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Selection of feedback devices, controller design concepts, safeguard implementation, operator status and display capabilities, and mechanism movement simulation are topics that will be addressed.

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DESIGN PHILOSOPHY FOR WIND TUNNEL MODEL POSITIONING CONTROL SYSTEMS[1]

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KEYWORDS

Control System, Integrated, Positioning Control,Safety, Motion Simulation

ABSTRACT

Wind tunnel testing usually requires positioning of the aircraft model in the airstream. This paper presents the design philosophy for a typical generic automatic control system for use in the wind tunnel facilities at Arnold Engineering Development Center in Tullahoma, Tennessee, and is presently used to accurately control the position and/or velocity of an aircraft in one to six degrees of freedom while taking into account the effects of outside influences.

Selection of feedback devices, controller design concepts, safeguard implementation, operator status and display capabilities, and mechanism movement simulation are topics that will be addressed.

INTRODUCTION

The Arnold Engineering Development Center is the free world's largest complex of aerospace test facilities and includes wind tunnels, propulsion test units, space chambers, and hyperballistic ranges. Ground testing in these facilities complements the more expensive and often more hazardous flight testing and can save time in the overall system development process. The wind tunnels at AEDC use air as the working medium and cover the transonic, supersonic, and hypersonic Mach number regimes. Variable density permits controlled variation of Reynolds number throughout a wide range.

Wind tunnel testing usually requires the positioning of the aircraft model in the airstream to simulate flight attitudes. Certain types of aerodynamic testing require positioning of the model at various angles of attack at fixed sideslip angles or various sideslip angles at fixed angles of attack. This positioning is quite difficult to accomplish manually since many sting support mechanisms can only position pitch and roll angles. Combinations of sting pitch and roll positions may be set to give the required model angle of attack and angle of sideslip. The problem is further complicated by sting bending and balance deflections caused by aerodynamic loads which vary depending on model attitude, Mach number, dynamic pressure, and sting stiffness.

[1]The work reported herein was conducted at the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Base, Tennessee 37389. Work and analysis for this research were done by personnel of Calspan Corporation/AEDC Division, operating contractor of the AEDC aerospace flight dynamics facilities. Further reproduction is authorized to satisfy needs of the U. S. Government.

Because of the increased requirement to test models at angles of sideslip and the difficulty in setting model attitude manually within a reasonable tolerance, closed-loop computer controlled systems have been developed for use in the wind tunnel facilities at the Arnold Engineering Development Center in Tullahoma, Tennessee, to provide a capability with a setting accuracy and speed that is unobtainable by manual methods. During air-on testing, the control system and associated model positioning mechanism is completely under computer control. The operator is present but only in a monitoring capacity. This capability has produced a significant increase in the number of polars that can be obtained per tunnel "on-condition" hour. The control algorithm compensates for sting deflections during model movement so that model attitude will be precisely oriented in the airstream.

Several independent mechanisms are used to position the model in the airstream. These are usually very massive systems weighing several tons and having from one to six degrees of freedom. Some mechanisms are electrically driven while others are hydraulically actuated and some are hybrid. Very sophisticated control systems are required to control mechanisms such as these while providing a vital link in the overall data acquisition process. Some control systems are dedicated to a particular mechanism while others can control up to four different mechanisms, one at a time. A typical model positioning mechanism installed in the wind tunnel is shown in Fig. 1, and a typical control system is shown in Fig. 2.

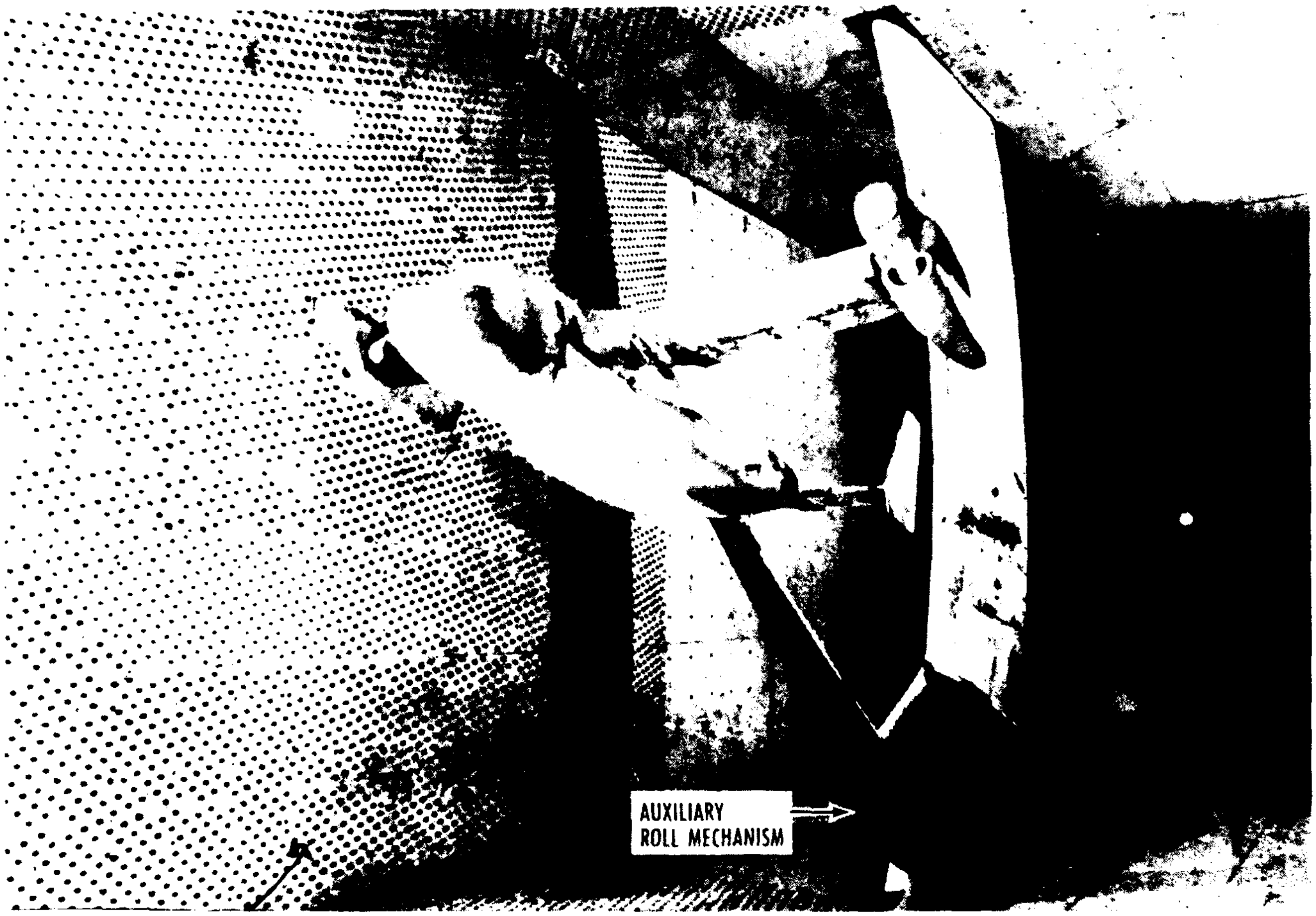

Fig. 1.Typical model positioning mechanism.

