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DESIGN OF A PRECISION ETALON POSITION CONTROL SYSTEM FOR A CRYOGENIC SPECTROMETER

By

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1. INTRODUCTION

The National Aeronautics and Space Administration (NASA) Upper Atmosphere Research Satellite (UARS) will be launched in 1988 to study the distribution of a series of trace elements in the upper atmosphere and to study atmospheric dynamics.[1] The UARS carries on board a cryogenically cooled infrared spectrometer to measure the concentration of a series of chemical species that are important for understanding the ozone layer in the stratosphere. This device, known as the Cryogenic Limb Array Etalon Spectrometer (CLAES), uses a multiposition filter wheel combined with tilt-scanned Fabry Perot etalons to obtain the high resolution required for these experiments.

The CLAES optical system is sealed in a dewar where it is maintained at cryogenic temperatures by a supply of solid hydrogen. Operating temperatures for CLAES range from 130 K at the entrance aperture to 13 K at the focal plane.[2] Figure 1 is a schematic diagram of the CLAES showing the relative location of the major system components.

In this paper we describe the design and test of a special control system using a unique actuator concept to provide position and scan control for the CLAES etalon. Results of performance tests at cryogenic temperatures simulating the CLAES on-orbit environment will be discussed.

2. PROBLEM DESCRIPTION

2.1 Requirements

The six primary performance requirements for the CLAES etalon position control system are summarized and briefly discussed as follows:

- Precision angular positioning for each of the four etalons
- Rapid step response between adjacent data-taking positions of an individual etalon
- Rapid rotation of the etalon assembly to the next etalon to be used for data-taking
- Minimum dissipation of thermal energy from the actuator to conserve cryogen
- Operation of actuator components in vacuum and 20 K
- Reliable operation over the approximately 2-year mission duration

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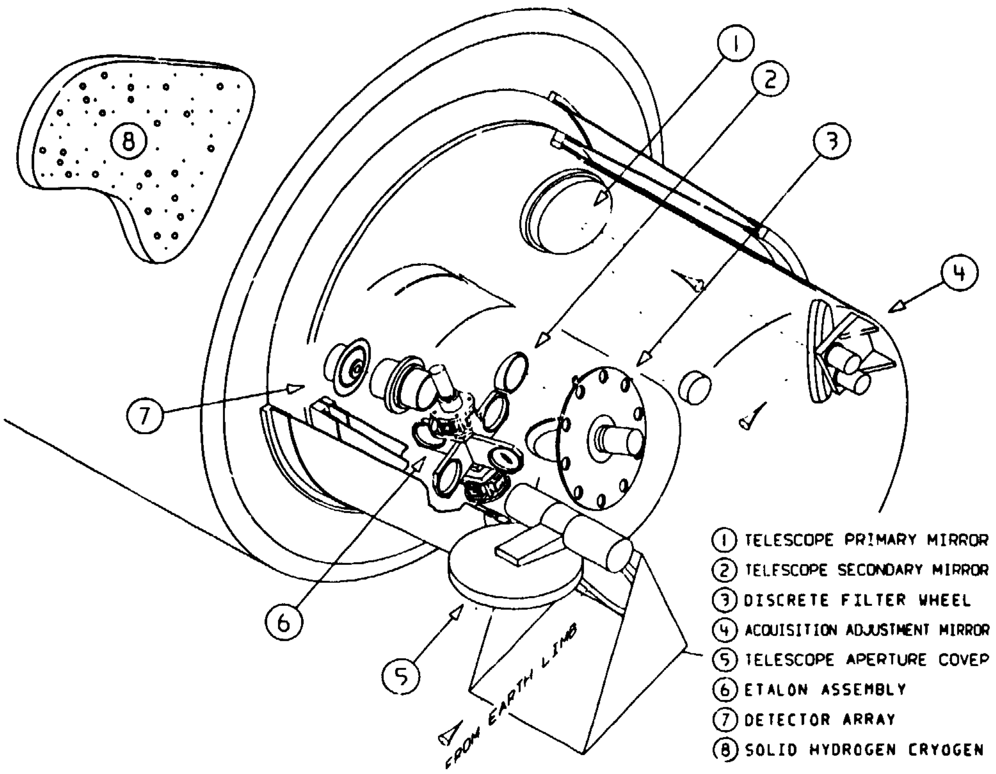

Figure 1. CLAES Baseline Configuration

Individual etalons must be positioned with an accuracy of 0.022°. In a system sensing angular position using a digital encoder, this requirement translates into an accuracy of 14 bits.

The data-taking capability of the CLAES is predicated on the ability to take a new reading every 125 ms. Based on the sensitivity of the focal plane detectors, a period of approximately 30 to 40 ms is available for the etalon to rotate 0.1° to the new data-taking orientation.

In addition to the rapid and precise positioning of an individual etalon in the optical path, it is also essential to reposition each of the four etalons in the incoming beam with as little delay as possible. A goal of 1 s for a 90° rotation has been set for this function.

Minimizing the dissipation of thermal energy is an essential requirement for any long-life cryogenic mission. This is especially important when the heat producing mechanism (in this case, the rotation actuator) is coupled to an optical element whose temperature is also critical. Therefore, the design of the actuator must be such that the resistive thermal energy dissipated during operation is kept in the range of 1 to 5 mW.

Reliable, long-life operation of electromechanical devices in a cryo-vac environment creates a number of constraints on the design of the actuator. In particular, the brushes, commutator, bearings, and gear trains used in standard servomotors are sources of failure. In addition, careful attention must be paid to tolerances and the potential for differential thermal contraction so that the mechanism will function throughout the temperature range from cryogenic to ambient.

2.2 Potential Solutions

A number of potential solutions are available to meet the previously mentioned requirements. Probably the simplest solution would be to use a small stepper motor and move the etalon assembly in an open-loop mode by counting the number of steps the motor was commanded to move. This technique lends itself to microprocessor control and is easy to implement. Another possible solution is to use a standard dc servomotor with a position feedback loop and drive the etalon assembly through a gear reduction mechanism to provide the desired torque/speed relationship.

The difficulties with both of these and similar approaches are related to meeting the fairly stringent servomechanism requirements while simultaneously providing reliable operation in a cryo-vac environment. For example, some form of gearing is necessary for a stepper motor to have the required angular resolution. Unfortunately, it is not possible to meet the slew requirements with a geared stepper motor because an excessively high-pulse rate (steps per second) would be needed. A geared dc servo motor can meet the resolution and slew rate requirements, but the reliability of a mechanical system with brushes, commutator, gears, and numerous bearings becomes a problem. In addition, the performance of a geared system is always degraded relative to a direct drive arrangement because backlash in the transmission introduces nonlinearities which are difficult to compensate for. Brushless dc motors to avoid many of these problems, especially if configured for direct drive; however, the semiconductors used for the electronic commutation will not operate at cryogenic temperatures.

Therefore, based on the previous discussion, an ideal system would use an actuator with enough torque output to operate in a direct drive configuration. This system would have the continuous positioning ability of a dc servo motor and the rapid slew response of a stepper motor. In addition, the system would use feedback control for precision and repeatability, but would be simple enough to ensure reliability for a long-life mission.

