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MASTER

A PROGRAMMABLE CONTROL SYSTEM FOR SCANNING CYLINDRICAL PARTS

R. E. Neal

March 1975

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OAK RIDGE Y-12 PLANT
OAK RIDGE, TENNESSEE

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ABSTRACT

As an alternative to numerical contouring control, a programmable control system has been designed and implemented for scanning cylindrical parts. The system provides the advantage of low cost and eliminates the delays associated with part tape production. The system operates by enabling an axis drive motor and continuously monitoring the accumulated output from an encoder mounted on the shaft. The accumulated counts are continuously compared to a number representing the required motion; and, when the two are equal, the desired motion has been executed.

There are seven variables that must be specified for scanning a particular sized cylinder. In this system, all the variables are inputted via switches.

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INTRODUCTION

The modern automatic control system can be said to have evolved from the desire of primitive man to simplify his existence. He soon learned that by applying his strength to mechanical devices, such as wheels and levers, he could more readily accomplish his objectives. Years later his descendants learned to utilize such external power sources as the wind and water. Inventions like the steam engine and harnessing electrical power led to the development of manual machines that required very little power input from the operator. The desire to free the operator from the monotonous tasks of controlling processes, and the inability of man to duplicate certain machine functions, led to the development of the technology of automatic control systems.

Often, in industry, automatic controllers are called upon to guide a machine tool or other device repeatedly over the part surface until the operation is complete. Such devices fall into the general category of numerical control (NC) which is defined as the operation of processing equipment by a series of coded instructions comprised mostly of numbers.⁽¹⁾ For purposes of this discussion, the term "NC system" will apply only to the conventional closed-loop, industrially produced machine.

Commercial NC systems fall into two basic categories, depending on the feedback method employed: (1) the digital-feedback system most often used for inspection applications; and (2) the phase-analog system usually used for machining. A basic block diagram of a single-axis digital system is presented in Figure 1. The machine control unit (MCU) accepts input and provides command signals to the servo system. For each motion required, the distance, speed, and direction must be specified. The commanded distance is defined by the number of pulses issued to the bidirectional counter, the speed is defined by the frequency of the pulses, and the direction is controlled by choosing the proper input line. The comparator is essentially a subtractor whose output is a digital signal proportional to the difference in the two inputs. This difference is converted to an analog signal and added to the tachometer output, creating a velocity-error signal which serves as the input to the amplifier that drives the axis motor. (For linear motion, the motor turns a lead screw which converts turns to distance at a defined ratio.) An encoder mounted on the motor shaft provides quadrature pulses to a quadrature to up-down converter. Each pulse either increments (forward) or decrements (reverse) the feedback counter whose output is compared with the output of the command counter. When no difference exists, the required motion is complete.

A single-axis phase-analog system is depicted in Figure 2. In order to make this system operate, two phase-analog voltages must be produced—one to indicate the commanded position, the other to indicate the feedback position. To generate the feedback signal, the resolver is excited by a two-phase source at the reference frequency (a few hundred cycles). This action induces, in the output winding, a single-phase sinusoidal voltage which shifts in phase relative to the reference as a function of the resolver shaft position. The output is converted to a square wave which serves as the position feedback signal. The commanded position signal is produced by feeding the output of the clock oscillator to the command phase counter which divides the clock signal down to the same frequency as the reference. The relative phases of the position feedback signal and the command phase counter output are compared by the phase discriminator, thereby producing a position error signal whose

Figure 1. SINGLE-AXIS DIGITAL NUMERICAL CONTROL SYSTEM.

Figure 2. SINGLE-AXIS PHASE ANALOG NUMERICAL CONTROL SYSTEM.

magnitude and polarity are a function of the relative phase displacement of the inputs. This signal, after amplification, is used to drive the motor and resolver in the direction required to reduce the error signal. The system thus far described would simply hold the axis at a fixed position. In order to produce motion, the position command signal must be phase shifted so that the rate of phase shift and the total phase shift are proportional to the desired velocity and displacement. To accomplish this motion, the command phase counter is designed to accept input from the MCU. For each control pulse produced, a certain phase shift results that causes a calibrated displacement, the amount of which is a characteristic of the machine design. The velocity is proportional to the frequency of the control pulses and the total displacement to the number of pulses. The direction of the phase shift at the position command signal with respect to the reference dictates the direction of machine motion.⁽²⁾