The model positioning control systems have been standardized across all wind tunnels, as much as possible, to minimize spare parts inventories and to minimize training so that operational personnel can be transferred back and forth between test units. Human factors have also been considered to optimize location of the functions which the operator must observe or interact with, and to maintain a relatively consistent location of these functions between test units.

DESIGN CONSIDERATIONS

BACKGROUND

The control systems used for model positioning in the wind tunnels at AEDC are complex, closed-loop feedback control systems which operate under computer control. Many factors which influence the system operation and resulting cost must be carefully considered in the design process. Such factors include personnel and equipment safety, operating environment, the type and number of model positioning mechanisms to be controlled, software versus hardware trade-offs, desired operating modes, human factors, and system engineering/configuration management.

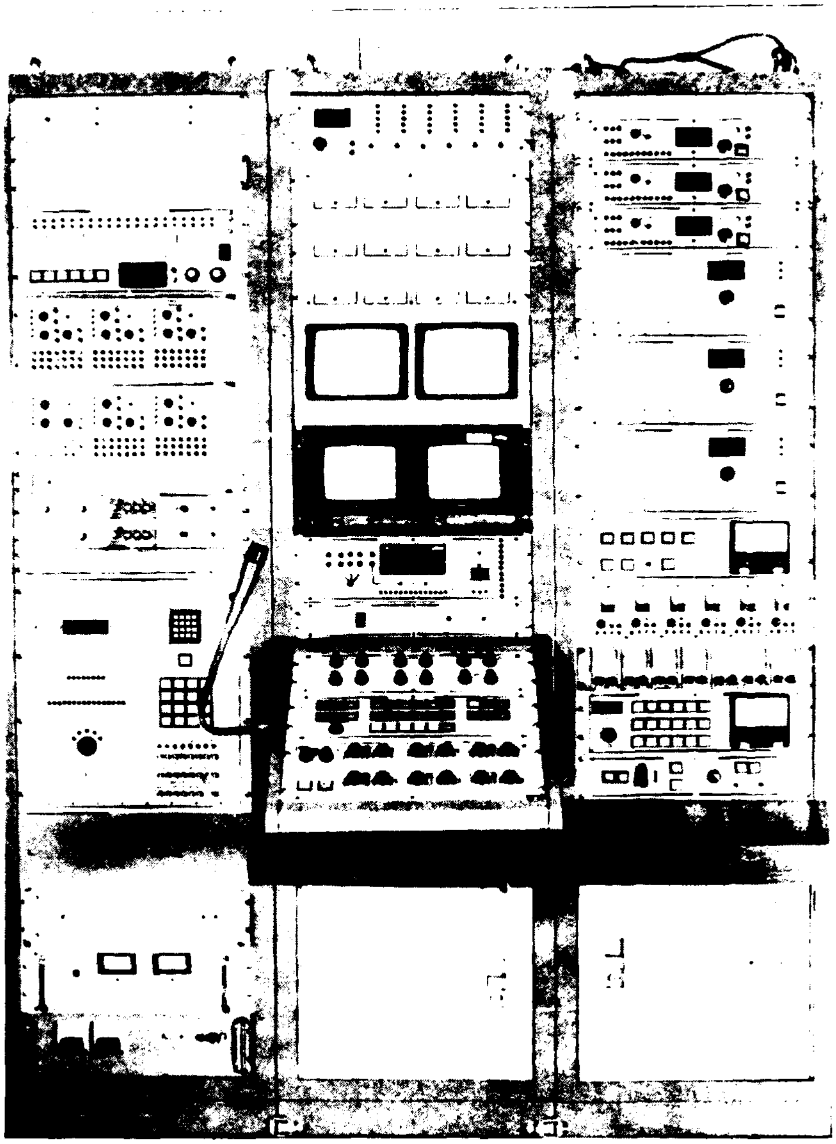

Fig. 2. Typical control console.

In today's environment of increasing energy and manpower costs, it is imperative that the maximum amount of data be obtained while the test unit is operating. This goal is achieved by designs which automate the test article control and data acquisition processes. The technical objectives are to maximize operational efficiency, provide safe and reliable operation, minimize human error, and provide effective system communication. The operational efficiency is addressed by providing control systems compatible with multiple mechanisms, centralizing functions into a single operator station, and providing a simulation capability which permits simultaneous check out of the software and concurrent manual control of the model.

SAFETY CONSIDERATIONS

A safe and reliable control system operation is provided by features such as bumpless transfer between control stations, adequate stability margin on all control loops, placement of critical control algorithms and monitoring functions in Read Only Memory (ROM), and fail-safe or fail-soft operation. In addition, numerous system safeguards are implemented using programmable logic controllers which have proven to be very reliable and allow operational changes, usually without requiring hardware modifications.

Depending on the test unit and the type of data desired, safety issues can and do greatly affect control system hardware and associated software designs. Some mechanisms are massive and have expensive models mounted on them which must be protected. Additionally, test unit operations personnel are required to work on or around the model while the system is powered up and operational. These personnel must be adequately protected, whether the system is in computer or manual control. The design and implementation of safeguards and countermeasures is a significant part of the total project cost.

ENVIRONMENTAL FACTORS

The test unit operating parameters such as vacuum and temperature can drive the design. For example, in the hypersonics area where operating temperatures are quite high, water cooling for the drive motors and position feedback elements must be considered. The air loads plus mechanism loads can also dictate the type of actuation used and will affect the resulting design.

MULTI-MECHANISMS

One item which can seriously affect the complexity of the design is whether the control system is to be dedicated to one positioning mechanism or to several mechanisms. At AEDC, some control systems must be able to control a maximum of four different mechanisms having from one to three degrees of freedom. An additional requirement in this case is that the switchover from one mechanism to another must be quick and with a minimum of manual intervention such as repatching of electrical signals. Designs have been developed which require that the mechanical positioning system simply be connected into the proper cabling disconnect interface inside the test unit. The control system is then reconfigured with a single switch and requires no patching at the control system. Typical items which are selected during the reconfiguring process are engineering unit display constants, travel limits, mechanism identification, control channels, safety interlocks, etc.

