GROUND SUPPORT EQUIPMENT, HUMAN FACTORS STUDIES

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INTRODUCTION

Remote-handling equipment for radioactive material is a relatively recent innovation. Only two decades ago, a fist-sized lead container and a pair of tweezers were generally sufficient. The development of nuclear weapons produced increasing demands for equipment which would supply more protection as higher levels of radiation were encountered. The tweezers were exchanged, first for long-handle tools, then for manipulator devices and remote-control machinery. The shielding requirements caused the evolution of special handling rooms, or hot cells, to contain radioactive source material.

Today there are programs in the planning stages to utilize nuclear propulsion power in flying vehicles. To support these programs, a new feature is needed in remote-handling equipment: the element of extreme mobility. Nuclear propulsion systems will not be handled in the classic hot-cell manner, except for assembly, or disassembly of subsystems.

As a complete assembly, the propulsion system must be handled in the open, with the reactor radiation relatively unconfined, and with the workers enclosed in shielding. This turnabout in the man-to-source arrangement has profound effects on the selection of remote-handling equipment, as will be discussed in this paper.

BACKGROUND OF THE PROBLEM

There are three methods of approach to the mobility requirement in ground support of nuclear propulsion systems. These are shielded manned vehicles, trailing cable robots, and radio control robots.

The present discussion is limited to the shielded manned vehicle approach. This method is the most simple of the three, and therefore lends itself to easier identification of the remote-handling problems.

A cab of substantial weight is needed to protect a worker in the presence of a shutdown propulsion reactor. This is true for a nuclear rocket engine even if the reactor has been operated for only a short time at full power. The alternative of waiting for radioactivity decay to reduce the intensity of the radiation field has a point of diminishing returns. Following a relatively short operation of a nuclear propulsion reactor at full power, the radiation field can be of sufficient intensity to prohibit an unshielded approach for a period as long as a year.

The weight of the cab, while a disadvantage in many respects, does not present serious design problems for a vehicle which is to operate on paved areas. This criterion can affect the decision on the approach to the problem; if the cab weight is excessive for the terrain where the vehicle is to be applied, a robot system offers the advantage of lighter weight.

A manned cab is human-engineered to supply the occupant with a good view of operations and of controls; also, controls are arranged for operator convenience. Various personal necessities such as filtered breathing air are provided. These requirements are straightforward, and require no elaboration.

In the system approach to ground support of a nuclear propulsion device, it is necessary to establish design criteria on the handling system. To do this, the remote-handling tasks must be identified and studied. This description of tasks is used to define the handling capacity of the support system.

For illustrative purposes, the AMF approach to the problem of designing ground support equipment for nuclear aircraft will be discussed. In the AMF approach, the remote-handling tasks were defined after a study of the proposed airplane system. While the actual list was extensive, citing just a few will indicate their nature:

1. Towing the airplane
2. Supplying aftercooling air to the reactor
3. Removing the nuclear engines

The diversity of the list indicated the need for a family of vehicles. An extensive effort was made to reduce the total number of specialized units by combining functions. The list eventually included the following vehicles for normal flight line operation:

1. Tow Vehicle to move the aircraft on the ground when the engines are shutdown

2. Power Package Handling Vehicle to replace nuclear power plants in the airplane, and to transport the power plants to the engine maintenance facility

3. Prime Mover Vehicle to move and control the operation of special purpose trailer-vehicles

4. Air Supply Vehicle, a special purpose trailer which provides aftercooling air

5. Utility Vehicle to provide visual inspection, direct aircraft access, and to permit the performance of minor maintenance

6. Cowl Handling Vehicle (required in certain ANP configurations), an unmanned trailer to remove the engine cowling to permit power package replacement

The system described in very summary fashion above was predicated upon the cabilities of handling the airplane anywhere on the runways, and of being able to remove the highly radioactive power package after every flight. By removing the power package, the radiation level around the airplane is very greatly reduced, thus permitting immediate access by maintenance personnel to some portions of the aircraft without shielding.