In the following sections, a precision etalon position control system is described that meets the requirements of the CLAES as previously discussed. The system uses commands from a microprocessor to drive a unique actuator that combines the advantages of a stepper motor and a dc servo motor. This low-power unit develops enough control torque so that it can be connected directly to the etalon assembly without the need for intermediate gearing.

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3. ACTUATOR CONCEPT

3.1 Principle

The concept developed for the CLAES etalon wheel actuator was evolved in direct response to the requirements defined in Section 2. The cryovac conditions coupled with long-life mission were strong drivers for an unpowered rotor -direct drive design. High torque and accuracy requirements combined with the need for unlimited angular rotation resulted in a concept that combines the characteristics of stepper motors and dc torquers.

The "stepper" part of the actuator has four stable positions, 90° apart, that correspond to the nominal positions of each etalon. The "torquer" part is obtained by applying to the rotor bidirectional proportional control torques that can continuously move the rotor about its stable position, in the prescribed range of ±15°. The stepper performs the switching between etalons and the "torque" achieves the precise positioning.

3.2 Magnetic Design

The hybrid stepper/torquer concept can be integrated in a single magnetic assembly as shown schematically in Figure 2. The rotor is a dipolar permanent magnet and the stator consists of four pole pieces that are energized by separate windings. When the windings of two adjacent pieces are producing the same poles, only one rotor position is stable (Figures 3a, 3c, 3d and 3f), achieving the stepper effect. When the windings are driven differentially, bidirectional torques are obtained (Figures 3b and 3e).

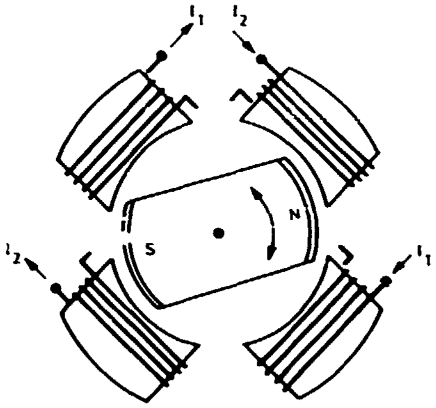

Figure 2. Actuator Magnetic Assembly Concept

Because of the symmetry of the system, the same behavior is obtained about each of the four equilibrium positions. The shape of the pole pieces must achieve three objectives:

- Produce the maximum torque for a given magnetization
- Achieve a rather constant torque/magnetization characteristic within the ±15° range
- Make it possible to slew between two adjacent (90°) quadrants

The last two objectives lead to pole pieces that are widely overlapping so magnetic interactions remain present even for large deviations from the

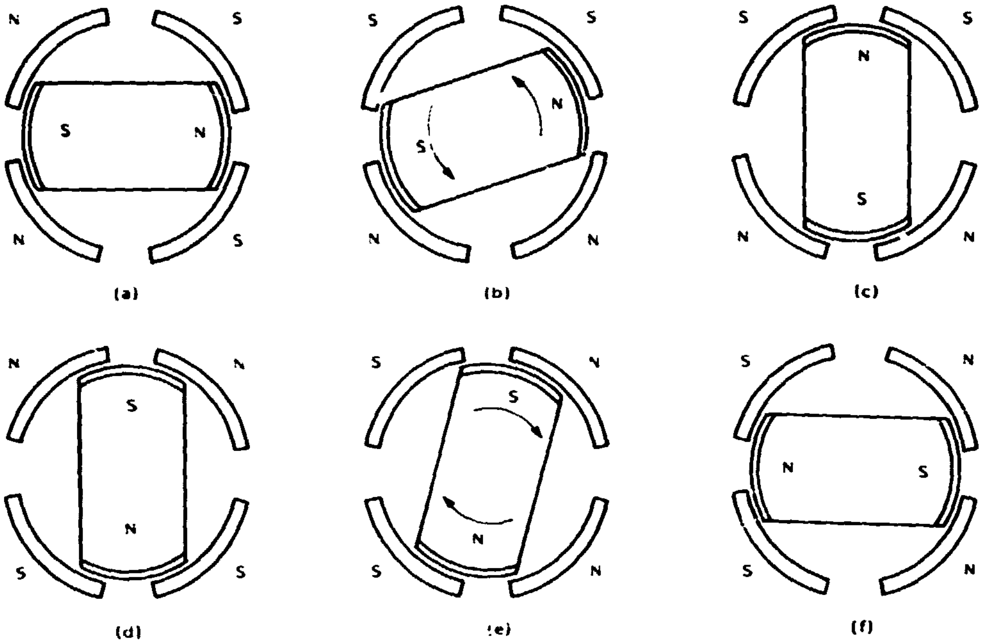

Figure 3. Actuator Stepper and Torquer Nodes

nominal position. The maximization of the torque involves the distance d between two adjacent stator pole pieces (Figure 4). In the case of a linear (translating) rotor, and assuming a constant magnetization, the magnetic force acting on the rotor is a function of the position of the rotor and of the distance d, as well as of the magnetic gap g (distance separting the rotor from the stator). This force can be computed and the results are shown in Figures 5 and 6 corresponding to rotor and stator pole pieces of length equal to 100 gaps. The relative position of the rotor is expressed in units of gaps and the force in normalized units. The curves were computed for several values of the distance d and they indicate that d should be equal to about one-forth of the stator pole piece length.

The actual magnetic design used the previous ideas, but the geometry of the system was modified from the conceptual concentric design of Figure 2 to a lateral design as shown in Figure 7. This arrangement was preferred for the following reasons:

- Allows a smaller gap between stator and rotor (thus a higher force level) because of a lower differential thermal expansion and sensitivity to bearing accuracy
- Makes it easier to manufacture and replace the permanent magnets
- Results in a more compact design, which is desirable because of the limited space available in the CLAES dewar

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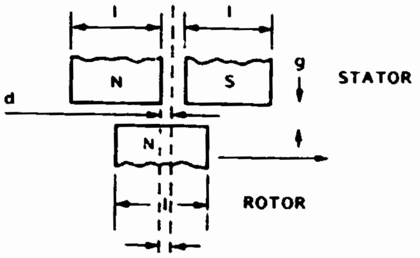

