The Space Congress® Proceedings

1988 (25th) Heritage - Dedication - Vision

Apr 1st, 8:00 AM

Robots Refurbish Space Shuttle Hardware USBI

Tony S. Humble

Alan R. Fertig

ROBOTS REFURBISH
SPACE SHUTTLE HARDWARE
USBI

TONY S. HUMBLE

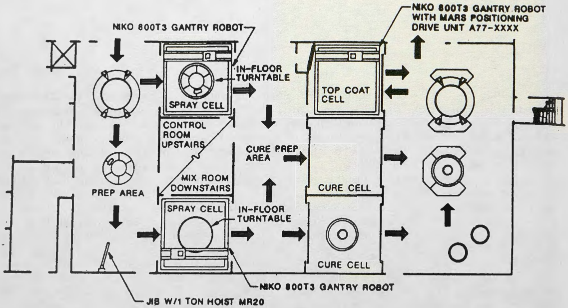
ALAN R. FERTIG

USBI, a division of United Technologies Corporation (UTC), was awarded a contract by the National Aeronautics and Space Administration (NASA) to refurbish the non-motor sections (nosecap, frustum, forward skirt, and aft skirt) of the Solid Rocket Boosters (SRB) used in the space shuttle program. As NASA's major contractor for processing and refurbishment of the SRB's, our company has successfully refurbished all the SRB's flight hardware to date. The planned insulation refurbishment process of the SRB's consists of thermal protection system (TPS) removal; surface preparation; reapplication of Marshall Sprayable Ablative (MSA-2), a thermal ablative material developed at Marshall Space Flight Center; and topcoat spraying of Hypalon paint to seal the ablative material.

In the past, refurbishment of the SRB's was done by hand at the Vehicle Assembly Building (VAB). This process was slow and tedious, and introduced personnel to potentially hazardous working environments. A means of reducing costs and providing enhanced quality assurance was desired. Therefore, the need arose to implement a degree of automation to the refurbishment process. The introduction of a new automated process system would reduce the manual labor element, limiting the need for personnel to come in direct contact with hazardous materials. And because of the reliability and accuracy of robotics, NASA would be assured of receiving the highest possible quality product , at the lowest cost.

In January 1984, USBI was selected by NASA to design and build a new facility at Kennedy Space Center to process the SRB's using the latest technologies. In response to NASA's request to introduce automated systems in the refurbishment of the solid rocket boosters, the new facility was designed to produce SRB flight hardware utilizing robotics and state-of-the-art computer controlled production techniques. Many determining factors for the degree of automation were considered: 1)the cost effectiveness of such a program, 2)robot systems versatile enough to perform many different tasks on each structure, 3)safer processing environments. To facilitate insulation removal after booster retrieval , a facility utilizing robotics and incorporating a high pressure water blast system was designed by Marshall Space Flight Center's Production Enhancement Facility (MSFC PEF) and installed at Cape Canaveral Air Force Station (CCAFS). The Assembly and Refurbishment Facility Manufacturing Building was designed with three robotic cells for insulation application.

LOW BAY ARF TPS AREA LAYOUT



AUTOMATION CONCEPT

Incorporated in the new Assembly and Refurbishment Facility are three (3) Niko 800T3 Overhead Gantry Robots standing nearly 30 feet high, with a fourth Niko robot located at the new High Pressure Water Blast Facility at Cape Canaveral Air Force Station. The Niko 800T3 offers simplicity of programming by using the parametric method rather than conventional point to point programming. And because of the gantry style design, it is capable of working in any area of its cubical envelope, therefore providing for nearly limitless tasks. The Niko 800T3 Robot is a six (6) axis robot consisting of 3 translational axes and 3 rotational axes.