Recalling that AMF produces manipulators, it is significant that the system does not include a universal-manipulator equipped vehicle. The utility vehicle is equipped with very simple, mechanical, grappling devices that exactly fit the mission of the vehicle. The utility vehicle is used to unlatch inspection panels, to grasp and move aftercooling air ducts, but it is not intended for detail remote maintenance. When the original study was made of the nuclear airplane system by AMF, it was the knowledge of universal-manipulator limitations which led to the policy of removing the power package before performing detail maintenance. In the following section, present laboratory manipulators are discussed to highlight the limitations inherent in their use.

MANIPULATOR EQUIPMENT

Present hot-cell operations center around the use of manipulator devices. The manipulator provides a linkage between a worker and a workpiece. There are many different versions of manipulators, the most common identification of classes being the master-slave and the power-driven types. The master-slave, mechanical, linkage-type manipulator is the most popular remote-handling device in the remote-handling field. It is a pantograph device which is highly favored because of the ease and naturalness of operation. When the operator moves the master handle, the slave end repeats the motion exactly. Development work has been performed to increase the applications of this type of device. For example, AMF has produced a model with a lifting and handling capacity that equals or exceeds the strength of the human operator. Also, Argonne National Laboratory and others have investigated systems which replace the mechanical linkages with servo systems.

The power-driven type manipulator has an electric linkage between the control point and the working arm. The arm is powered by electric or hydraulic actuators. The control consists of electrical switches. Performance time with this type of device does not compare favorably with the master-slave manipulator. The major advantages are the compact control, and the possibility of very great force multiplication.

Whether or not great mechanical strength should be incorporated in a premium handling device is, however, a point of debate. The general utility of the massive manipulator is greatly reduced, because its physical size limits its usefulness in close quarters. In a mobile application, such as is encountered in the ANP type of handling, the very heavy-duty power manipulator has the capacity to produce damage to the structure being worked upon through an error of operator judgment.

The compact control of the power-driven manipulator is a significant advantage in the manned shielded cab, where space is at a premium.

Based on even the little which has been said about the two types of manipulators, a conclusion can be reached: both types of manipulators have drawbacks when considered for mobile applications. The ideal manipulator would be a combination of the best features of each type. To highlight some of the features of the ideal manipulator, the general factors in a manipulator system will be discussed in the following:

A. EFFICIENCY

A man using a manipulator to perform a task which is normally performed by hand is at a disadvantage, if performance times are compared for the two work situations.

This disadvantage ratio has a wide range of values. There are some very simple manual tasks which are impossible to perform with any present manipulator equipment. If tasks are compared which can be performed by a manipulator there are order-of-magnitude values which have been based on test results. A man using a master-slave manipulator takes an average of 6 to 8 times as long to do a job as he would need if the work is performed by direct means. The power-driven manipulator is more inefficient than the master-slave type by a factor of 5 to 10. These ratios vary greatly between specific operations. If machine screws are to be threaded into holes, the time required will be affected by the size of screw, type of head, type of tool used with the manipulator, and whether or not lock washers are used. The view of the operator is of great influence. If the hole cannot be seen, the task is generally impossible.

It must be remembered that manipulator equipment was developed to permit important experimental work to be performed in radiation laboratories. The criterion used in designing remote-handling equipment was to accomplish the task; speed of operation was of secondary importance.

The next generation of manipulator equipment will have more design emphasis placed on speed of operation. This is because the mission of remote handling is changing from the experimental laboratory to the remote maintenance and servicing aspect.

B. SENSE OF FEEL

One advantage of a master-slave type manipulator over a power-driven type is described as the sense of feel which the master-slave system provides. This "sense of feel" is a convenient way of describing a condition; the terminology is, however, misleading. There is no sense of feel in a manipulator claw. The information which is transmitted from the slave end of the device to the operator can be best described as resistance to motion indication. The operator can recognize a condition where the slave arm cannot move in a particular direction because of an obstruction. He can decide how much force he wishes to apply to overcome the obstruction. He can apply this force up to the limits which the manipulator can tolerate.