Figure 4. Linear Rotor Model for Pole Piece Optimization

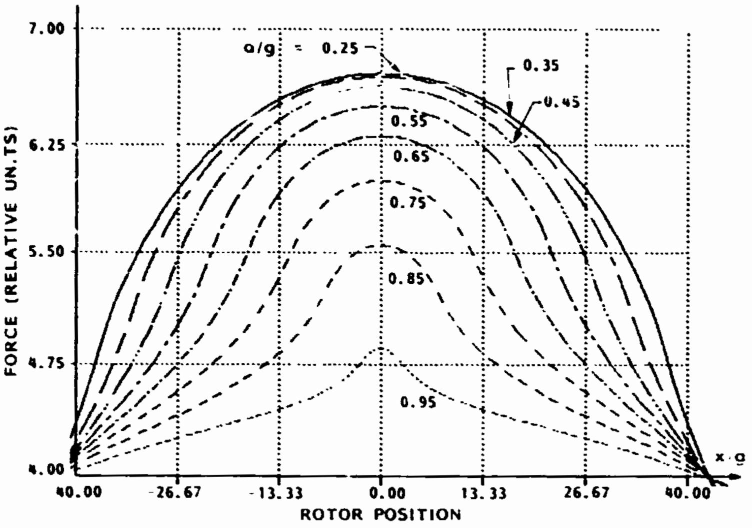

Figure 5. Rotor Forces Versus Rotor Position for Various Values of d/g

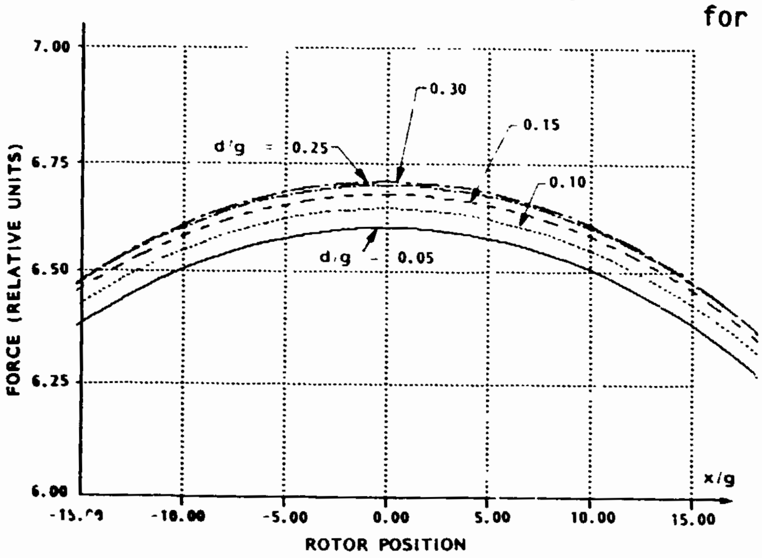

Figure 6. Rotor Force Versus Rotor Position for Various Values of d/g

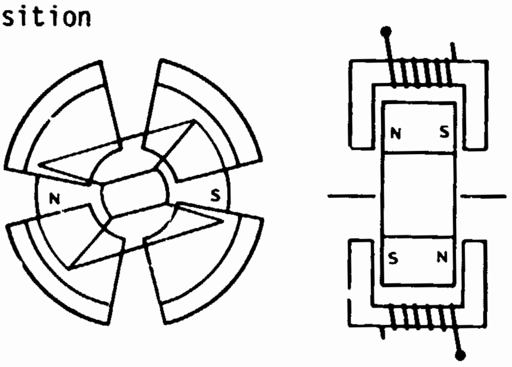

Figure 7. Lateral Magnetic Design

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Finally, the windings of the four stator pole pieces are grouped in pairs, because two opposite pole pieces (with respect to the rotor axis) are always of opposite magnetic polarity. Therefore, only two control inputs to the actuator exist: the currents I_1 and I_2 in the corresponding pairs of windings (Figure 2).

3.3 Mechanical Design

The mechanical design of the prototype actuator is shown in the enlarged view of Figure 8. The stator pole pieces are mounted between two aluminum plates connected to each other by steel bolts. The rotor is attached to a stainless-steel shaft supported by BarTemp bearings mounted on the aluminum plates. Belville washers were used to center the rotor. Alnico permanent magnets are fitted in the rotor and covered with soft iron pole pieces to distribute the magnetization more uniformly. An actual view of the actuator is displayed in Figure 9.

4. ETALON CONTROL SYSTEM CONCEPT

4.1 Control System Overview

The CLAES etalon position control system operates by sensing the angular orientation of the etalon assembly, comparing the measured orientation with the desired etalon angle, and applying a control torque to the assembly to drive the resudial error to zero. In addition, rate information is used to damp oscillations and to provide a quick transient response.

The control system has been mechanized in a hybrid configuration with a microprocessor used for generating commands with discrete logic to determine error signals, control phasing, and mode switching and with analog circuitry to provide feedback compensation.

Figure 10 is a schematic diagram of the control system. The etalon angular position (sensed by the resolver) and its angular rate (sensed by the tachometer) are the prime inputs to the control system. The error signal is constructed by comparing the actual and commanded position. The feedback loops include integral, proportional, and rate terms; the actuator produces a torque T_c such that:

$$T_c = K_P (\theta - \theta_c) - K_I \int (\theta - \theta_c) - K_R \dot{\theta} \qquad (1)$$

The integral control loop counteracts the effects of mass imbalance, bearing friction, magnetic cogging, and other phenomena that would introduce a static position error.

This control law is activated in each of the four quadrants, and the commanded angle Θ_c can be either 0°, 90°, 180°, or 270° with a range of ±15° about those values. For a given magnetization or current into the windings, the torque obtained is a function of the angle Θ and can be approximated by:

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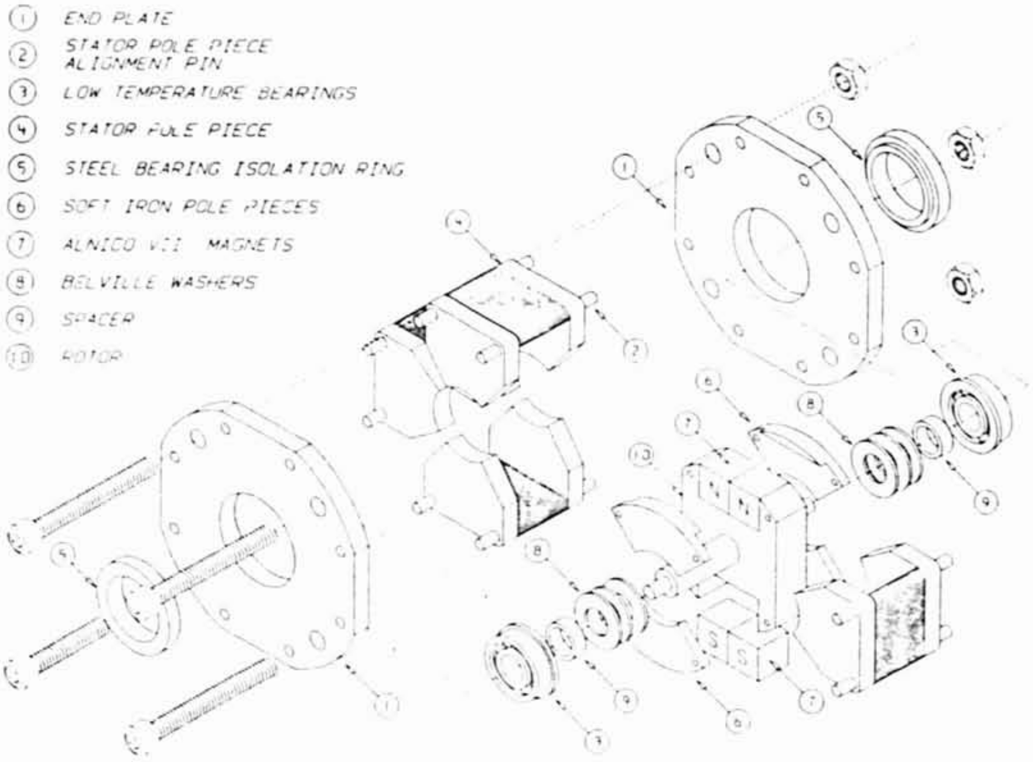

