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DEVELOPMENT OF IN-SITU TEST PROCEDURES FOR TMI-2 AXIAL-POWER-SHAPING ROD-DRIVE MECHANISMS

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ABSTRACT

General Public Utilities Nuclear Corporation (GPUNC), Babcock & Wilcox (B&W), and EG&G Idaho participated jointly in tests at Diamond Power Specialty Corporation, Lancaster, Ohio, to develop an in-situ dynamic test procedure for application to the TMI-2 Axial Power Shaping Rods (APSRs). An APSR drive mechanism was set up with operating controls and instrumentation. Testing took place on an air stand installation and on an autoclave which simulated conditions of a stator in a water-filled reactor. Dynamic tests established mechanism electrical transient and acoustic signature characteristics associated with mechanism response to energizing and running in various modes. Static tests determined characteristics unrelated to actual motion. Analysis of data from the controlled experiments resulted in development of a set of baseline characteristics to be used as a reference for evaluating the condition and response of installed APSRs. A test was devised for use at TMI-2 to verify APSR operability, to drive the APSRs to their lower limits, and to acquire data for potential clues to condition of the reactor core.

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FIGURES

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INTRODUCTION

One of the initial steps in the TMI-2 Core Inspection and Recovery Program associated with reactor vessel head removal was an attempt to insert the Axial Power Shaping Rods (APSR) to their lower limit in order to uncouple the drive mechanism leadscrews from the shaping rods. Appendix A contains a detailed description of an APSR drive mechanism and its operation.

It was postulated that monitoring insertion would provide data related to the condition of the rod drive mechanisms and the reactor core. To determine if one could actuate the APSRs while monitoring the electrical parameters and acoustic patterns and ascertain if the rod assembly was damaged, General Public Utilities Nuclear Corporation (GPUNC), Babcock & Wilcox (B&W), and EG&G Idaho jointly participated in a Proof of Principles Test at Diamond Power Specialty Corporation, Lancaster, Ohio, in early March 1982.

A typical Mark B APSR, as shown in Figure 1, was set up with operating controls and instrumentation. By analyzing the data from numerous controlled conditions, a set of baseline characteristics was developed that could be used as a reference for evaluating the unknown condition and response of the TMI-2 APSRs. Testing was performed both on an air stand and on an autoclave mockup. The air stand consists of a rod drive stator and rotor assembly with a 4-ft section of exposed leadscrew. The autoclave test stand is a pressure vessel designed to mate with the motor tube and drive, so that tests may be conducted either wet or dry.

The overall objective of the Proof of Principles Test was development of an in situ dynamic test procedure for application to the TMI-2 APSRs. Specific objectives of the test were as follows:

- Familiarize personnel involved in procedure preparation with the general operating characteristics of the mechanism and its controls

- Structure acoustic instrumentation and analysis to:

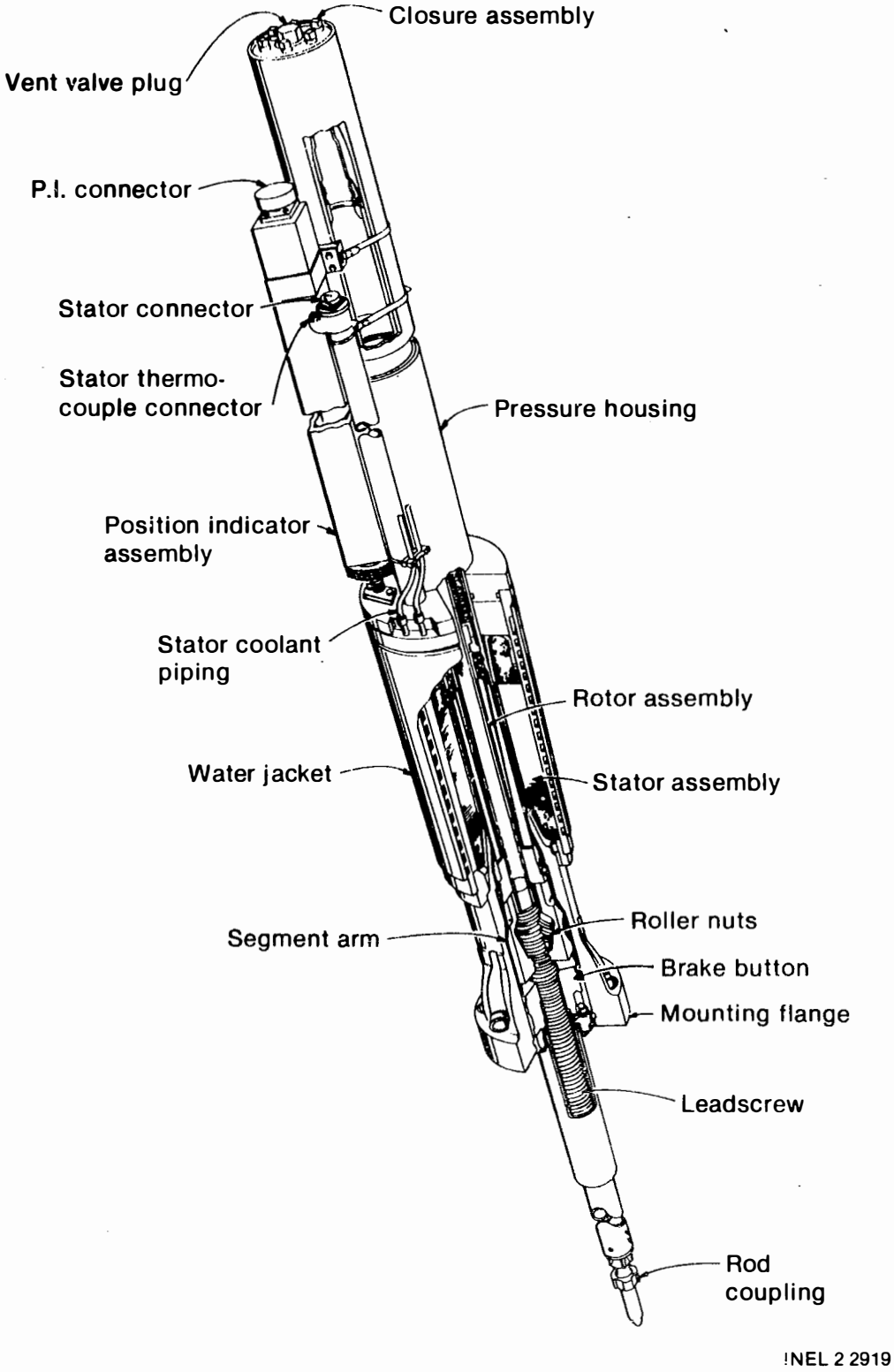

Figure 1. Axial Power shaping rod drive mechanism.

- Detect the impact associated with latching of the roller nuts, pole slip, and unlatching

- Detect the presence and magnitude of rotation prior to latch

- Distinguish between rotation of the roller nuts with and without latch

- Differentiate qualitatively and quantitatively between a loaded and unloaded leadscrew

- Evaluate sensitivity to loose parts falling in the vessel

- Determine if there is gas or water in the motor tube

- Select optimum sensor locations to use when performing the work at TMI

o Determine electrical signatures for rotor latch, movement, and pole slip

o Determine the force exerted by the leadscrew mechanism as a function of driving current and speed

o Determine if absence of shaping rods could be ascertained from the drive mechanism's electrical parameters

o Determine motor heating rate if without coolant

o Predict rotor position so that initial energizing would match that position and not cause leadscrew motion.

Instrumentation for measuring and continuous recording in real time was provided for stator voltage and current, acoustic response, developed force, and mechanism temperatures. Static measurements were made of stator winding resistance, and inductance under certain conditions. Visual observations provided verification of type and degree of movement (see Appendix B, Diamond Power APSR Acoustic Data Report, on microfiche attached to the inside of the back cover).