Both types of NC systems are usually quite capable, although expensive, machines. For any operation they are to perform, several steps must be taken to convert a designer's conception of a part into a finished product. A drawing must first be made from which a programmer can convert every required movement or action into a series of coded instructions. These instructions must then be transformed into a mode acceptable to the reader of the MCU. The acceptable mode may be through perforated tape, magnetic tape, tabulating cards, or direct from a computer storage [disk, magnetic tape, core memory, or read-only memory (ROM)]. Required transition from the designer's concept to an acceptable input produces a significant delay in obtaining the desired result. After the information is loaded into the reader and the cycle is initiated, the MCU issues the data required to cause the desired actions to occur.

In performing a particular operation, a head must be translated parallel to the axis of rotation for either the inside or outside wall of cylinders of various sizes a required number of times. The axes must also retrace their path to an unimposing "home" position when the operation is complete. As illustrated in Figure 3, three basic motions

Figure 3. BASIC MOTIONS REQUIRED FOR SCANNING A CYLINDER.

are required for such performance: (1) from home, the head must move perpendicular to the axis of rotation a sufficient distance to obtain proper orientation with the part diameter (X length); (2) motion must then occur parallel to the rotational axis the distance required to allow the start of each scan to occur near the front of the part (Y length); (3) the final motion is executed parallel to the part the number of times required for the completion of the process, after which the path is retraced to home. Because this is a simple operation, the capabilities of an NC system are wasted.

In order to more efficiently scan cylinders of various sizes, a system is required that eliminates the delays associated with making new part tapes every time part dimensions change (several hours in this case). The length of the three required motions and the number of scans should be entered directly by the operator at the control console. The system should be as simple to operate as possible and very reliable, since only one of its kind will be available and schedules must be met. The need for a system capable of meeting these requirements forms the basis for the work described in this report which was performed at the Oak Ridge Y-12 Plant.^(a)

(a) Operated by the Union Carbide Corporation's Nuclear Division for the US Energy Research and Development Administration.

A PROGRAMMABLE CONTROL SYSTEM

CONTROL ALTERNATIVES

Numerical Control Assets and Liabilities

Numerical control systems possess many features that make them attractive for the solution of control problems. Standard systems are available that can be adapted to fill the need in most control applications, and they are very accurate and produce better repeatability in that human interaction is minimized. This lack of interaction downgrades the quality of employee required to perform a machining operation from skilled craftsman to trained operator. Management, therefore, has better control over both the machining operation itself and the quality of the finished product.

The impressive credentials of NC systems have led to their almost universal acceptance as the answer to control problems, but certain other factors should be taken into consideration before decisions are reached. In the first place, the scope of the project for which NC is being considered must be large enough to justify the costs. A large initial capital outlay is required to purchase the equipment, and a highly trained technical staff must be employed to program and maintain the systems. In the second place, the job should be of sufficient complexity to require the capabilities of an NC system. Certain operations are so simple that they waste the flexibility and accuracy of a sophisticated machine.

Alternative Systems

Programmable Controllers - For many control applications, alternatives exist which provide the desired control more economically and efficiently. For example, programmable controllers are available in various degrees of sophistication that can solve many control problems. They are special-purpose devices with core and/or ROMs. Such controllers, coupled with the required axes drive motors, can replace NC as an alternative to manually manipulated machine tools. If a particular pattern is to be followed repeatedly and no flexibility is required, the part description can be permanently stored in an ROM; and, upon initiation of the cycle (most machining operations are initiated by depressing a "cycle start" button), the programmable controller issues the commands that cause the axes motors to turn. Each turn produces a translation of that particular axis an amount that depends upon the axis lead screw.

Stepping-Motor Drive Systems - Another control alternative is an open-loop stepping motor drive system. As an example of how such a system operates, suppose that cones of various sizes are to be scanned in much the same fashion as the cylinder depicted in Figure 3. The same three basic motions are required with the exception of the fact that the scan motion must be executed by both the X and Y axes, as noted in Figure 4. A block diagram of how the system would operate is given in Figure 5. When the cycle is initiated and the X length is read into the desired travel register, a pulse is applied to the control gate that allows pulses from the oscillator to be fed to the translator circuits. These logic circuits convert each pulse into the correct sequence to drive the motor one step. The pulse counter, initially reset by the start pulse, increments itself each time a pulse is applied to the translator. When the accumulated total in the counter equals the number required for the X motion (X length),

