Feature

Cost effective robotics in the nuclear industry

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Abstract

Purpose – Aims to clarify the use of "nuclear" robots with special reference to one UK contractor (Magnox) and the cost-effectiveness of its decommissioning programme.

Design/methodology/approach – Goes through the protocol of the use of robots in the disposal of contaminated scrap.

Findings – Justifies the use of a built-to-order modular linear (Cartesian) robot system required by Magnox.

Originality/value – Provides valuable advice for handling nuclear materials, especially reactors.

Keywords Nuclear reactors, Robotics, Cost effectiveness, United Kingdom

Paper type Technical paper

Introduction

Many nuclear "robots" are not really robots according to the ISO definition of a robot which is "automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes". Tele-robotics is where a robot arm in the hazardous environment is remotely operated from outside the environment. But there are a great many applications where some degree of autonomy is desirable, for example, for a routine operation or where the motions are complex and accurate or cannot be seen by the operator. In these cases, a conventional industrial robot system is preferable.

Industrial robot justifications fall into four basic categories:
1 reduction of production cost;
2 improvement in quality;
3 human is bad for the product; and
4 product or process is bad for the human.

Clearly most nuclear applications fall into the fourth category.

The UK nuclear industry is currently decommissioning most of its old Magnox power stations. Decommission sites are not high technology. The nuclear industry takes no risks. Whereas a new power station might be expected to be hi-tech, decommissioning prefers lower technology, tried and tested.

The projects described in this paper were for use in decommissioning one of the UK's old Magnox power stations set in the hills of Wales.

Overview

The Magnox contractor designed a system for disposing of low level contaminated scrap and intended to use a large steel container for disposal of contaminated items. Contaminated scrap parts such as bits of pipe, wiring, etc. are dropped into a large steel container. When full the container (or box) is filled with resin and capped off. It is possible for the outside of the box to be contaminated either with dust, spilt resin or other material and the customer needs to swab the outside of the box before bringing it into the open. The box is, therefore, moved to a second chamber where it is to be swabbed by a robot. The box stands about 1.5 m high by about 1.5 m^2 with rounded corners (Plate 1).

Magnox's contractor planned to use one or more robots to wipe swabs over the whole of the outside of each box before opening the outside door. The plan had a major weakness. It seemed the contractor designed the room for the box, but did not allow any room for the robot. There was certainly no room for a conventional robot such as the kind used in the auto industry. The robot, therefore, had to be designed to fit in the available space between the box and the wall.

The intention is always that the boxes will not be contaminated, but there is the possibility that they will be. It is, therefore, possible for the robot to be exposed to radiation. We were confident that our standard designs would withstand quite high exposures. The customer expected very low levels of exposure, but could not be specific as the box was in theory supposed to be clean. The worst scenario that we could predict would be a mechanical failure that required a human being to enter the chamber and service the robot.

Solution

ST decided to use three Cartesian robots working together to swab the vertical faces of the box, leaving the top face to be manually swabbed using a manual arm or wand operated through a gimbal in the outer wall.

The scheme called for the following protocol:
1 The operator places a clean swab in a holder onto a shuttle in a glove box (Plate 2).
2 The shuttle withdraws into a cavity between the glove box and the swabbing chamber.

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Plate 1 The waste box (within white line) after leaving the swabbing chamber

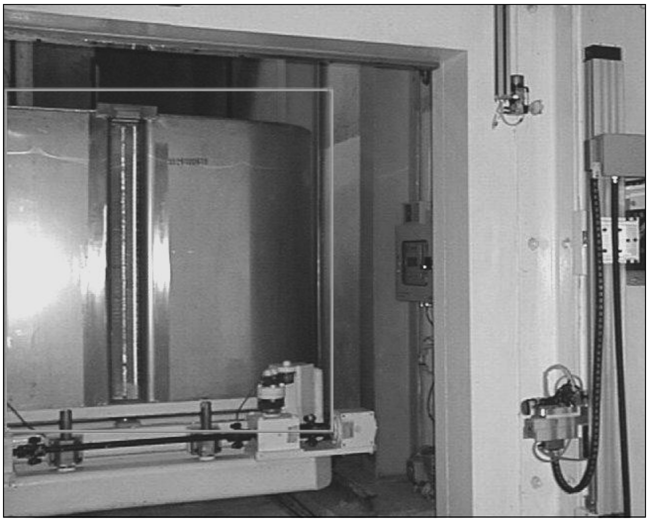
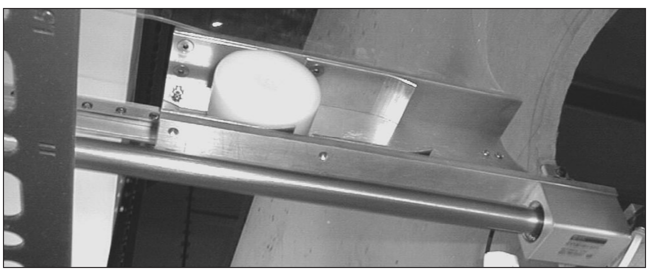