TEST FACILITY

The tests were conducted at the B&W Control Rod Drive Test Facility of Diamond Power Specialty Corporation in Lancaster, Ohio. The test specification was prepared by EG&G Idaho and reviewed by B&W. The test was conducted under B&W direction. The dynamic tests were initially performed with the APSR mounted on an open framework called an air stand where the roller nuts were visible and the leadscrew accessible for application of weights and insertion of a force-measuring instrument. The tests were repeated and refined with the APSR mounted on the Diamond Power autoclave, which is more representative of a reactor installation.

Instruments were calibrated according to the National Bureau of Standards and all instruments were within current calibration dates. A Quality Assurance representative witnessed the test. A block diagram of the control and instrumentation arrangement is shown in Figure 2.

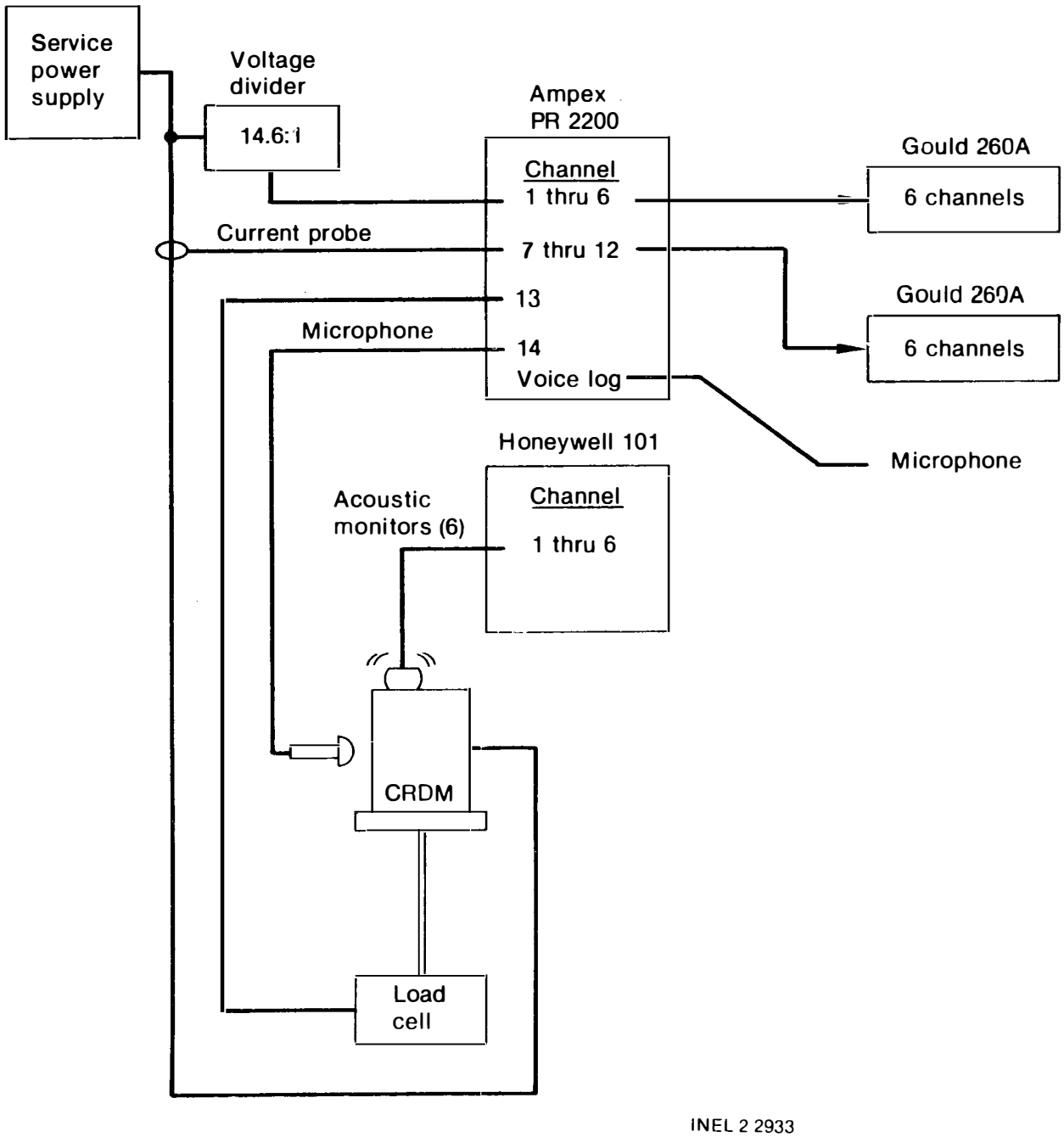

Figure 2. Block diagram of APSR control and instrumentation arrangement.

DYNAMIC TESTS

Dynamic tests were performed to establish the APSR electrical transient and acoustic signature characteristics associated with the mechanism's response to energizing the stator in various modes.

The acoustic signals for each event were amplified and reproduced in real time via a loudspeaker to familiarize the test personnel with the essential audible characteristics of that event. To provide specific characterization of each type of signature, the data were magnetically recorded and analyzed, either online or by playback of the record, by a Nicholet 660A Signal Analyzer.

The stripchart recorder used for real time visual display had an upper frequency limit of approximately 100 Hz, a limit insufficient for providing a realistic visual characterization of the acoustic events. Although an acoustic signal along with a microphone signal, was displayed during these tests, it was to serve as an event marker to call attention to the electrical data displayed rather than for providing a discernable signature for the event.

Force Generated versus Current and Speed Test

The primary purpose of the force versus current and speed test was to determine and evaluate the force exerted by the leadscrew on a fixed point as a function of the applied current and speed of rotation. A secondary purpose was acquisition of electrical transient and acoustic signatures associated with pole slip events.

This test could be performed only on the air stand. The mechanism was initially set up so that the leadscrew rested against a force cell in the down direction. For a given applied current, the speed was varied from single-step up through 100%, and the resulting force measured. A revised form of the test for single-step and jog speeds only was instrumented for force both up and down. The results of this test are shown in Figure 3.