Figure 4. MOTIONS REQUIRED FOR SCANNING A CONICAL PART.

the control circuitry closes the pulse gate, resets the decade counters, allows the Y length to be read into the Y desired length register, and issues a start pulse for the Y axis motion. This motion is executed in like manner and is discontinued when the contents of the Y decade counter equal the desired motion (Y length). A clear pulse then resets both counters, allows the X scan and Y scan to be read into the desired length registers, and issues a "start" command for motion in both the forward X and Y directions. Pulses applied to the translator are accumulated until both the X and Y counters contain the numbers representing the required length. Both axes operate independently of each other so that if the X scan length is reached before the Y scan length, X motion is disabled until Y is complete. When both X and Y counters contain the desired numbers, the scan counter is decremented, both counters are zeroed, and motion is initiated in the reverse direction. The direction of travel is reversed by changing the input level of the direction control in the translator. Again, both counters are incremented until the X and Y scan lengths are reached. This reversal process is repeated until the operation is complete. If no scans are remaining when the axes return to the Y length position, both counters are zeroed, the Y length is read into the Y desired length register, and motion is enabled in the Y reverse direction. After this motion is executed, X travel is enabled in the negative direction until the axes return to the original home position. In this operation there are six variables that can be either programmed or hardwired: X length, Y length, X scan length, Y scan length, X axis velocity (oscillator frequency), and Y axis velocity. A logic system can be designed that allows all these variables to be inputted via switches; or, if the same scanning motion is to be repeated continuously, the inputs can be hardwired. The system represents an open-loop method of performing a control operation. There is no velocity or position feedback, but the reliability of the stepping motor systems has been well established.^(3,4)

Special-Purpose Hardwired Controllers - An alternative remains that could be called a special-purpose programmable controller. Commercially available controllers are designed with flexibility that allows them to be adapted to meet the customer's requirements. In certain applications, a hardwired logic system can be constructed to perform the control

Figure 5. OPEN-LOOP STEPPING-MOTOR CONTROL SYSTEM.

function more economically and efficiently. For example, consider a process that requires only one axis to be driven at a time. (A block diagram of a single-axis analog drive system is shown in Figure 6). When the cycle is initiated, the axis is enabled, providing power to the axis motor through a relay closure. As motion continues, pulses from an encoder mounted on the motor shaft are counted by a hardwired controller. When the number of accumulated counts is equal to the number corresponding to the desired travel length (desired travel

Figure 6. ONE-AXIS ANALOG DRIVE SYSTEM.

length may be programmed or hardwired by switches), the relay is deenergized to break the path, and the next motion is initiated. Position feedback is provided by the encoders, but no velocity feedback is built into the system. The velocity for each motion is programmed by changing the input gain of the amplifier system that drives that axis motor.

System Selection

Scanning of a cylinder previously described and illustrated in Figure 3 presents several requirements. First, the spindle must be rotated at various speeds that the operator selects at the console. Second, two axes must be independently controlled (neither moves while the other is moving) in such a way as to execute the three required motions. Finally, the scan parameters (X length, Y length, scan length, X axis velocity, Y axis velocity, and required scans) must be inputted by the operator at the console. All the control alternatives discussed were considered for accomplishing this task. The decision was reached that on the basis of simplicity, reliability, cost, and the availability of components, a special-purpose controller for an analog drive system represented the best selection.

THE PROGRAMMABLE CONTROL SYSTEM

All the control alternatives discussed consist of three fundamental sections: (1) the input, (2) the MCU, and (3) the axes drive system. Each of the sections of the programmable control system for scanning cylinders are discussed separately in the subsections that follow.

Input

There are several input modes that could be incorporated into the programmable control system. Possible alternatives include a Teletype, ROM, or switches, since all of these modes meet the basic design requirement of immediate parameter change by the operator at the

console. Of the alternatives, switch input is easier to implement from the design standpoint and is probably more convenient for operator interaction. For these reasons, switches were chosen as the input mode for all scanning parameters.