Figure 8. CLAES Etalon Motor Mechanical Design

Figure 9. CLAES Motor View

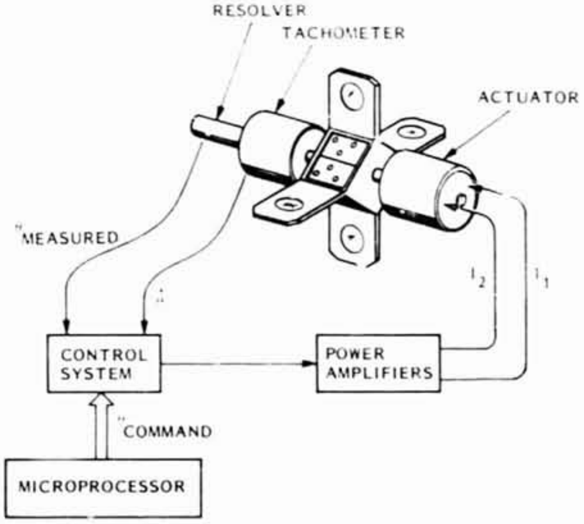

Figure 10. Etalon Control System Schematic

$$T_a = K_a [(I_1 - I_2) \cos \theta + (I_1 + I_2) \sin \theta] \qquad (2)$$

where K_a is a constant.

In the control mode defined by Equation 1, I_1 and I_2 are made equal or opposite, depending on the quadrant in which the system is operating. Although the rotor can be commanded to go to the next (or previous) quadrant by setting I_1 and I_2 to the proper value, once a 90° rotation has been obtained, the torque goes to zero and it becomes necessary to switch the signs of I_1 and I_2 to ensure the correct control law. Therefore control of the actuator is handled by three separate control systems:

- A proporational control compensation systen described by Equation (1)
- A slew controller providing commands for changing quadrants
- A switching logic controller to set the proper winding connections

4.2 Tachometer Concept

To implement the rate feedback loop described previously, an angular rate sensor is desirable. With a conventional tachometer, the rate signals will have to be switched according to the operating quadrant to ensure the proper sign. The use of conventional tachometers presents the same inconvenience as found in conventional motors, (i.e., moving electrical contacts). In the present case, however, an elegant solution is available by using a tachometer design identical to that of the actuator. Because of the reversibility principle, when the actuator is forced to rotate, currents are created in the windings proportional to the angular rate in such a manner that they create forces opposed to the motion (i.e., the usual back emf effect). Thus rate feedback can be achieved automatically by simply connecting the tachometer windings to the corresponding actuator windings (through electronic compensation and power amplifiers). In this case switching is not necessary because the feedback polarity is always correct. This feature simplifies the electronics and also increases the reliability of the system. Some alignment is required, of course, between tachometer and motor pole pieces, but does not need to be very accurate. For simplicity and cost reduction purposes, two prototype actuators were built, one used as the motor and the other as the tachometer. In a final design the tachometer would be made much smaller.

A schematic of the etalon assembly is shown in Figure 11, including the motor, the wheel, the tachometer, and the resolver.

5. CONTROL LOGIC

The control requirements for the etalon servo can be divided into two catagories: slewing and fine control. The slewing mode is used to rotate the etalon assembly rapidly between the four individual etalon elements with a typical slew maneuver requiring a 90° rotation in less than 1 s. Occasionally it may be necessary to make 180° rotations. Fine control of the etalon assembly provides precise positioning of an etalon in the incoming

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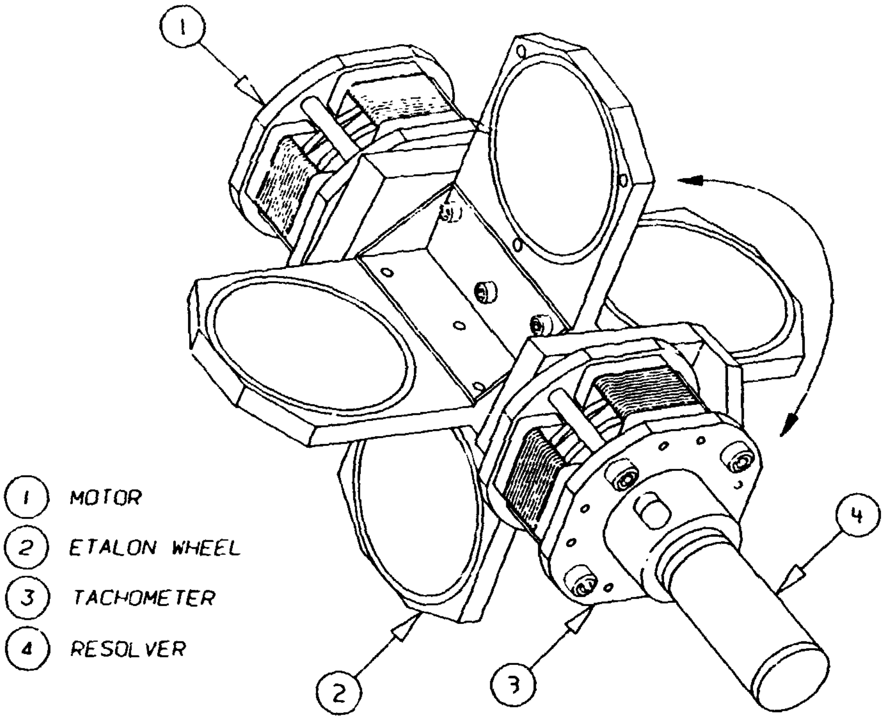

Figure 11. Etalon Wheel Assembly

beam and is also used to make incremental angular position changes as the spectrum is scanned by the focal plane. The etalon is held stationary during a measurement sequence, then rotated by approximately 0.088° so that a new measurement can be made. In addition, the fine control mode is used to rapidly scan the etalon or make large angle changes for repeating a measurement sequence.

The design of the control logic for these two functions is complicated by the way in which the actuator operates for fine control and for slewing. The slewing mode uses the effect of a rotating magnetic field vector to force the rotor to reorient itself in much the same way a synchronous motor operates. During fine control a different control strategy is employed primarily because low-power dissipation is critical. Control torque is generated by a combination of attractive and repulsive forces which are proportional to the magnitude of the error signal. Thus in the fine control mode, force (and current) is not applied unless there is a position error to correct.