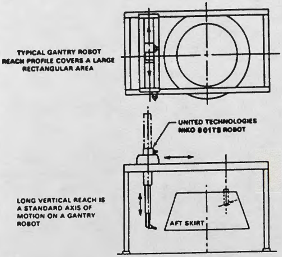
AXIS	TRAVEL LIMIT	MAXIMUM SPEED	POWER TRANSMISSION
X	241.0 in.	1000 mm/sec.	Cyclo Gear
Y	219.5 in.	1000 mm/sec.	Cyclo Gear
Z	163.0 in.	750 mm/sec.	Ballscrew
A	270 deg.	120 deg/sec.	Harmonic Drive Gear
B	225 deg.	120 deg/sec.	Belt Driven
C	320 deg.	120 deg/sec.	Belt Driven

Manipulation Weight: 80 kg.
Accuracy of Repetition: ± 0,35 mm

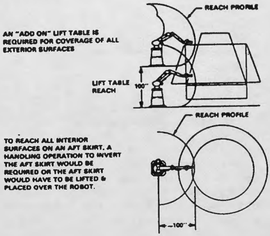
As can be seen in the following pictorials, the overhead gantry robot design offers a dimension unattainable by a conventional stationary flex arm robot. The most distintive feature of the gantry robot being its ability to reach all intrerior surfaces of the aft skirt.

COMPARISON OF ROBOT SYSTEMS

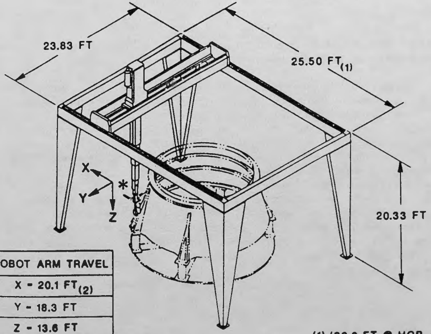
STEELWELD NIKO (OVERHEAD GANTRY)



TYPICAL FLEX ARM ROBOT REACH PROFILE



NIKO 800T3 GANTRY ROBOT ARF CONFIGURATION



ROBOT ARM TRAVEL
X - 20.1 FT(2)
Y - 18.3 FT
Z - 13.6 FT

* 3 POSITION ARTICULATED JOINT

(1) (32.0 FT @ HGR AF)

(2) (25.2 FT @ HGR AF)

Work performed by the robot is accomplished through the use of several end effectors. These tools are tailor-made to a specific process application in order to interface the robot to the SRB structure. The end effector tools for each of the processes are listed in the table below:

PROCESS	END EFFECTOR
Sanding	Sanding Motor & Brush
Cleaning	Vacu-Blast System
MSA-2 Ablative Spray	Spray Gun, Camera & Lights
Hypalon Topcoat Spray	Spray Gun
Insta-Foam Spray	Spray Gun, Camera & Lights
Inspection	Cameras & Lights
Surface Prep	
MSA-2 Application	
Hypalon Application	

The Niko Robot is controlled by an Allen Bradley 8200R CNC Controller. With the integration of the the Allen Bradley 8200R control to the Niko 800TE, we have a flexible robot with a configurational control system providing a totally flexible robotic system. The 8200R was chosen because of its ease of operation and its compatibility with the cartesian coordinate system of the Niko Robot.

The heart of the 8200R is the controller assembly. The controller assembly consists of the following components:

The Controller, which includes the processor, and executes the executive software and governs control operations.

I/O rack, where I/O modules can be installed to connect the processor to external devices.

Power Supply.

Bubble Memory Unit which stores the contents of control memory on a nonvolatile bubble cartridge.

Four separate interface devices are used: the main control panel, secondary control panel, teach pendant, and CRT/keyboard assembly. The main control panel provides a means for turning the robot control on or off, task program selection, cycle start and stop, speed override, mode selection and establishing Emergency stop. The secondary control panel is primarily used in developing and testing task programs and maintenance troubleshooting. The purpose of the teach pendant is to simplify teaching and editing task programs by being in closer proximity to the robot while limiting the robot to slower speeds for personnel safety. The keyboard is used to enter operator commands that initiate system operations and to enter task program blocks either for execution, or for storage in the controls memory. The CRT displays information about the states of both the control and the robot.