There are four control parameters that define the contour scanning of a cylindrical part: X length, Y length, scan length, and the number of scans required (Figure 3). In order to calculate the X length for external scanning, the operator adds the desired standoff to the cylinder radius and subtracts the sum from the distance from the home position to the centerline of the part (distance to the centerline minus the standoff minus the radius). For internal scanning, the X length equals the distance to the centerline minus the radius plus the standoff. Y length is obtained by subtracting the part length from the Y distance from home to the baseline of the part. Scan length is usually the part length; but, for certain applications, overtravel is allowed at both turnaround points. The number of scans is simply a function of the process and is inputted through a commercial predetermining counter at the operator's discretion. As seen in Figure 7, the required lengths are specified via lever switches. Three decades are provided for each motion, with the least significant digit representing tenths of an inch. These binary-coded decimal outputs are converted to binary and inputted to the comparator of the control logic. The input conversion logic is illustrated schematically in Appendix A.

The three remaining parameters that must be specified are: the Y axis velocity, the X axis velocity, and the spindle speed. The pushbutton switches on the control panel (Figure 8) control by voltage division the input to the operational amplifiers that drive the axis motors. No velocity-position error signals are generated in the system.

Control Logic (MCU)

The purpose of the MCU is to accept input commands and create an output that properly describes the required sequences. In the case of the cylinder, the MCU must accept the four control parameters previously described and sequentially enable and disable the axes motors when required to properly execute the cycle. A flow chart of the logic decisions necessary for scanning a cylinder is presented in Figure 9; a block diagram of the implementation of these decisions is presented in Figure 10.

After the operator has entered the four control parameters, the "cycle start" button is pushed. This action sets the output of all the counters in the MCU to zero and enables the X axis forward motion by applying a logical "1" (+ 3 volt) input to a relay driver (Appendix C, Page 31). As the motor turns, the quadrature output of the X axis encoder is converted to up-down pulses at a rate of 200 per revolution. The X axis lead is 0.25 inch per revolution (Figure 11); therefore, when 80 encoder pulses have occurred, the X axis has moved 0.1 inch. Their occurrence is detected by "anding" the 2^4 (16) and 2^6 (64) binary outputs. Each 80-pulse event resets the X divider to zero and increments the X length counter. The contents of the counter are continuously compared with the binary X length input. When the two are equal, the X position is asserted, disabling the X forward motion and enabling the Y forward motion.

The Y axis lead is 0.2 inch per revolution. Therefore, with an encoder output of 200 pulses per revolution, the Y axis travels 0.1 inch for every 100 pulses. For every 100 pulses

(a) Controls and Indicators.

156993

(b) Configuration of the Required Logic.

156992

Figure 7. SPECIAL-PURPOSE SCAN CONTROL UNIT.

Figure 8. CONTROL PANELS OF THE PROGRAMMABLE SYSTEM FOR SCANNING CYLINDRICAL PARTS.

accumulated by the Y divider, the Y counter is incremented and the Y divider is reset. As shown in Appendix B, Page 26, the 2^2 , 2^5 , and 2^6 outputs are not simply "anded". The additional circuitry is necessitated by timing considerations. During the Y motion, the contents of the Y length counter are continuously compared with the binary Y length register; and, when the two are equal, the run position is asserted. This action disables the Y divider and allows the encoder pulses to be applied to the scan circuitry through the

overshoot compensator which is discussed in the following paragraph. The Y encoder pulses applied to the scan divider accumulate, as previously described (Appendix B, Page 27), and the scan-length counter is incremented for every 100 counts. When the counter contents equal the scan-length input, reverse is asserted, disabling the forward motion, decrementing the scan counter, and enabling the reverse Y motion. The reverse counts from the Y axis encoder are then accumulated (by incrementing the divider) until 100 pulses have been counted. This occurrence decrements the scan-length counter, since the Y axis is moving in the reverse mode (the input is gated into the up or down counter input, depending on the direction of motion) and clears the scan divider. The output of the scan-length counter is continuously monitored by the zero detector; and, when all zeroes are present, one complete scan has been accomplished. If additional scans are required (the scan counter does not contain zero) or "go home" is not asserted (Figure 7), reverse motion is disabled and forward motion is enabled. This process continues until one of the previously mentioned scan termination signals is asserted. Such assertion allows the Y axis motor to continue to run in the reverse mode, with the encoder pulses incrementing the Y divider and each 100-count overflow decrementing the Y length and resetting the divider until all zeroes are contained in the Y length counter or the Y axis limit switch is asserted. When one of these conditions is met, the Y axis has returned to the Y home position and motion is disabled. Motion is then initiated in the X reverse direction and continues until the X length counter contains all zeroes or the X limit switch is asserted. When such is the case, the required scanning has been completed, and the axes have returned to the home position.