If a master-slave manipulator is used to locate and lift a pencil which is located somewhere on the top of an otherwise clear table in a darkened hot cell, the process would be very random. The operator would know when the table top was encountered. He could grope about, actuating the manipulator claws. If the claw brushed against the pencil, it would not be detected. He would need a gauge at the master handle to indicate normal squeeze, so that the reduction in squeeze occasioned by the presence of a pencil in the claw could be detected.

If a rigid pipe is attached between the walls of a darkened hot cell, in the range of a manipulator, an operator using a master-slave manipulator can locate the pipe, and, by trial and error, can eventually grip the pipe with the tong. (It is possible to damage a manipulator in this type of experiment unless caution is exercised.)

Master-slave manipulators were cited in these dark hot-cell examples. A power-driven manipulator does not lend itself to this kind of operation, since the resistance to motion information feedback is very limited in this type of device. It is doubtful whether any present power-driven manipulator could accomplish either task without involving damage to the manipulator.

The feedback of resistance to motion information becomes a very important advantage in normal hot-cell operations. The operator is able to obtain at least a limited sense of touch through the device, to assist him in performing work.

C. CONTROL

When the master handle of a master-slave manipulator is moved, the slave end moves and responds exactly to the motion. Speed and direction of the slave are selected by the human arm response of the operator.

The substitution of switches, joysticks, or knobs, to select speed and direction is a cumbersome complication. In some types of power-driven manipulators, the situation is so complex that the operator must rely on visual observation of the resulting motion in the arm. For example, consider a power-driven arm with great flexibility, such as 180° rotation at the joints. The power arm tested employed a very compact array of electric switches to control different motions of the arm. Very quickly the operator can identify a given switch as moving a segment of the arm in an arc about a particular joint, in the manner that the forearm pivots about the elbow. If the switch is moved in one direction, the arm pivots in one direction; moving the switch in the opposite direction causes a reversal of the motion. In our given situation the operator soon learns that rotation of the elbow joint 180 degrees causes great confusion in guessing which way the arm will move for a given switch movement. The same position of the switch can cause a movement upward or downward, depending on the rotation of the elbow joint. During an operation where a number of joints are being moved, the operator will tend to move the switch and watch to observe the direction of the arm movement. This slows operation. There is a danger that in this mode of operation the operator can accidentally move the wrong switch in the compact array and watch for a given segment to move. In the meantime, the incorrect switch can cause a different arm motion to be doing something that the operator is not immediately aware is happening.

The analog type of control which the master-slave manipulator employs is very necessary in the ideal manipulator; however, the size must be very greatly reduced for control cab applications. Also, the configuration of the slave arm must be modified.

D. SIZE OF MANIPULATOR

Two elements of size must be considered in mobile remote manipulators. One is the reach which is necessary, the other is cross-sectional size. Factors which influence this decision are the distance at which the human operator is located from his work, and the strength capacity of the mechanical arm. If the shielded cab can be moved close to the work, the arms can be relatively short. The advantage gained is in the view of the work. Work can be performed more effectively at 6 feet, than at 12 feet of separation distance.

If the arm must possess a length of 10 feet or more, and even moderate strength capacity is needed, the cross section of the arm must be proportionally larger, and will obstruct the view of the work. The larger size will also limit the accessibility of the arm in close quarters work. A common defect in long manipulator arms is oscillation, particularly under mild loads. If the arm has a tendency to oscillate, fine positioning is very difficult to accomplish.

The ideal remote-handling manipulator arm would be under six feet in length, fully extended. In the mobile application, the shielded cab would be arranged to permit positioning close to the work.

E. SUMMARY OF IDEAL MANIPULATOR FEATURES

The ideal manipulator for shielded cab applications is an articulated mechanical arm which can duplicate the major motions of the human arm. It is under six feet in length, and has strength commensurate with that of the human operator. The compact control is of an analog nature. There is a feedback system which gives the operator an indication of the forces being applied, either proportionally, or in one-to-one relationship.

This ideal manipulator should be developed along with the system on which work will be performed, so that tools and features can be tailored to the needs of the handling task. By this type of approach, the product can be expected to permit remote operations in times commensurate with direct operations.