HUMAN FACTORS

All operator control panels are designed utilizing human (ergonomic) factors concepts so that the most efficient layout is achieved. The operator has access to all displays and status information in real time which is necessary to properly and efficiently operate each system. An attempt has been made to minimize human errors mainly through two means: (1) conveniently located control and monitoring panels which provide an optimum man/process interface, and (2) having predetermined control algorithms and sequences under computer control during test unit operation. Automatic limit overrides for the various control systems eliminate the possibility that the model may be driven in the wrong direction when it clears a travel limit. Also at each interactive operator station, industry-proven software packages for the operator/monitor screens have been used.

SYSTEM ENGINEERING/CONFIGURATION MANAGEMENT

System Engineering defines the overall development process and includes items such as requirements definition, design reviews, readiness reviews, and system documentation.

The key item in any design is a well-defined user requirements specification. It represents the best results that will be obtained and is necessary for effective communication between the requestor, designer, and user. It is the document that provides the basis for measurement of performance. A good requirements document is especially required in control system design for the test units, since data productivity and equipment/ personnel safety are very significant issues. The user requirements specification must address critical areas such as angular ranges, angular velocities, resolution, accuracy, operating modes, mechanical load drive requirements, etc. Once this specification has been prepared, it is imperative that all users of the system critique the document to ensure that the system will satisfy their requirements when it is developed. This process should be completed and documented in a formal Requirements Review with all users present.

There are two design paths that essentially run concurrently. The control hardware and the computer system (hardware and software). Usually, the development of a major control system for a model positioning mechanism will involve a sophisticated software program for the various control algorithms, operating modes, and polar execution routines. Both of these paths must consider the mechanisms to be controlled and the type of data to be obtained.

As the design progresses, it is imperative to conduct formal design reviews to ensure that all users are satisfied with the design and that all potential problems are being discovered and properly addressed. At least three design reviews are held for each system designed at AEDC. This serves another important function because it educates the system users as to how the system will operate when completed and instills a sense of ownership in each user. When the system is finally implemented, there is no dissension on the users' part because they were an integral part of the design and review process.

Once the fabrication is completed and the initial operation in the wind tunnel is pending, an Operational Readiness Review is held to ensure that all parties concur that the system is ready for initial operation. An Item Readiness Review is held before the project is closed out to ensure that all deficiencies have been resolved and that all system documentation is current.

KEY FEATURES

Regardless of the test unit in which the control system is installed or the number of mechanisms controlled, each control system can be divided into the following functional areas: position control, velocity control, feedback elements, position calibration, operator interface, simulate capability, and system safeguards. The key features of each of these functional areas are discussed in this section.

TYPICAL BLOCK DIAGRAM

A block diagram of a typical control system is shown in Fig. 3. During test unit operation, the system is always under computer control through a primary outer control loop in which the facility computer commands a model attitude and the control system function is to set the model to the commanded attitude. The control software is hosted in the facility computer and contains the control algorithms and the desired run polars for each test program. The run polars are combinations of pitch and roll angles which are required to position the model to the desired attitudes.

Certain types of aerodynamic testing require positioning of the model at various angles of attack at fixed sideslip angles or various sideslip angles at fixed angles of attack. This positioning is quite difficult to accomplish manually since the sting support system can only position vertical angle and roll angle. Combinations of sting pitch and roll positions may be set to give required model angle of attack and sideslip angle. The problem is further complicated by sting bending and balance deflections caused by aerodynamic loads which vary depending on model attitude, Mach number, dynamic pressure, and sting stiffness. Because of the increased requirement to test models at angles of sideslip and the difficulty in setting model attitude within a reasonable tolerance by manual methods, computer controlled systems have been developed to provide this function in the wind tunnel.

The concept developed is a closed-loop position control system with tachometer velocity feedback for rate control and compensation for acceleration and deceleration control. The major parts of the control system are the servocontroller, programmable controller, engineering unit display microcomputer, feedback elements, and the circuitry which is used to select control location and whether the system is in manual or computer control.

The control systems have the capability of being controlled manually from several control stations or by position and rate commands from a computer network via the control computer. Position and rate commands

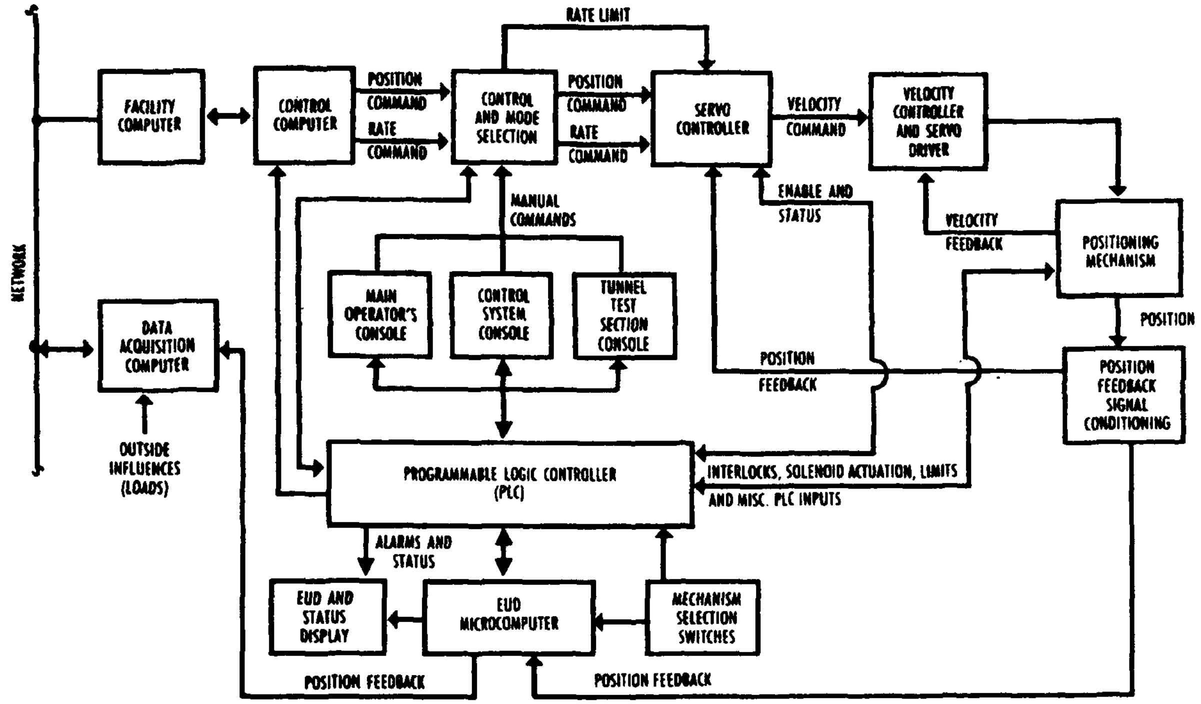

Fig. 3. Typical model positioning control system block diagram.

are generated from algorithms which utilize the position feedback and model load data to calculate the true model position. The commands are then adjusted a small amount to account for sting deflections. This ensures that the model is accurately positioned to the desired spatial coordinates. Position and rate updates to the control system can be outputted approximately ten times per second. In addition, the facility computer performs software limit checks on the position commands to ensure that they are within previously prescribed values. Position commands outside of the software limit values result in an automatic termination of the polar.