Use of the overshoot compensator was alluded to in the preceding paragraph. For both X and Y length motion, the up and down encoder pulses are fed into an "OR" gate and are used to increment the divider. Direction of the axis motion controls the incrementing or decrementing of the length counter. This method is adequate for the X and Y length motions; but, with many repetitions of the scan motion, inertial overshoot of the Y axis can result in an appreciable error if the overshoot is not equal for both reversals. The circuitry required to solve this problem is illustrated in Appendix B, Page 30. Every time a forward pass is executed, and the turnaround point is reached, some counts are accumulated in the scan divider before the reversal is executed. The overshoot compensator allows encoder pulses to decrement the scan divider until it contains all zeroes. After this step is accomplished, the scan divider accumulates encoder pulses and decrements the scan-length counter for every 0.1 inch of reverse motion. When the scan-length counter contains all zeroes, motion is reversed; but, as before, some overshoot occurs. The scan divider is again decremented to zero before the next scan counting begins.

The MCU of the controlled analog drive system essentially consists of a repetition of three control segments. By specifying a resolution of 0.1 inch and counting pulses at a rate of 100 pulses for 0.1 inch, a theoretical accuracy of 0.001 inch is realized for any of the Y motions. A theoretical accuracy of 0.00125 inch is realized for X axis motion. This achievement far exceeds the accuracy requirements of the process for which the machine was designed (± 0.100 inch).

Analog Axis Drive Systems

In discussing the function of the MCU, mention was made of the fact that the application of a +3 volt signal to a relay driver enables motion (Page 13). For the

Figure 9. FLOW CHART SHOWING LOGIC DECISIONS MADE BY A HARDWIRED CONTROL SYSTEM.

Figure 10. COMPONENTS OF THE HARDWIRED CONTROL SYSTEM.

Figure 11. MACHINE AXES CONFIGURATION.

purposes of explanation, one scan will be traced from its initiation to its return to home. When the operator presses the "cycle start" button, a +3 volt signal is applied to the base of the X forward relay driver transistor (Appendix C, Page 31). This action saturates the transistor and energizes Relay K2. The relay closure (Appendix C, Page 32) allows a negative input to be applied to the preamplifier, the magnitude of which depends on the axis velocity selected. The amplified signal drives an 800-watt power amplifier which causes the X axis lead screw to rotate clockwise, creating motion in the X forward direction (Figure 11). When the X position is reached, the signal is removed from the X forward driver and +3 volts are applied to the base of the Y forward driver. This step enables the closure of Relay K22, allowing motion in the Y forward direction. Such motion continues until reverse is asserted. Then the "1" signal is removed from Y forward and applied to Y reverse, changing the sign of the input and reversing the direction of Y travel. When Y home is reached, the signal is removed from the Y reverse driver and applied to the base of the X reverse transistor, enabling return to the home position. Velocities of all the axes motions are calibrated by adjusting the loop gains of the amplifier system and the voltage applied at the input. Periodic checks of the velocities reveal that accuracies of $\pm 5\%$ are maintained over an extended period of time with no short-term fluctuations. This accuracy stability is more than adequate for the particular application considered. Tachometer feedback is used only to provide stability and interacts in no way with the machine positioning. No control is exercised over the spindle except manual on-off and rotational speed (Appendix C, Page 34).

Other Design Considerations

Limit-Switch Closures - Limit-switch closures at the travel extreme of both the X and Y axes serve a dual purpose on this machine. In the first place, they prevent overtravel and, therefore, protect against tooling damage in the event of a machine malfunction. Appendix C, Pages 31 and 32, illustrate how this safety feature is accomplished. For example, if the X forward limit switch is asserted, Relay K5 is energized. Further forward motion is now impossible since no voltage is available to the coil of Relay K2.

The limit-switch closures also provide input to the control logic, preventing overtravel during the automatic operation and serving as a convenient and repeatable home position. Such utilization presents a problem since a very noisy relay closure must serve as an input to a noise-sensitive logic system. The circuitry used to solve this problem is shown in Appendix D, Page 35. These circuits convert a switch closure at +24 volts into an isolated signal at +5 volts via optical isolators. These isolators are four terminal devices that convert an electrical input signal into photon energy (via a light source) and reverse the conversion process through a photosensor, producing an electrical output. Such isolation prevents the introduction of a high-frequency noise into the MCU.