Figures 3a, 3c, 3d, and 3f illustrate the change in polarity of the stator pole pieces for a slew of 90°. It is important to note that the rotor aligns itself between two poles, each having identical polarity. The strong force obtained by applying the maximum current to both sets of coils is the reason that the slew mode has the characteristic "snap" motion in which the rotor experiences a rapid acceleration followed by an equally rapid deceleration. Figure 12 shows the switching logic that translates the desired

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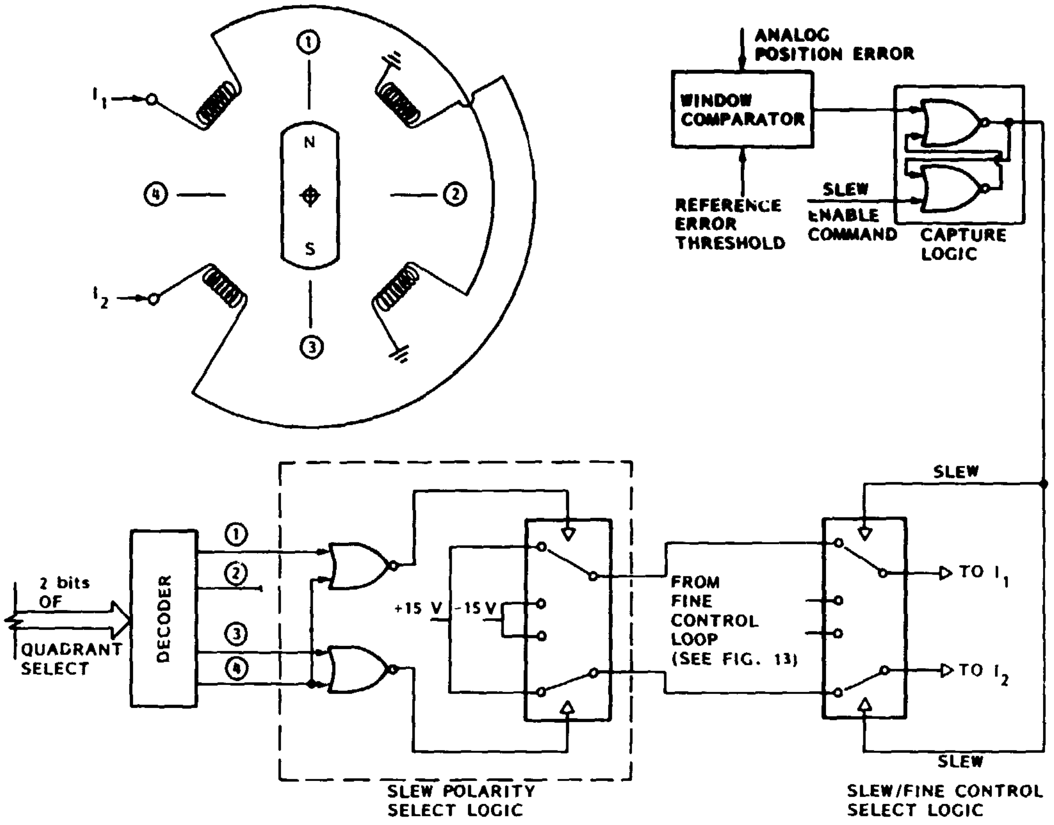

Figure 12. Slew Logic

orientation of the rotor into the correct magnetic polarity for each of the pole pieces. This figure also depicts the logic that senses the completion of a slew maneuver and switches the system to the fine control mode. This logic resets the slew mode so that the system cannot execute another slew unless the microprocessor reenables the slew logic. This feature is important because the threshold detector which senses the completion of a slew maneuver operates by comparing the desired angle with the measured etalon position. If the position error should inadvertently exceed this threshold when the system is in fine control, the slew mode would be reinitiated if the slew logic had not been previously disabled.

A typical magnetic polarity orientation for the stator poles when the system is in the fine control mode is seen in Figures 3b and 3e. The force-generating mechanism is now attractive-repulsive as compared with the slew mode in which it is attractive only. Although it would be possible to operate the fine control mode in the same manner as the slew mode, it would require that a magnetic field be available continuously for the control system to "steer" so that the rotor would be positioned. In the attractive-repulsive scheme, the magnetic field is activated only in proportion to the magnitude (and polarity) of the angular error. If the system is operating exactly

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on the desired angular orientation or very close to it, almost no magnetic field is required from the stators. This, of course, means that the power dissipation in the system is kept at a very low level, an important requirement in cryogenic applications.

The use of an attractive-repulsive technique demands that two polarities of control signal be available so that one set of stator coils can generate the attractive component and the other set the repulsive component of the control force. In addition, as the rotor changes quadrants, it is necessary to change the polarities of the control signals to the stators so that the correct overall control system polarity is maintained. The switching logic to command the control signal polarity change is shown in Figure 13. This logic, which is a function of the rotor orientation (i.e., which quadrant the rotor is in), is the electronic equivalent of the mechanical commutator in a dc servo motor. The advantage in the present application is the lack of mechanical parts which are sensitive to both the temperature and vacuum environment, therby eliminating potential reliability problems.

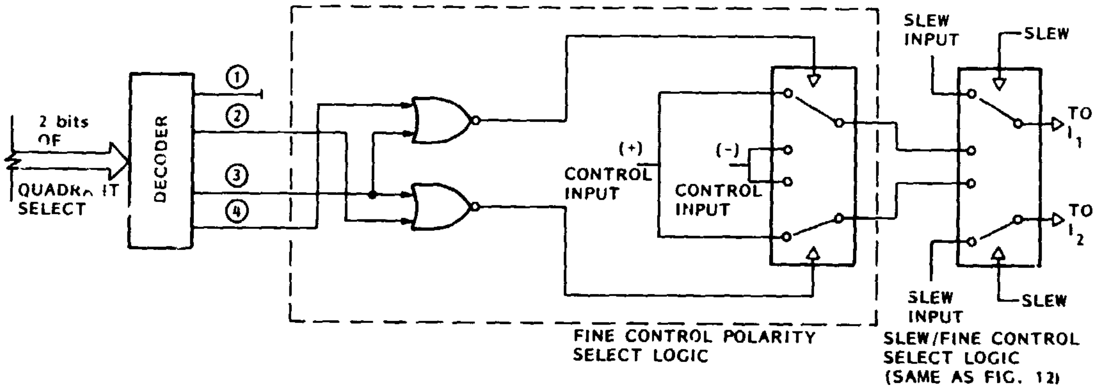

Figure 13. Fine Control Logic

6. CONTROL SYSTEM IMPLEMENTATION

To make best use of the components that were already part of the overall CLAES system design or were known to be reliable for operation at cryogenic temperatures, the etalon control system was designed to use both analog and digital components. For example, the control of other components in the CLAES optical train and the data-taking sequence is provided by a system microprocessor. It was only natural then, to include command generation of the etalon assembly as part of the system microprocessor function. In addition, as discussed in some detail in the previous section, mode switching, control signal polarity, and slew logic are controlled by discrete digital components. The simplest way to implement the control loops, however, was to use analog techniques rather than add another microprocessor and to develop the specialized software required for a digital control loop.

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An example of the application of hybrid techniques in the control system design is the use of a 400-Hz resolver to measure the etalon assembly orientation. The output of the resolver is actually converted to 16 bits of digital data and combined with the commanded angle that was generated by the microprocessor to provide a 16-bit angular position error signal. The conversion of analog data into digital data was done because (1) the commanded angle was a digital word, (2) the ready availability of extremely accurate, high performance resolver-to-digital converters that eliminate the need to design and build resolver electronics, and (3) the improvement in performance gained using digital subtraction to generate the error angle rather than analog subtraction.

Figure 14 illustrates the details of the control system mechanization. After the position error has been converted to an analog signal, it is integrated to provide the integral control signal. The position and integral signals are summed with both a positive and negative polarity so that both polarities will be available to drive the actuator.