Once the control system servocontroller has received a position and rate command, either manually or from the control computer, the positioning mechanism is driven at the commmanded rate until the position feedback is equal to the position command. As long as the commanded and feedback values are not exactly equal, a differential error will exist at the input of the servoamplifier. The servocontroller converts this differential position error into a velocity command for the velocity controller and servodriver which, in turn, drives a prime mover connected to the positioning mechanism. As the mechanism approaches the desired position, the velocity command is reduced and the mechanism slows down until the command is zero.

The position feedback is utilized by the engineering unit display (EUD) microcomputer to provide the EUD display capability. Buffered position feedback data are sent directly to the Data Acquisition Computer for all normal operational modes. Simulated position feedback data that precisely emulate the mechanism movement are also sent to the Data Acquisition Computer for the simulate mode which permits simultaneous checkout of the computer network software and concurrent manual control of the model.

The Programmable Logic Controller (PLC) monitors all limits, interlocks, and switch positions and energizes only the appropriate output functions as determined by the control logic program. The output functions include system status information and energization of control relays that cause the mechanism actuators, contactors, and valves to actuate. These items are enabled only when all of the safety input conditions necessary to ensure safe and controlled movement are satisfied.

During mechanism movement, air loads and load disturbances cause variations in the velocity rates; therefore, a correction is required. A tachometer is generally used to provide the necessary velocity feedback. Velocity feedback has also been derived by sampling the counter electromotive force (emf) of the drive motors during non-drive periods on some systems that utilize electric motors.

POSITION CONTROL

Figure 4 shows a simplified position control block diagram. Two types of position control loops have been designed and used. These are the move-pause and continuous movement, which is really a setpoint ramping-type loop. As will be shown later, continuous movement is also possible with the move-pause type controller using the velocity bound network to control the rate while utilizing position commands that result in saturation of the position servo input amplifier. Regardless of the type of controller used, the positioning mechanism is always driven until the position feedback is equal to the position command value.

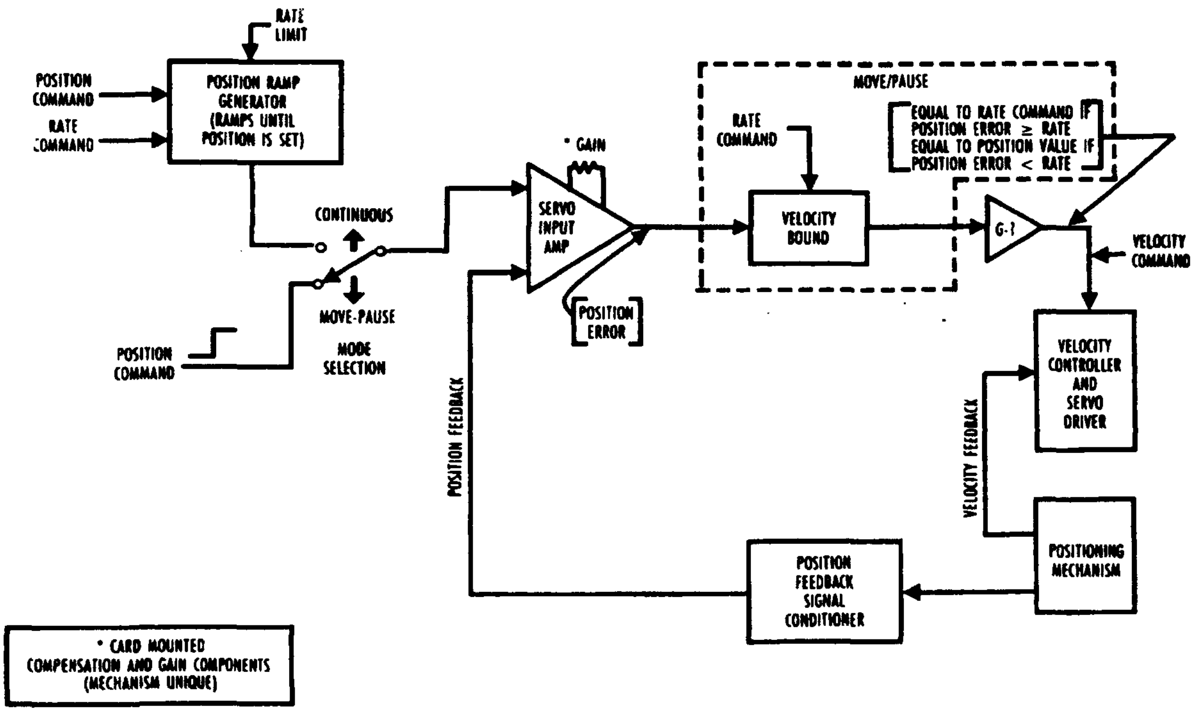

Fig. 4. Position control block diagram.

During move-pause type operation, the desired movement path is divided into point-to-point increments. At each point, the test article is momentarily stopped so that position and model data can be acquired. Movement to these point-to-point locations does not necessarily have to be achieved in a coordinated fashion. However, this type of control system utilizes a velocity bound network that can easily be used to control the velocity rates. The final desired position location is input to the control system. The desired coordinated movement path is then traced by controlling the velocities using rate commands to the velocity bound network.

To determine how the velocity bound network can be used to control the velocity rate and, therefore, trace the desired movement path, assume that the servo input amplifier gain is equal to fifty. Whenever the absolute value of the difference between the position command and the position feedback is equal to or greater than 0.2 v, the servo input amplifier output or position error will become saturated at 10 v. The velocity bound network limits or clamps this saturated position error value equal to the rate or velocity command value. Figure 5 shows a family of these maximum velocities created by different rate command setpoints plotted against the position error difference voltage.

If the maximum velocity rate is input, the bound network has no effect and the mechanism can move at the maximum possible velocity in either direction when the position loop is saturated. The V1 curve indicates the largest possible velocity of the mechanism when the velocity or rate setpoint is reduced to a 5-v value. The position servo input amplifier does not have to saturate before the bounding action begins. Note that the bound network begins to limit the output bound voltage and, therefore, the velocity rate command to the velocity controller when the position error difference at the servo amplifier input is only 0.1 volt. If the velocity setpoint is reduced further, the maximum possible velocity or rate command is also reduced.