Also housed in the Control panel are two Allen Bradley Data Highway Modules. The Data Highway Modules provide a communication link between the 8200R Robot Controller, Programmable Controllers, Vision System Image Flow Computer, and the Host Computer.

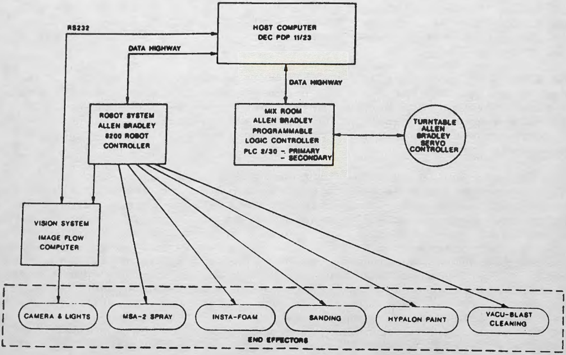
An Allen Bradley PLC 2/30 Programmable Controller is used to control the mixing of materials and to provide feedback to the 8200R. During program operation, the PLC 2/30 processor continuously monitors the status of input devices such as flow meters and pressure transducers in the mixing sequence and based on user program instructions, either energize or de-energize output devices. Programming is accomplished with a 1770-T3 Industrial Terminal.

To meet NASA's specifications a Series 1000 Image Flow Computer (IFC) and RGB monitor were chosen to provide an accurate means of thickness measurement and surface inspection. The IFC uses pipelined cellular logic architecture and parallel processing to permit fast analysis of images collected by video cameras. It is designed to run on BLIX (Basic Language for Image Transformation) which is an interactive language that permits complex inspection and robot guidance programs to be written quickly and easily. The IFC also incorporates a full duplex RS-232 communication link as the host interface. The IFC application software causes the vision system to perform the required inspection task and transmit data to the host. The software acquires an image of a portion of the SRB structure via the video camera, processes the image, and displays a result (a visually enhanced image highlighting any surface flaws) on the RGB monitor. The data sent to the host includes a frame number and fault data, which reports the position of that image on the SRB structure.

A means of consolidating the 8200R, the PLC 2/30 PC, and Image Flow Computer into a user friendly workstation was achieved by employing a DEC PDP 11/23 Host Computer. The Host Computer controls and/or monitors all equipment (robot, mix/supply room, turntable, and end effectors) based on predefined process parameters. The host enables the operator to control a process from startup to shutdown. Once the operator's process entry is confirmed, the host executes the sequence of events which executes the process. Throughout all operator/host communications an acknowledge message informs the operator of workcell status depending on the outcome of each event within the workcell.

Another feature in the refurbishment process is a 16 ft. in-floor air-bearing turntable which rotates the structures. Control of the turntable is directed by the host computer via the turntable's resident Programmable Logic Controller. The host is capable of determining turntable speed and position based on feedback from the PLC. Turntable position feedback is provided by an encoder with 12-bit resolution. The Mobile Assembly Refurbishment Stand (MARS) units are platforms that transport the SRB structures within the facility. An indexing method is provided to ensure alignment of the structure in reference to the in-floor turntable in a repeatable fashion.

AUTOMATED TPS SYSTEM INTERFACES



COMPUTER CONTROLLED PROCESSES

The refurbishment of the SRB's involves several integral processes.

Hydrolasing
Sanding
Surface Cleaning (Vacu-blast)
Vision Inspection
MSA-2 Application
Hypalon Spray Application
Insta-foam Application

Hydrolasing: Once the SRB's have been disassembled after launch and recovery, each major reused structure begins refurbishment with a robotic high-pressure hydrolaser that removes the external insulation and paint. Previously accomplished by using a manual high pressure (10,000 PSI) water blastgun and followed with a dry gritblast airgun, procedures were slow and hazardous. The new hydrolasing system has a capacity to deliver 20,000 psi, at a maximum of 32 gpm flow rate. The stripping process is controlled via the host computer according to each of the structures process parameters. This new system results in cleaner and faster removal of paint and insulation.