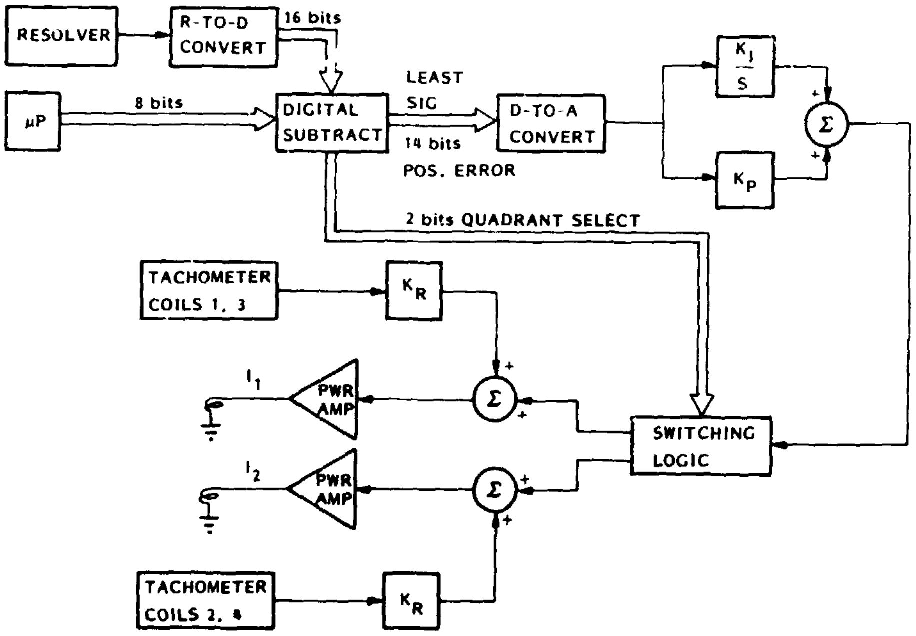

Figure 14. Etalon Control System Mechanization

An interesting feature of the mechanization is the use of polarity switching logic for the position and integral feedback loops but not for the rate (tachometer) loop. This feature is shown in Figure 14 in the summation of the rate signal with the integral plus position error signals which occurs after the polarity switch. The rate signal bypasses the switching logic because the tachometer is electrically identical to the actuator (i.e., the tachometer output changes polarity in exactly the right way to match the requirements of the motor input signal). Because the resolver does not have this polarity

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reversal mechanism inherent in its electrical configuration, the position control signals require the special polarity control as described in detail in the previous section.

The motor drive electronics are also shown in Figure 14. The output power amplifiers are of the current-feedback type, which means that they generate an output current proportional to the input signal. Because the control torque developed by the actuator is directly proportional to the current in the coils, it is important to use a current amplifier rather than a voltage amplifier in this application. In the past, this type of mechanization required discrete components; however, advancements in integrated circuit design now permit the use of what is essentially a single chip power op-amp with a current feedback loop to provide the desired function.

The entire set of interface and control electronics fits on two small circuit boards (see Figure 15). One board houses the data latches, address decoders, and R-to-D and A-to-D converters. The other board contains all of the analog control circuitry and switching logic. The power amplifiers are mounted separately because it was initially felt that their higher operating temperatures and cooling requirements would preclude use in proximity to the low-power components. The system runs at such a low average power level (as discussed in the next section), however, that the separation of the output devices proved to be unnecessary.

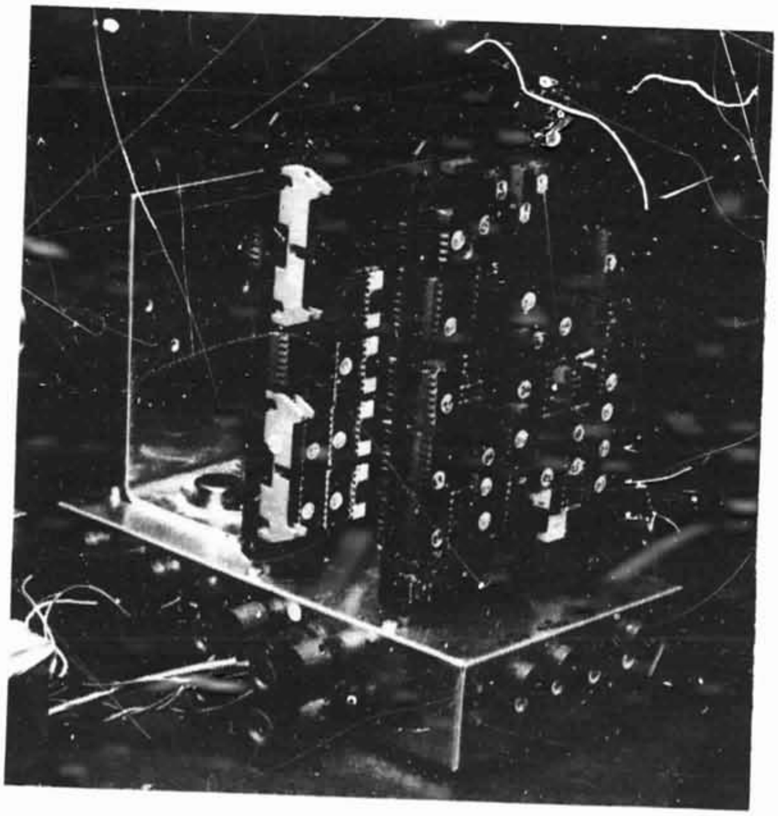

Figure 15. Control System Electronics

Power for the electronics is provided by ±15 and 5 Vdc power supplies. In addition, the R-to-D converter requires a 400-Hz signal at 6-Vrms to power the resolver and generate the reference signals within the R-to-D converter. None of the power supply voltages or frequencies (in the case of the 400-Hz signal) are critical, and the system can tolerate 15-percent deviations from the nominal and still function properly.

7. CRYO-VAC PERFORMANCE TESTING

An essential part of the development process for a system like the CLAES etalon position servo is performance testing. In particular, because the environmental conditions are so severe, at least some portion of the performance testing must be done in conditions that simulate actual operation as closely as possible. Because testing in a cryogenically-cooled vacuum chamber is expensive and time consuming, a great deal of preliminary testing and system tuning is accomplished at room temperature in the laboratory. The results presented in this section are a combination of data obtained from both room temperature and cryo-vac tests.

There were two primary objectives to the performance testing; (1) to determine the validity of the control concept and (2) to evaluate the performance of the system in cryo-vac conditions. The room temperature tests were especially important because of the novelty of the hybrid control electronics and the actuator itself. Potential problems associated with cryo-vac operation including bearing stiction, mechanical interference caused by thermal contraction and gradiants, and changes in the actuator magnetic properties.

7.1 Control System Tests

These tests were conducted in the laboratory at room temperature and consisted of measurements of step response for small angle increments, time required for 90° slews, and position repeatability and accuracy. Because digital subtraction is used to generate the position error signal, only the position error is available from the control electronics. The absolute position was measured independently by an optical system consisting in a laser beam reflected by a small mirror mounted on the etalon wheel onto a linear photodetector. These tests were useful to tune the control system gains and adjust the slew mode switching threshold.