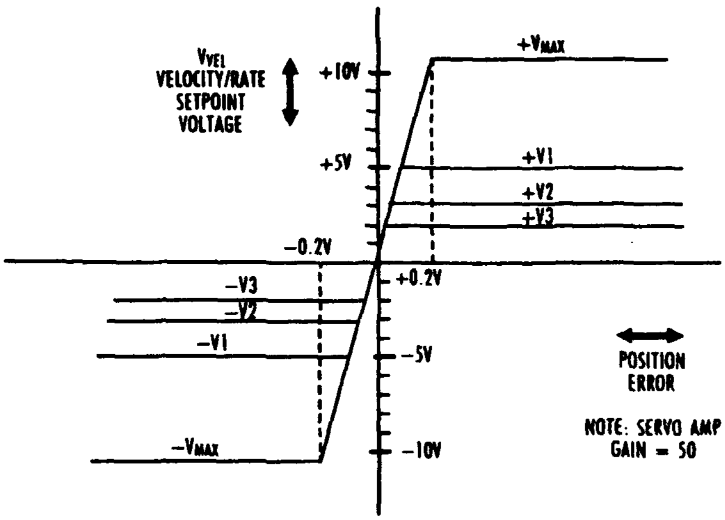

Fig. 5. Velocity versus position error difference.

This velocity bound network creates a dual mode servocontroller that operates in a velocity-dominant mode when the servo amplifier output or position error is greater than or equal to the rate command, but becomes a position-dominant controller when the servo amplifier ouput is less than the rate command. Even though the position loop is the dominant control loop when the position error is less than the rate command, the velocity control loop, which will be described in the next section, is still active and is attempting to maintain zero velocity error and is controlling the acceleration and deceleration characteristics.

The continuous movement or position setpoint ramping type position controller is utilized in some model positioning control systems. This technique produces precise, coordinated, continuous movement of the model along the desired path. This type controller utilizes the position and rate commands to generate a ramped position setpoint to the servo input amplifier. The slope of this position setpoint ramp determines the velocity or rate of mechanism movement. The positioning mechanism and the position setpoint ramping is stopped when the position feedback becomes equal to the final position command value. This technique produces very accurate velocities with extremely small velocity errors, even at very slow rates.

When digital servocontrollers are implemented, the continuous or setpoint ramping technique is generally used to generate the continous velocity controlled movements. The velocity bounding technique is generally employed for analog servocontroller designs.

The velocity bound technique is generally less complex to implement hardware wise than the ramping technique, but periodic velocity calibrations are required to ensure adequate velocity accuracies. Oftentimes, a velocity setpoint curve-fit equation is required. Additionally, the velocity bound technique does not permit accurate low-speed control. However, the ramping technique results in very accurate velocity rates even at extremely slow velocities and does not require periodic velocity calibrations to ensure the velocity accuracy. Both techniques are utilized by several control systems at Arnold Engineering Development Center.

VELOCITY CONTROL

The velocity control loop utilized is shown in Fig. 6. When a velocity or rate command is applied to the input of the velocity control loop, the servodriver will output the necessary drive voltage or signal to the prime mover which will drive the mechanism at the commanded rate. If a load disturbance should cause the mechanism to slow down, the velocity feedback output will decrease, resulting in a larger differential error signal at the input to the driver amplifier which causes the servodriver (servoamplifier for motors or voltage-to-current converter for servovalves) to output more drive signal. The larger drive signal produces a corresponding increase in the mechanism velocity. The drive amplifier attempts to maintain a zero differential error at its input to minimize the velocity error which is inversely proportional to the velocity loop gain.

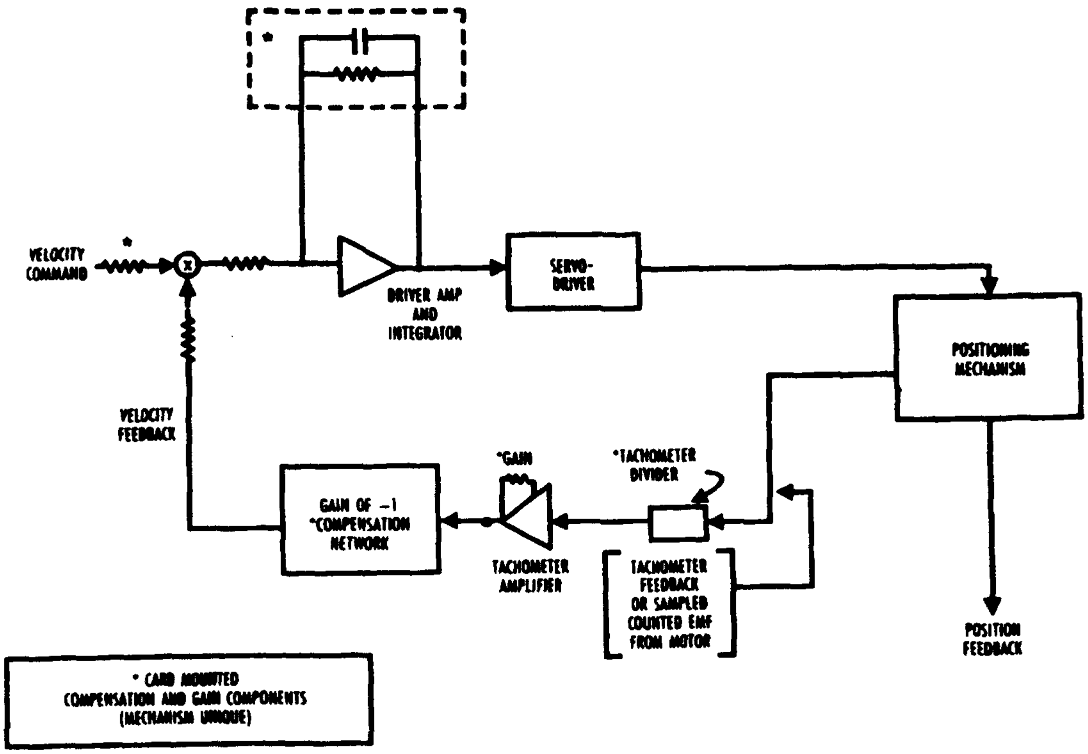

Fig. 6. Velocity control block diagram.

The velocity control loop utilizes a driver amplifier that acts as an integrator which has the effect of softening the acceleration and increasing the velocity control loop stability. The integration also minimizes positioning errors by integrating small position error signals until the drive is large enough to cause the model to move to the desired position. Most systems utilize analog integration circuitry, but digital integrating velocity controllers have been designed and used at AEDC.

A compensation network is provided in the velocity or tachometer feedback loop. The compensation network provides the acceleration and deceleration control for the system and also results in increased system stability. Optimization of the controller gains and compensation values have resulted in control systems with sufficient gain to produce low velocity errors without instabilities. Gain and compensation values are determined by measuring the step function response on a digital signal analyzer from which the resultant gain and phase margins can be obtained.

The gain and compensation passive components are located on a separate card edge-type printed circuit board so that they can easily be removed and replaced. The cards for each mechanism are unique and must be inserted into the control system when the matching mechanism is installed in the tunnel.