Sanding: The next step in the process is sanding. A pneumatic sanding end effector is utilized to prepare the surface for the thermal protection ablative. The sanding tool is positioned inches from the surface and the rotary turntable indexes an unsanded portion of the structure into the robot work envelope. At this point, the robot controller initiates sanding of a structure section. This process repeats until all sanding operations are complete. Two passes over the entire structure are made perpendicular to each other to insure a proper surface texture.

Vacu-blast: The vacu-blast process consists of a pressurized hot water vapor system and a vacuum reclamation system. This process utilizes a generator to provide a high velocity hot water vapor blast impingement on the surface to be cleaned. The vapor blast is surrounded by a vacuum pick-up system for immediate removal of atomized water, dislodged sanding debris and contaminants. The performance of this system recovers 95 to 98 percent of the water used during the cleaning process. The structure remains motionless while the vacuum blaster passes over the surface for this cleaning process.

Following the sanding and vacu-blast processes, inspection for proper surface texture is required to insure a proper bonding surface for adequate adhesion of the MSA ablative. This is accomplished with the vision inspection system. The vision inspection system verifies acceptable conditions and can isolate areas that are over- or under-sanded and for any grease or contaminants that may have been missed during the cleaning process.

MSA-2 Application: The next step in the process is the application of the thermal protection ablative. The MSA-2 application is the most automated sequence in the entire refurbishment procedure. It entails the use of the vision inspection system to translate the thickness of MSA-2 during the application of ablative to each structure. The host computer initiates the proper sequence of events to the PLC 2/30, which begins mixing the ablative material. Once the correct properties have been achieved, the ablative is then transferred to a spray nozzle end effector, and the spray gun traverses up along the side of the structure at a fixed distance while the turntable is rotated at three RPM. During the spraying operation, a structured light source is required to measure the coating thickness. The vision system uses a least-squares linear regression to determine the equations of the edges of interest. From these equations, the host computer translates the wet thickness. The vision system has the capability of rejecting an image based upon a low correlation coefficient. If a calculated line equation yields a low correlation coefficient, the vision system captures another image and processes it. This continues until the results from a good image are returned to the host. This information provides data to the host for the calculation of the applied material thickness. This procedure is repeated continuously throughout the entire spray sequence to provide a smooth and uniform application.

Insta-foam Application: The interior of two major structures require the application of insta-foam material to protect the structure from water impact damage. The Niko's overhead gantry design is capable of performing this task. With the structure positioned on the rotating turntable, the robot controller positions the robot manipulator arm to pass over the structure's inside surface until the desired coverage is achieved. Spraying operations are visually monitored via the vision system to insure complete coverage. Due to surface deviations, many passes may be required to guarantee all surfaces are insulated.

Hypalon Topcoat Application: This topcoat spray application is required to seal the outer surface ablative material. The structure is transferred to the topcoat robot cell and positioned inside the robot envelope. At this time, the spray end effector is mounted on the manipulator arm. The robot controller then positions the spray gun to sweep at a 30 degree angle across the surface. During the spray operation, the spray gun is cycled on and off by the Allen Bradley Controller. Three coats of paint are applied to the surface: the first pass being horizontal, the second pass being perpendicular to the first, and the third pass repeating the direction of the first. After spraying is complete, the manipulator arm moves to the tool attach point, where technicians remove the spray gun and attach the vision inspection end effector. The surface inspection is performed as the robot manipulator arm passes the camera over all areas of the structure. The vision system inspects the painted surface for complete coverage, and records the location of areas where any blisters or sags are detected.

CONCLUSION

All phases of the automated concept at USBI's Assembly & Refurbishment Facility have been installed and are currently undergoing final integration and programming.

USBI's continued commitment to excellence is exemplified by this integration of robotics with state-of-the-art computer systems for the refurbishment of the Solid Rocket Boosters non-motor segment. Based on USBI's successful track record and with the promise of superior quality achievable from robotics, NASA is assured of receiving the highest quality hardware for many years to come.