Figures 16 and 17 show a typical angle increment-decrement sequence in which the etalon is commanded to move 21.1 and 5.27 arc-min, respectively. The transition time for the 21.1 arc min-step was 80 ms and only 20 ms for the 5.27 arc-min step. The latter result betters the CLAES requirement for the etalon assembly to execute this maneuver in less than 25 ms. Quantized motion caused by limit cycling on the resolver's fourteenth and fifteenth bit is apparent in Figure 17.

Slew response was measured by monitoring the position error signal, because there was no convenient means of directly measuring large angles. Mode switching threshold and rate feedback gain were critical for achieving the required performance.

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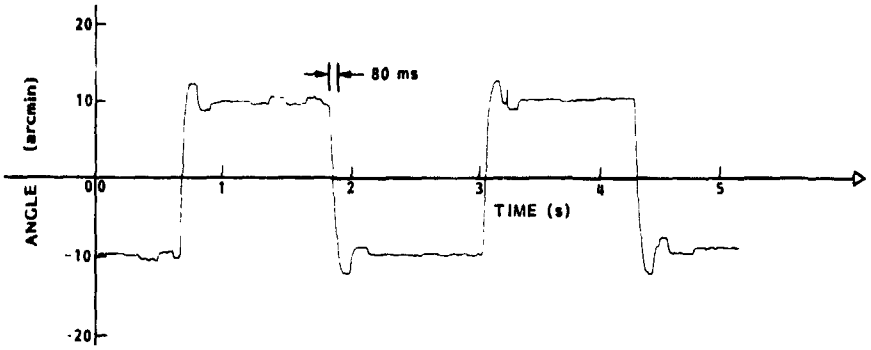

Figure 16. 21.1 arc-min Increment Decrement Sequence at 23°C

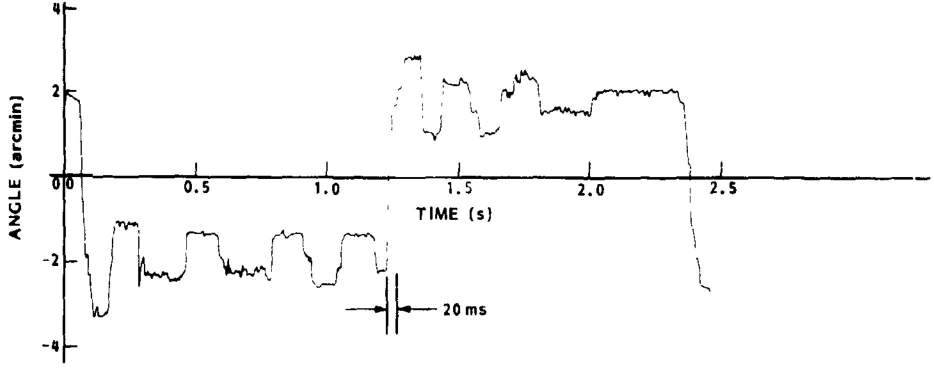

Figure 17. 5.27 arc-min Increment Decrement Sequence at 23°C

7.2 Cryogenic Testing

Cryogenic tests were conducted in a vacuum chamber with liquid nitrogen cooled walls. An overall view of the etalon test assembly can be seen in the photograph of Figure 18. Also seen in the photograph are details of electrical and cryogenic feedthroughs, the liquid nitrogen cooling shroud, and the cold plate to which the system is mounted. Additional cooling was obtained using a gaseous helium refrigerator to bring the temperature of a "cold finger" to about 10K. The close up photograph of Figure 19 shows several insulated copper braids attached to various parts of the system to ensure proper cooling. The entire etalon assembly is insulated from the mounting plate by ceramic standoffs to maintain the low temperature produced by the cold finger. The local temperatures were monitored using special low-temperature platinum resistance thermometers. A glass window allowed some direct viewing of the wheel assembly, making it possible to perform optical measurements using the etalon filters themselves.

The few problems that were encountered during the preliminary tests were principally mechanical in nature. The first attempts to operate at low temperature failed when the rotor assembly stopped responding to commands. Application of maximum current in the motor windings was unable to free the system. Upon disassembly, it was discovered that the bearing races were brinelled. A subsequent analysis indicated that a substantial differential thermal contraction existed between the stainless-steel bearings and the aluminum end-plates in which they are mounted. The solution selected to

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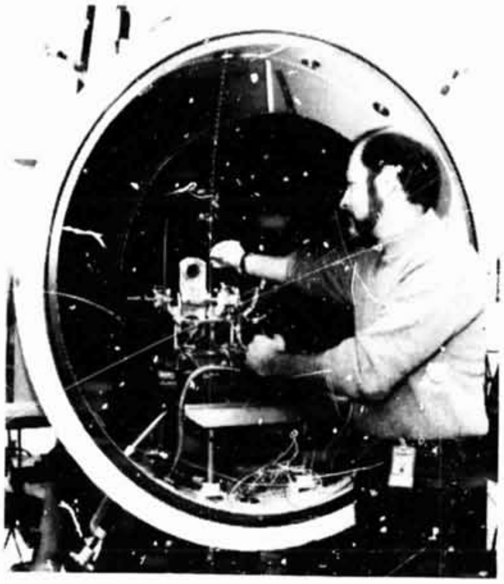

Figure 18. Cyro-Vacuum Chamber Test Assembly

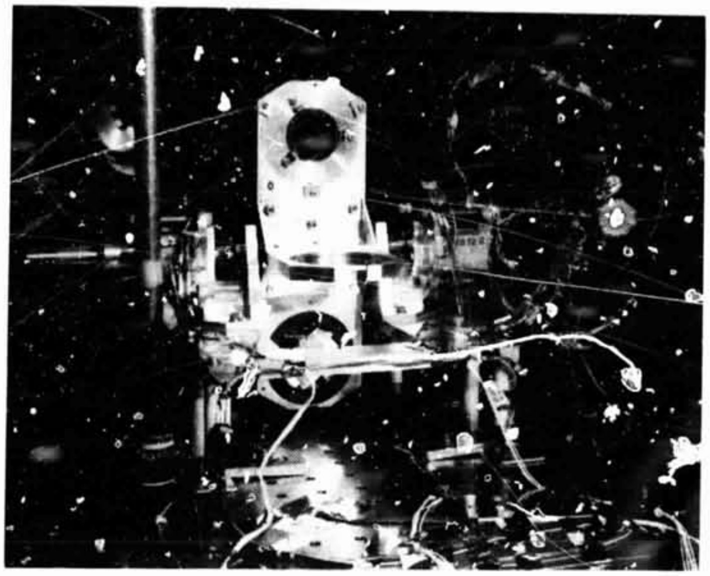

Figure 19. Etalon Wheel Cryo-Vacuum Test Assembly

alleviate this problem was to mount stainless guard rings around the bearings to prevent distortions in the relatively thin outer races.

In subsequent tests, although the bearings were no longer damaged, the motion of the etalon assembly became erratic as the temperature decreased and eventually stopped completely. Two possible explanations were offered: a deterioration in the strength of the permanent magnets with an associated loss of torque output or, more likely, some other source of temperature dependent bearing friction. Magnetic tests were then conducted and new magnets compared with magnets that had been used previously. In various tests these magnets had been subjected not only to thermal cycling, but to large demagnetizing fields as well. No significant difference was noted. The core material of the stator pole pieces was tested independently at 10 K and showed the expected slight increase in hysteresis and saturation magnetization.