FEEDBACK ELEMENTS

Absolute value position feedback devices are used since the control system must know the exact positions for each movement at all times to ensure the safe positioning of the model. Even if the power has been turned off, the system must retain the proper position feedback values when powered up. Either absolute digital encoders or highly linear potentiometers are used. Potentiometers are generally used when wiring space is minimal, but digital encoders are preferred since the position readout calibrations are not subject to analog drift and temperature effects. Digital feedback encoder systems will maintain their position calibration characteristics as long as the mechanical system driving the encoder and the encoder are operating properly. Anti-backlash gears are always used to drive the feedback device.

POSITION CALIBRATION

Initially, the mechanism is calibrated at many points through several complete excursions to determine the bias, precision index, and uncertainty. The readout curve fit conversion constants for up to a fifth-order curve fit, if necessary, are then calculated by use of a curve-fit program. The resulting constants are used to calculate the engineering unit display values from the position raw data. Thereafter, a few points are checked on a daily basis using a position standard which is traceable to the National Institute of Standards and Technology.

If the data obtained from the multipoint calibration show the mechanism movement to be linear, a daily two-point calibration is used to verify the integrity of the movement. This is typical since most of the movements are linear and each movement is equipped with potentiometers having excellent linearity and near-infinite resolution. The excitation voltage and zero offset potentiometers are adjusted to set the movement to the span and zero locations accurately. The approximate values of the excitation voltage and zero offset potentiometers are known in advance. The two-point calibration procedure at the full-scale and zero locations is then used to fine-tune the excitation voltage and zero offset potentiometer settings. These values are closely monitored throughout the test to ensure the integrity of the position calibration.

For systems that require Digital-to-Analog Converter (DAC) position commands, determination of the conversion constants required for calculation of the voltages necessary to position the mechanism at the desired locations is performed daily. This process has been automated using the computer network. These command conversion constants are utilized by the facility computer to convert the desired mechanism positions into the corresponding DAC voltage setpoints. Using these conversion constants enhances the control positioning accuracies of the system.

OPERATOR INTERFACE

An operator interface to the control system and data acquisition process is provided in the wind tunnel control room. From this centralized control console, the operator can select the control mode and control source for the control system. Either manual or computer control modes can be selected. The operator can select one of three control consoles (main operator's console, tunnel test section console, or control system console) when the control system is being operated in the manual mode. The operator interface also includes the necessary status indicators to provide monitoring of the system safety and health status. A computer terminal displays the current pitch/roll polar being executed, the current point in the polar, and the corrected model angles. Emergency shutdown capability is also provided which allows the operator to manually intervene with the automated process, if necessary, to inhibit all movement should an anomaly be detected. Finally, microcomputer-generated engineering unit displays of mechanism position and velocity are provided for the operator for monitoring purposes.

A block diagram of a typical EUD microcomputer is presented in Fig. 7. This microcomputer provides the engineering unit display for each of the control system operator consoles and determines whether the actual position feedback or simulated position feedback values are sent to the data acquistion system. The microcomputer contains the hardware and software necessary to read the position feedback data, calculate the engineering unit position and rate values using the selected mechanism curve fit constants in up to a fifth-order curve-fit equation, and provide a display output of these calculated positions and rates every 0.5 sec to several operator consoles. The position curve fit constants for every possible mechanism are input to the microcomputer, while in a setup mode, via an interactive terminal. These constants are stored in battery backup Random Access Memory (RAM). Selection of the appropriate curve fit constants is automatically accomplished by the mechanism selection switch, which is also used to reconfigure the safeguard control logic. The setup mode also provides calibration outputs that are utilized to calibrate various components of the control system. While the microcomputer is in the setup or calibrate mode, operation of the control system is prevented by the programmable logic controller safeguard system.

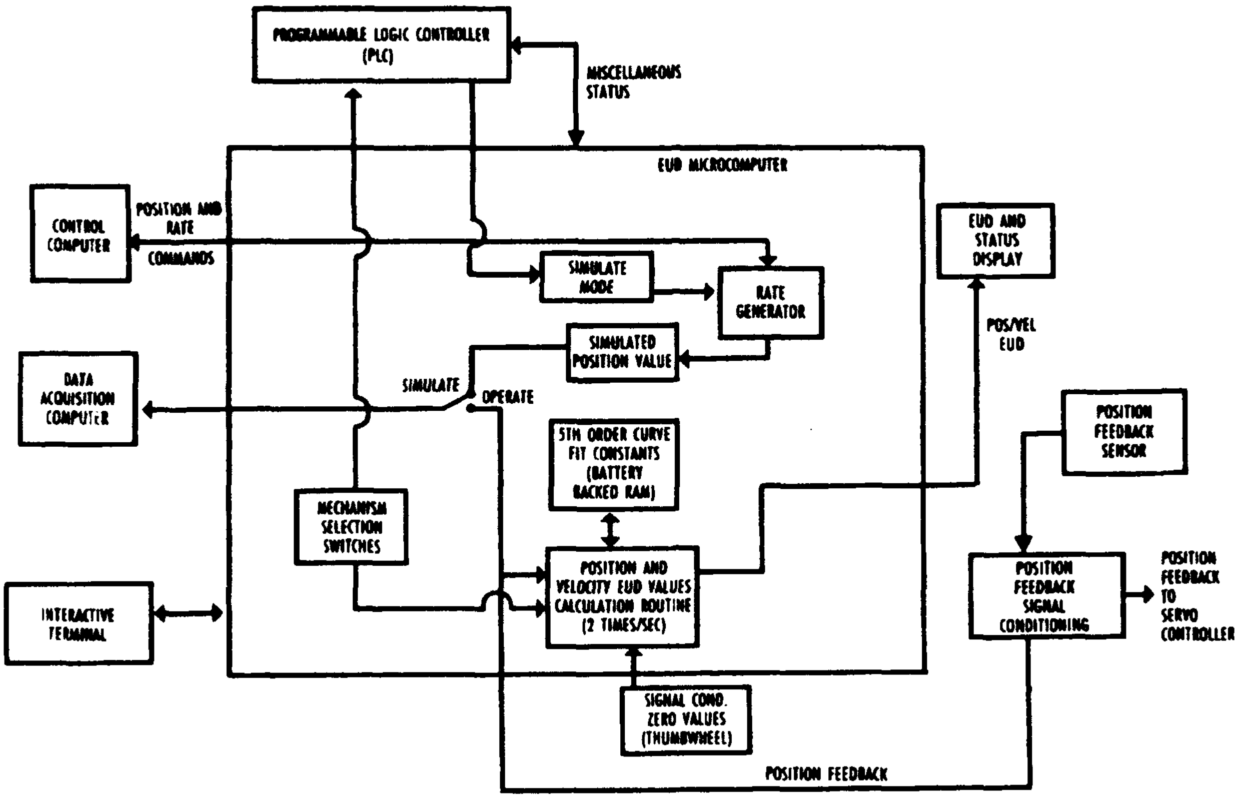

Fig. 7. EUD microcomputer block diagram.