Plate 2 Shuttle to pass swabs between chamber and glove box



3 A lead shield door in the glove box closes over the cavity and another then opens in the chamber.
4 Robot "A" takes the swab and holder and carries it down to robot "B" (Plate 3).
5 Robot "B" takes the swab and holder and passes it to robot "C" (see Plate 4 inset). A second function of robot "B" is to take the swab along the wall to within reach of a manual arm where a human worker can take it and swab the top of the box (Plate 4).
6 Robot "C" takes the swab itself, leaving its holder with robot "B".
7 Robot "C" then swabs the box one side only after locating and measuring the box (see later).
8 The box rotates 90° and the robot swabs the next side and so on for four sides.
9 When finished robot "C" places the swab back in the holder being held by robot "B", which takes it back along the side of the chamber to robot "A".
10 Robot "A" places the swab and holder on the shuttle.
11 The shuttle withdraws into the cavity, inner shield door closes, outer door opens and the operator can take the swab off the shuttle for measuring.
12 If any contamination is found on the swab the procedure is repeated until the box is clean.

In the actual design robot "A" is only a two-axis Cartesian robot and robot "B" is actually only a single linear slide. Therefore, these were treated as one robot with the three axes driven by one controller. Robot "C" is a four-axis Cartesian robot with a yaw-axis hand.

Plate 3 Robot "A" passing swab and holder to robot "B"

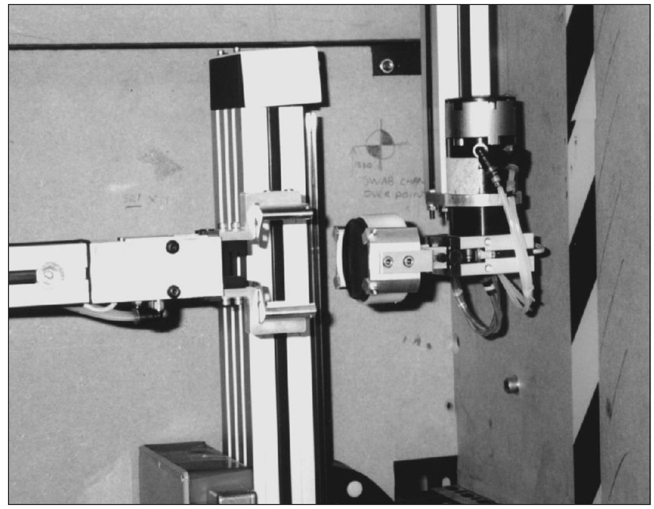
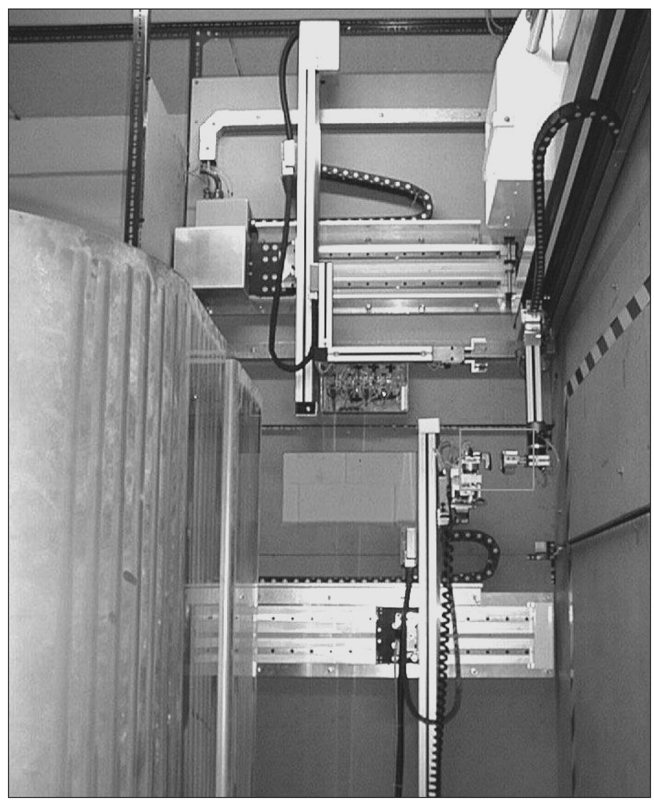