It was found that the combination of the static preload on the Belville washers and their axial compression due to the thermal contraction of the stator pole pieces caused an increase in the axial bearing loads of approximately 20 N per bearing. This resulted in excessive friction torques which the actuator was unable to overcome. A reconfiguration of the washers to remove the room temperature preload solved the problem as long as the actuator was tested alone. Finally, it was determined that distortions in the support structure were causing enough misalignment at cryogenic temperatures to inhibit smooth operation throughout a full 360°. Removing the hard mechanical mounting to the support plate eliminated warping of the etalon assembly.

Subsequent tests were successful for demonstrating full operational capability at 17K. Figures 20 and 21 show the system performing the same angle increment-decrement test as seeen in Figures 16 and 17. Although some minor changes in control system gains were required to retune the system for cryogenic operation, the performance is essentially identical to that at room temperature. Performance during slew maneuvers is shown in Figures 22 and 23. In Figure 22, the current pulses to one of the stator pairs is shown during four slews comprising a full 360° rotation. The very low current required to control the etalon assembly between the slews is apparent. This control current, measured at less than 60 mA per stator pair, translates into a steady state power dissipation of 274 μW (each stator pair has a measured resistance at 17K of 0.038 ohms), which is substantially less than the 1- to 5-mW requirement.

Figure 23 is an expanded view of one of the current pulses that occur during a slew. The current saturates at the drive amplifier limit of 2.3A. The entire maneuver is completed in less than 600 ms, which is comfortably within the 1 s per 90°-slew requirement.

A preliminary reliability test of the system has been completed in which the system was operated continuously in a scan and slew mode for 48 h at 18 K. While this is not as rigorous a test as eventually will be necessary to demonstrate flight qualification, it is an excellent indication that the present design has the potential to operate reliably in a cryo-vac environment for extended periods of time.

8. CONCLUSIONS

This paper has described the development and testing of a control system designed to precisely position etalons in the optical path of a cryogenic spectrometer. One feature of the system which is unique is the etalon assembly actuator, which combines the characteristics of both a stepper motor and a torquer. The successful operation of this system in cryo-vac conditions has been demonstrated for periods of up to 48 h at temperatures below 20K. The system has met or exceeded requirements for position accuracy, slew rate, power dissipation, and operational flexibility. Although the current configuration is not appropriate for flight hardware, it is not anticipated that major changes will be required to develop an acceptable design for the actual flight instrument.

REFERENCES

1 Roche, A. E., et al., "Performance Analysis for the Cryogenic Etalon Spectrometer on the Upper Atmospheric Research Satellite," paper presented at SPIE Conference on Technologies of Cryogenically Cooled Sensors and Fourier Transform Spectrometers, San Diego, California, August 1982, pp. 26 to 27.

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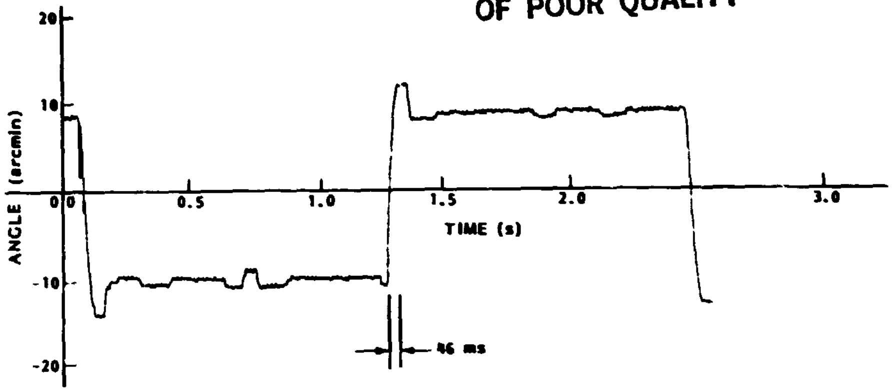

Figure 20. 21.1 arc-min Increment Decrement Sequence at 17 K

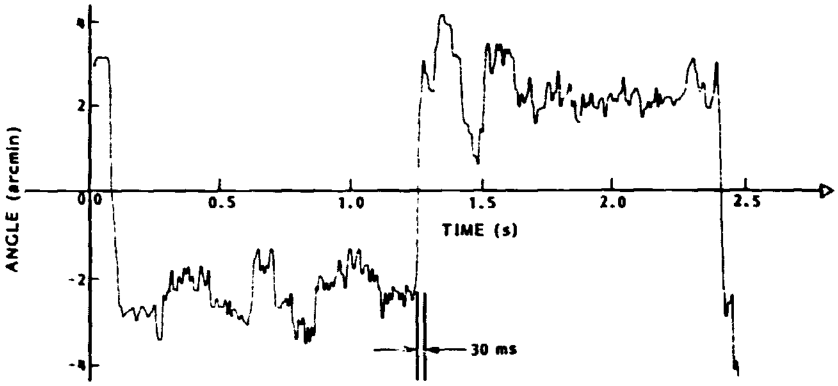

Figure 21. 5.27 arc-min Increment Decrement Sequence at 17 K

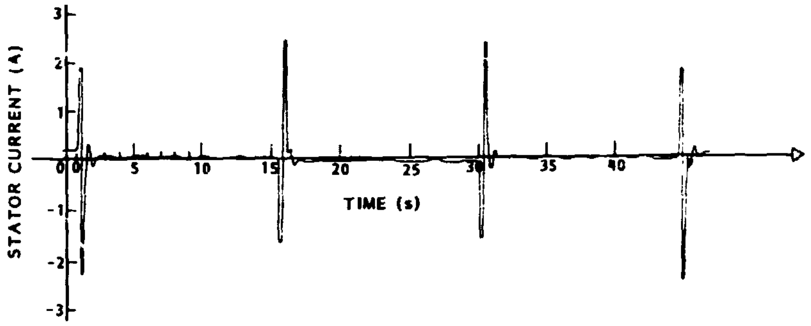

Figure 22. F. 90° Slews at 16 K

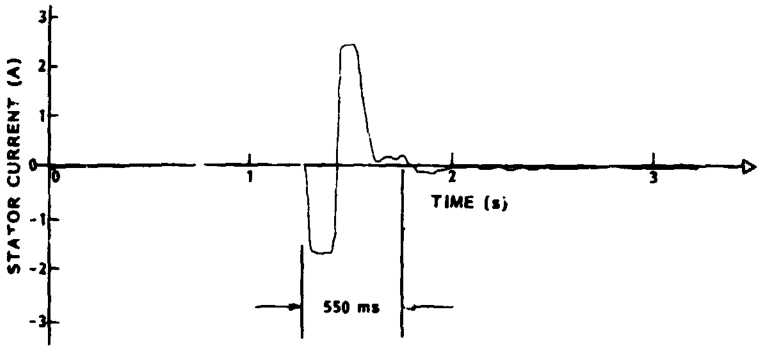

Figure 23. 90° Slew at 16 K

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[2] Naes, L. G., et al., "Two-Year Solid Hydrogen Cooler for the CLAES Instrument," paper presented at SPIE Conference Technologies of Cryogenically Cooled Sensors and Fourier Transform Spectrometers, San Diego, California, August 1982, pp. 26 to 27.