SIMULATE CAPABILITY

As shown in Fig. 7, when the control system is being operated in all normal operating modes, the actual position feedback values are always sent to the Data Acquisition Computer. However, for the simulate mode, the computer-commanded positions and rates are utilized to generate a simulated position value that increments or decrements at the commanded rate until this simulated value is exactly equal to the commanded position. This simulated position feedback value is then sent to the data acquisition system. This action exactly emulates the movement of the positioning mechanism. The simulate mode permits diagnostic checkout of the computer network control software and the positioning polar tables or sweeps while allowing manual operation of the positioning mechanism from any of the operator control stations.

SYSTEM SAFEGUARDS

A block diagram of the Programmable Logic Controller (PLC) safeguard system is shown in Fig. 8. The safegurard system will only energize the appropriate output functions based on the condition of the limits, interlocks, and switch position inputs as determined by the control logic program which resides in Programmable Read Only Memory (PROM). All system hard panel switches and/or interactive terminal function keys are connected as PLC inputs. Appropriate switch and/or function key response indicates normal PLC functioning and operation. All interlock and safety inputs are normally closed when the safe condition is present so that if the inputs are not connected or a wiring failure should occur, the PLC will generate a shutdown.

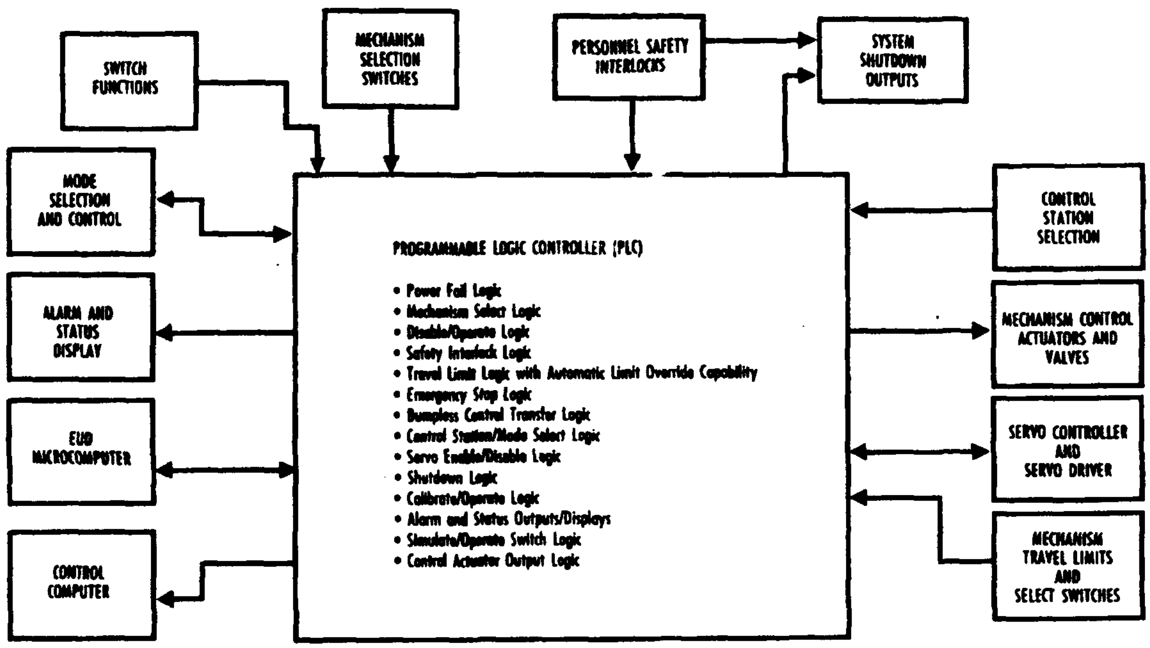

Fig. 8. Safeguard system block diagram.

The primary function of the PLC is to provide the safeguard logic that can quickly and safely shutdown the mechanism drives either individually or all at the same time. These shutdowns are usually accomplished by utilizing a combination of shutdown logic in conjunction with corresponding fail-safe hardware. The mechanism control relays which are driven by the PLC are used to energize mechanism actuators, contactors, and valves, and are disabled at the proper time in the shutdown sequence. Additionally, the servoamplifier and/or servocontroller is disabled, or the PLC signals the servocontroller to initiate a fast shutdown by quickly setting the position command equal to the position feedback. Fast shutdowns are utilized to stop mechanisms where the model can collide with other models or the test section walls. Fast shutdowns are usually employed for all digital controller-type designs but have also been implemented on some analog servocontroller designs.

The safeguard system also provides disable/operate logic. To obtain an operate condition, the operator must enable a momentary operate function. The operate condition will only engage or latch in, if, and only if, all switches and safety conditions are satisfied. The operate condition will immediately disengage or unlatch if any switch and/or safety interlock condition, even momentarily, indicates the presence of a shutdown condition or if the disable function is actuated.

Several of the model positioning control systems are capable of controlling more than one mechanism. The PLC provides mechanism selection logic which permits reconfiguring of all safeguards simply by selection of the appropriate mechanism by means of a single switch. Test type selection error logic prevents mechanism operation if the selected mechanism does not match the one installed. Permanent tunnel cabling exists at all possible installation locations for each mechanism. Contained in this permanent cabling are all velocity feedback, position feedback, motor drive, servovalve, limit switch, interlock, brake, control solenoid, and actuator signals. The proper cabling is simply connected to the mechanism at the desired installation location. Since the cabling from the control system to the control relays and motor contactors is permanently connected to the tunnel disconnect panels, once the proper cabling is connected, the system is completely patched and should be operational once the proper gain and compensation cards are installed.

Several control systems provide manual operational capability from as many as three consoles. The PLC contains the logic to ensure that only safe, bumpless transfers between these control consoles are possible. Remote control locations provide only manual control capability with manually input position and rate commands. Human factors have been considered in the design and layout of all operator control consoles. Each control console has been provided with adequate process visibility to ensure that the operator is informed of all present and past events. Conditions that prevent the operation are prominently displayed. All alarm and status displays and controls have been designed to provide for commonality between the various test units to enhance the transfer of operating personnel between test units. This commonality also minimizes spare parts and training requirements and enhances the maintenance and troubleshooting procedures.