Plate 4 The transport rail robot "B" is shown top right. For swabbing the box top the operator works through a window just to the left of the camera. Just above the transport rail is the motorized lead door to the glove box. The exchange of swab from robot "B" to robot "C" can be seen in the small white square



Design considerations

ST's standard designs were suitable for the most part, but we had to design a special telescopic axis (Plate 5) to hold the

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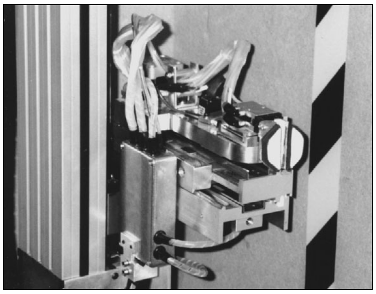
Plate 5 Specially designed telescopic extend axis with wrist and gripper to hold swab



swab against the box. The rotating wrist and gripper are integral with this axis module. We were forced to use every available bit of space to best advantage. In one system an air cylinder on the telescopic axis permits it to withdraw into the exit to get maximum possible stroke, then to park in a corner when not in use. All the grippers are also pneumatic.

All axes have connectors and quick-change fixings so that, wearing the proper protective clothing, one could replace an axis in less than hour in complete safety. The software would then take care of changes in calibration.

The second weakness or rather design problem to be overcome was that the dimensions of the box were not certain. The first task for robot "C", therefore, was to "feel" for the sides of the box. The gripper (Plate 3) was designed with a short spring-loaded throw and a sensor. The robot is then able to feel a surface by pushing until the sensor changed state. The robot searches for four points on the flat face of the box and also four points on the curved corners. The controller then calculates the exact shape, position and orientation of the box. In addition, as can be seen in Figure 1, the box has a channel down each side. These channels must also be first measured then swabbed. After swabbing the box is turned 90° and the search is repeated. As it transpired the dimensions of the boxes were even less accurate than originally specified but the system is able to cope.

Technology

ST robots are actually fairly low-tech where the drives and mechanicals are concerned which suits the ethos of a nuclear site. The simple designs are virtually maintenance free and intuitive to fix if there should be a problem. We use stepping motors with micro-stepping drives. These are monitored with incremental encoders. We do not use absolute encoders because of size as well as cost. Each axis calibrates to a datum using a proximity detector. From the datum both motor steps and encoder ticks are counted and continually compared for errors.

The clever stuff is all contained in the controller. Each system has two controllers. It ostensibly has three robots but the second robot (B) has only one axis, so is controlled by the same controller as robot "A". The master controller is the one that controls robot "C" for the swabbing operation. The second controller has very little to do and is slaved to controller 1 via serial. Each controller has two processors, one to carry out the program sequence, which is written in an extension of Forth that we call ROBOFORTH. This employs English language commands that are easily understood by any engineer or operator. The second processor is actually a DSP (digital signal processor), which is a sort of high-speed multi-tasking microprocessor that enables us to control each axis independently in real time. Controller 1 sends the same English commands down to controller 2.

ROBOFORTH

The power of ROBOFORTH is based on the power of Forth, a computer language written for the control of machinery. ROBOFORTH and the controller hardware are ideally suited to tasks such as searching and also running the robot while simultaneously controlling pneumatics, shield doors, etc. Calculations in ROBOFORTH are a bit laborious as it is not a maths-oriented language but they can be done.

Although Forth may be obtained for modern computers even with GUI interfaces it is primarily intended for embedded systems and indeed any system where you need to work close to the hardware. It is a complete system, compiler, interpreter, debugger and is even its own operating system unencumbered by such overheads as context switching, memory defragmenting and other time-indeterminate processes that slow super-fast Pentium processors down to a snail's pace.

ROBOFORTHs most powerful feature is the way it allows the user/programmer to think naturally in "mind-sized bytes", i.e. small simple functions that are easily tested with the hardware before being incorporated into higher level definitions. For example, the search for the box is programmed and easily tested with syntax such as:

```
: BOX-SENSOR PB 7; (box sensor is connected to port PB
  bit 7)
: SENSE
BOX-SENSOR BIT? 0 = (leaves true when the sensor goes
low, i.e. has sensed the box)
;
SET CRITERION SENSE
TELL EXTEND FASTSEARCH
```

This syntax is easily used in building the program, but can also be typed at the terminal at any time to verify the search is working or to debug hardware or software.