Part Protection Interlocks - In any operation, there are certain malfunctions that must disable machine operations in order to prevent part destruction. For example, in a machining operation, if the spindle should cease to rotate or if the axes should stop, the part might be grooved. In order to protect against such an occurrence, spindle rotation and axes-motion interlocks are installed on the cylinder scanning system. The spindle-rotation interlocks simply monitor the output of the tachometer. When the tachometer output falls below a preset level, a transistor is saturated, energizing a relay coil and disabling the process continuation.

The axis-motion interlock incorporates more complex switching circuits. The control relay is driven by three circuits in a wired "OR" configuration (Appendix D, Page 36). The Y axis tachometer is monitored continuously and the process is allowed to continue when: (1) the Y axis is moving forward with a velocity above the threshold (positive voltage feedback), (2) the Y axis is moving in the reverse mode with the feedback above the threshold level, or (3) the machine is not executing the scan cycle. If none of these conditions are met, a relay closure discontinues the process operation.

CONCLUSIONS AND RECOMMENDATIONS

The system just described meets the design requirements with minimum complexity. The machine capability is to scan any size cylinder within the limits of machine travel, with all inputs immediately accessible. No claim of added flexibility is made. Due to the minimum complexity, the system provides maximum reliability since no unnecessary parts disable the machine performance. For these reasons, the programmable control system can be said to represent the best alternative for scanning cylinders.

Imposition of additional requirements would necessitate reevaluation of alternative selections. For example, if the requirements were changed to demand simultaneous motion of the two axes, the MCU would have to be modified extensively. Instead of providing just an axis-drive signal, a digital-command signal would have to be generated, essentially creating the system depicted in Figure 1. As the requirements of the process become more demanding, the trend toward justification of an NC system is evident.

The programmable control system for scanning cylinders was fabricated and has been in operation for about a year. Accuracies of ± 0.005 inch are realized from the start of an operation to its conclusion. The difference in theoretical and observed accuracies can be attributed to mechanical uncertainty of the limit-switch closures and to random noise signals from the relay closures. Whatever the source, the error is of no significance. Maintenance problems have been few and those that have occurred have been readily solved due to the simplicity of the system.

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APPENDIX A

SYSTEM INPUT

SWITCH INPUT

SCAN LENGTH

R1 and R2 to be 1/4 watt 1% Resistors
 R1 - 3.3K
 R2 - 6.2K

All ICs
SN 74184

X CONVERSION

Y CONVERSION

SCAN CONVERSION

INPUT CONVERSION - BCD TO BINARY

APPENDIX B

MACHINE CONTROL UNIT

All Flops 7402 Jmpr. 3&4 and 1&5
on Each Chip

OVERSHOOT COMPENSATOR
D-I-50850

APPENDIX C

ANALOG DRIVE SYSTEM

MODIFICATIONS TO RELAY CONTROL PANEL
(Axes Drive)

APPENDIX D

OTHER DESIGN CONSIDERATIONS

*Allen Bradley Type PT001 Led Optical Isolators.

All Resistors 1/4 Watt Except Where Specified
All Transistors 2N3904

CYCLE START

GO HOME

HOME INDICATOR

AUTO - MANUAL AND EMERGENCY STOP

GO HOME INDICATOR

SWITCH LIGHTS

QUADRATURE CONVERTERS

PASS COUNTER CONNECTIONS

WIRING DIAGRAM

Connector	Description
J1A	Amp 3102A - 145 - 6P
J1B	Amp 14 6S
J1C	Amp 14 6P
J1D, J2F	Amp 14 6S
J2D	Amp 16 7S
J2E	Amp 14 6P
J9D	Amp 16 7S
J8D	Amp 16 7S
J5A, J6A	Amp 97 - 3102A - 145 - 2D
J5B, J6B	Amp 97 - 3106A - 145 - 2S
J8B & C, J9B & C	Cannon Feedthrough
J2B & C	TBEH 16S IPS-100

Cable	Description
1	6-Conductor Wire-06-992-7340
2	6-Conductor Wire-06-992-7340
5, 6, 8	Number 16 4-Conductor Wire to be Covered with Shield and Shrinkable Tubing
9	5 Conductor Wire-06-992-7338

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 Smith, R. D.
 Stoner, H. H.
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