One of the main features of the safeguard system is the travel limit logic that provides for automatic limit override capability when first level primary limits are encountered. The PLC will permit the control system to automatically drive the mechanism out of the primary limit only when the correct position command direction or polarity is commanded. If the operator is driving the mechanism in manual control, he does not have to decide on the proper drive direction and then override the limit. If the choice is made incorrectly, the PLC will not allow the control system to command the mechanism further into the primary limit. In addition to the primary limits, the computer network provides software limits on the position commands while operating in the computer control mode. Backup and/or max travel limit switches provide second level limit protection regardless of the operating mode. When a backup and/or max travel limit is encountered, the safeguard system shuts down and disables that drive so it cannot be driven in either direction.

A block diagram of the personnel safety interlock system is shown in Fig. 9. This is a hardware fail-safe interlock system that is totally independent of the PLC safeguard system. This system ensures that personnel working in the test section or in areas near the mechanism are adequately protected. This system can also be used to shut down all movement in an emergency. A keylock-type switch that allows removal of the key only when in the interlock position is provided at all test unit areas. When the interlock condition is

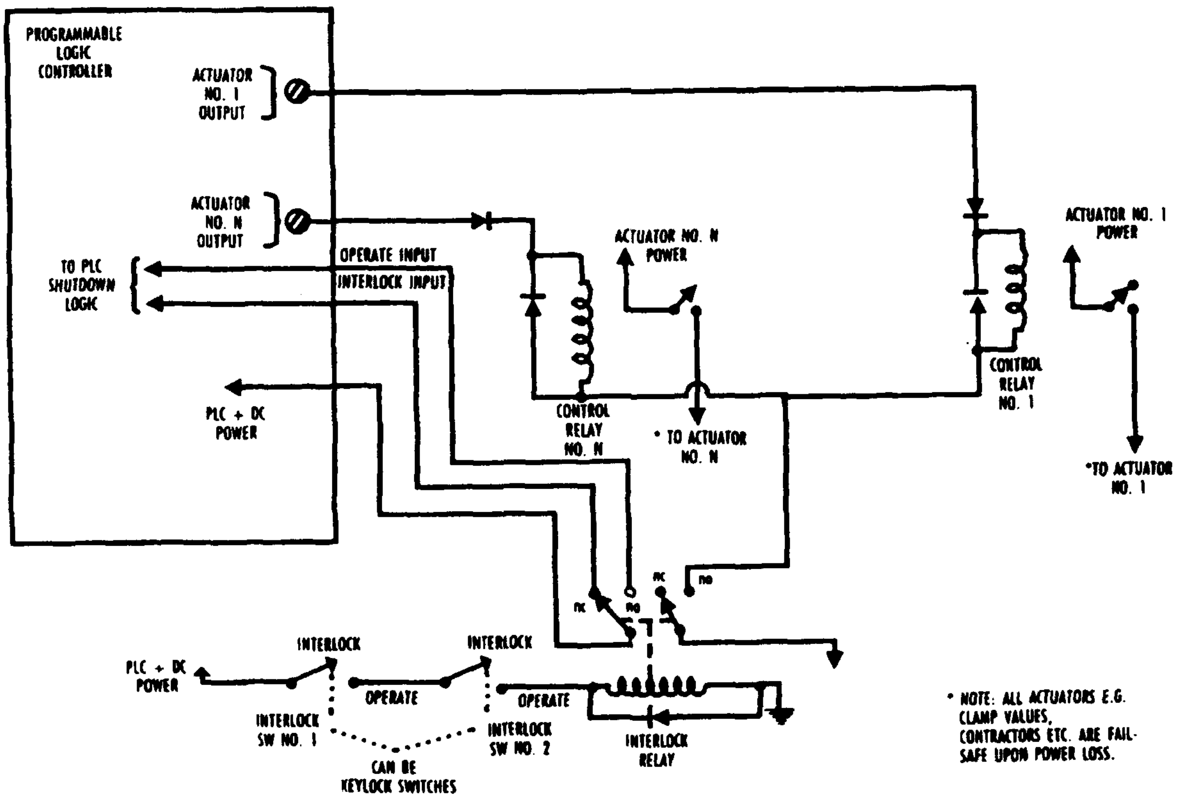

Fig. 9. Personnel safety interlock system.

selected or the interlock relay is de-energized, the power is removed from all control relays and contactors. These control relays and contactors control the application of power to all model control actuators, brakes, valves, and motors. All actuators, brakes, and valves de-energize to the fail-safe power-off condition when the interlock condition is selected and mechanism movement is impossible. The position of the interlock relay is also sensed by the PLC, which utilizes this input to shut down all drives for additional redundancy.

CONCLUSIONS

A basic control system design philosophy has been developed which can provide safe, reliable, and efficient positioning of aircraft models (up to six degrees of freedom) in wind tunnels. This design philosophy has been used since 1982 on six different model positioning control systems in three different test units (two transonic and one supersonic). Currently, a system is being developed for model positioning in the hypersonics test units.

In summary, benefits provided by this design philosophy are as follows: dual mode servocontrollers, simulate capability, Programmable Logic Controller-based safety and health monitoring, operator interface with centralized functions, and multimechanism control with minimal reconfiguration.

The dual mode servocontroller allows the model to be driven in a velocity-dominant mode up to maximum velocity when the position loop is saturated and occurs when the command and feedback differ by typically more than 0.2 v. This allows the model to reach the commanded location in minimum time. When the model position is within 0.2 v of the commanded position, the servocontroller switches to the position dominant mode which allows the model to approach the final position with little or no overshoot. The control loops can be easily optimized by compensating the velocity-control loop inside the servocontroller. This ensures that the model-balance combination will not be subjected to unnecessary dynamics caused by step inputs of position or velocity.

The simulate capability has proven to be one of the most useful design features. This allows the test-peculiar model attitude polars to be verified while simultaneously providing the capability to move the model using manual control for model installation and buildup purposes. By allowing these two important functions to be conducted in parallel, the installation time is decreased, whereas in the past verification of polars was not accomplished until the installation was complete.

In the past, the safety and health monitoring was implemented in several different parts of the system using relays and discrete components. The present design provides for centralized safety and health monitoring in a programmable logic controller. This method of monitoring has proven to be an effective means of ensuring safe operation while providing increased visibility to the process, enhanced maintainability, and greater reliability.

A control room console has been provided from which the various control consoles can be selected, and system operation can be thoroughly monitored. These operator consoles are standardized between test units to minimize training and to facilitate movement of operations personnel between the various test units. Displays and indicators are located at this console which allow the operator to monitor the position and velocity of each degree of freedom in engineering units and the status of all critical safety and health parameters.

Since some of the control systems must be able to drive more than one mechanism, it is important that this reconfiguration be done quickly and efficiently. This is accomplished by using a single switch to select system operating parameters, system safeguards, and the necessary constants to produce the required position and velocity engineering unit displays. Elimination of the control system patching and reconfiguring the system with a single switch has greatly reduced the number of human errors in this area and has significantly shortened the test installation time, especially when sequential tests utilize different model support mechanisms.