ROBOFORTH provides two entities for teaching the robot: ROUTEs and PLACEs. A place is a single named position, for example, the position at which the robot exchanges the swab with the other robot. A place may have an approach position. A route is a named list of positions, for example, the path the robot would take to get to the exchange position, and is also used for the creation of matrices. Normally the user teaches the robot these routes and places then writes a procedure in the window shown in the top left of the screen shot, which defines what the robot is to do with these positions and how to interact or interlock with outside devices through the input/output interface. The robot is also able to learn positions itself, as a result of, for example, a search. See Figure 1 (screen shot).

Electronics

The inclusion of anything electronic in the workspace depends on the circumstances. Obviously, the controller is outside the hazardous area but some electronics on the robot itself may be desirable. In particular, we use two electronic devices on each axis: one is a proximity detector used to

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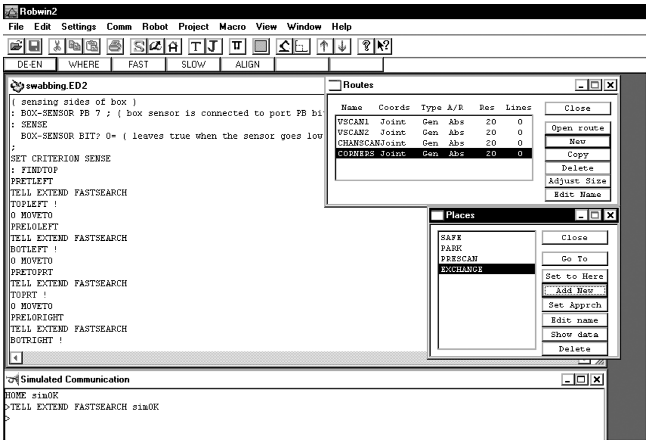
Figure 1 Typical programming screen for ROBOFORTH



calibrate each axis to a known datum, and the other is an incremental encoder that is used as a watchdog for the stepping motors. The proximity detectors are housed in brass tubes and the encoders are plastic. Small doses of radiation, i.e. a low level of radiation or short periods of exposure seem to have no detrimental effects on encoders or proximity detectors. Detrimental effects can include random malfunction or actual damage to the semiconductor. Hardened semiconductors may be obtained but we use low cost industrial components, as the cost of special treatments would have been prohibitive. Given the exposure quoted to us by the customer and our best estimates of the lifetimes of our semiconductor components on the arm we decided to install our standard components.

However, in one application the encoders and proximity detectors were destroyed. The customer admitted to us that whereas the exposure was supposed to be limited to the swabbing time there had been period when the box was in the ante-room for two weeks with the separating door left open. This information enabled us to add to our knowledge base. The system had been running for two years before this mistake was made.

The fallback position in our designs meant that this was not a major problem. First, the encoders are really only fitted as watchdogs to the stepping motors. They watch for collisions, stalls and errors that generally only occur when the robot is being programmed, in other words the programmer's mistakes. Once the robot is routinely running the encoders are redundant because the stepping motors are micro-stepped and never misstep or make any other kind of error. The software permits the encoders to be selectively disabled leaving one or more or all axes to run open loop. This is perfectly safe. It is actually extremely difficult to create an error. The robot can be recalibrated to datum at any time. This leaves the proximity detectors used for datum calibration. If they fail they can be replaced by micro-switches. Proximity detectors (the way we use them) give a repeatability of 40 μ whereas the micro-switches are only 0.1 mm. Given the fact that the box is hopelessly inaccurate by comparison and that the robot has to search for its exact size and location before it starts swabbing this repeatability is more than good enough.

In subsequent systems we are covering the encoders with a layer of lead. The weight is low enough not to affect robot performance but offers some protection.

Summary

ST Robotics, based in Trenton, NJ and Cambridge, UK makes low cost bench-top robot arms but in addition makes a modular linear (Cartesian) robot system that is designed and built to order and it was this format that was required by Magnox. The flexibility of both the mechanics and the software made these projects not only cost effective, but also the applications were probably impossible with any other technology.

We were always under the impression that the nuclear industry worked only with larger companies and was not particularly cost sensitive so it was a surprise when we were first contacted for a system for use in the UK's decommissioning program. We had supplied a number of robots for handling nuclear materials but this was the first reactor application. We learned a great deal of value that can be put to good use in similar applications.