing bilateral servo.

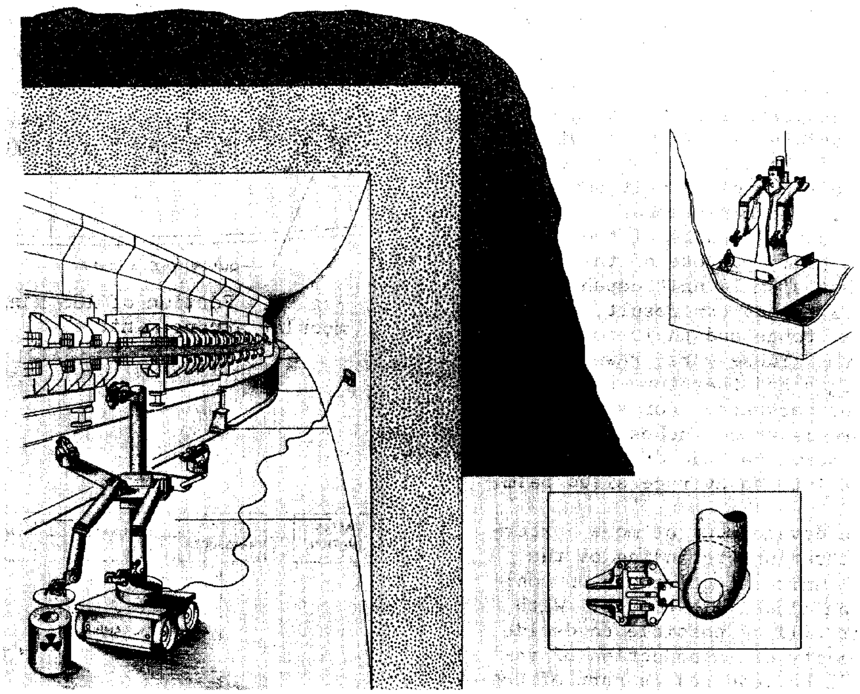

Fig. 5. Artist's concept of mobile manipulating unit.