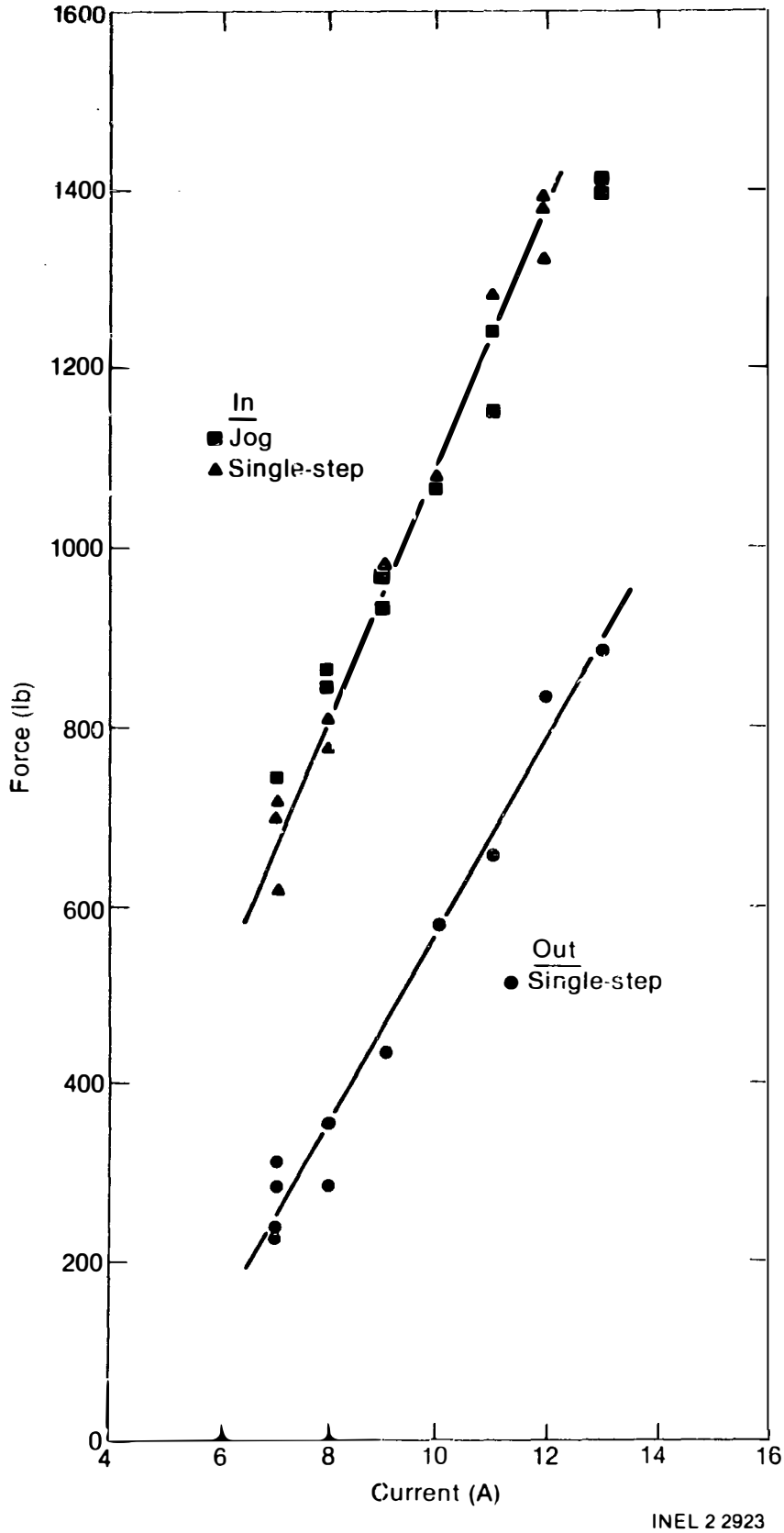

Figure 3. Leadscrew force exerted as a function of current and speed.

Weight Moved versus Current and Speed Test

The weight versus current and speed test was performed both on the air stand and in the autoclave. Figure 4 shows the air stand setup. The primary purpose of this test was to determine and evaluate the minimum current required to hold or move a load attached to the leadscrew as a function of speed and load. For a given speed and load, current was increased from an unlatched condition until latch and rotation ensued. The results are shown in Figure 5.

The secondary purpose of the test was acquisition of electrical transient and acoustic signatures associated with latch and run events. Unplanned but acquired were windmill events. Windmilling occurs when the stator field is strong enough to release the brake but not strong enough to restrain the torque induced by the downward load on the leadscrew. This phenomenon occurred only at leadscrew loads at or above 340 lb. At about 240 lb, slightly in excess of a normal APSR load, a current sufficient to achieve latch was also sufficient to hold or move the leadscrew in either direction without windmilling. It was determined that under some circumstances a windmill could be stopped by increasing the current. Figure 6 shows typical windmill signatures.

Latch and Roll

The purpose of the latch and roll test was to acquire electrical transient and acoustic signatures associated with the latch and roll event as a function of both the load and the angular misalignment of the applied field from the rotor position. Figure 7 shows the air stand installation with roller nuts and indicator for latch and roll test. The rotor was prepositioned to a B-C alignment (see Figure A-2, Appendix A) and the applied field offset in 15-degree increments up to 45 degrees. Forty-five degrees is a theoretically neutral point at which the rotor, in the absence of external inducement, would not rotate in either direction into alignment. Normally there is an externally induced bias towards counterclockwise rotation (IN movement of the leadscrew) caused by the weight of the leadscrew and attached rods, or experimental weights.

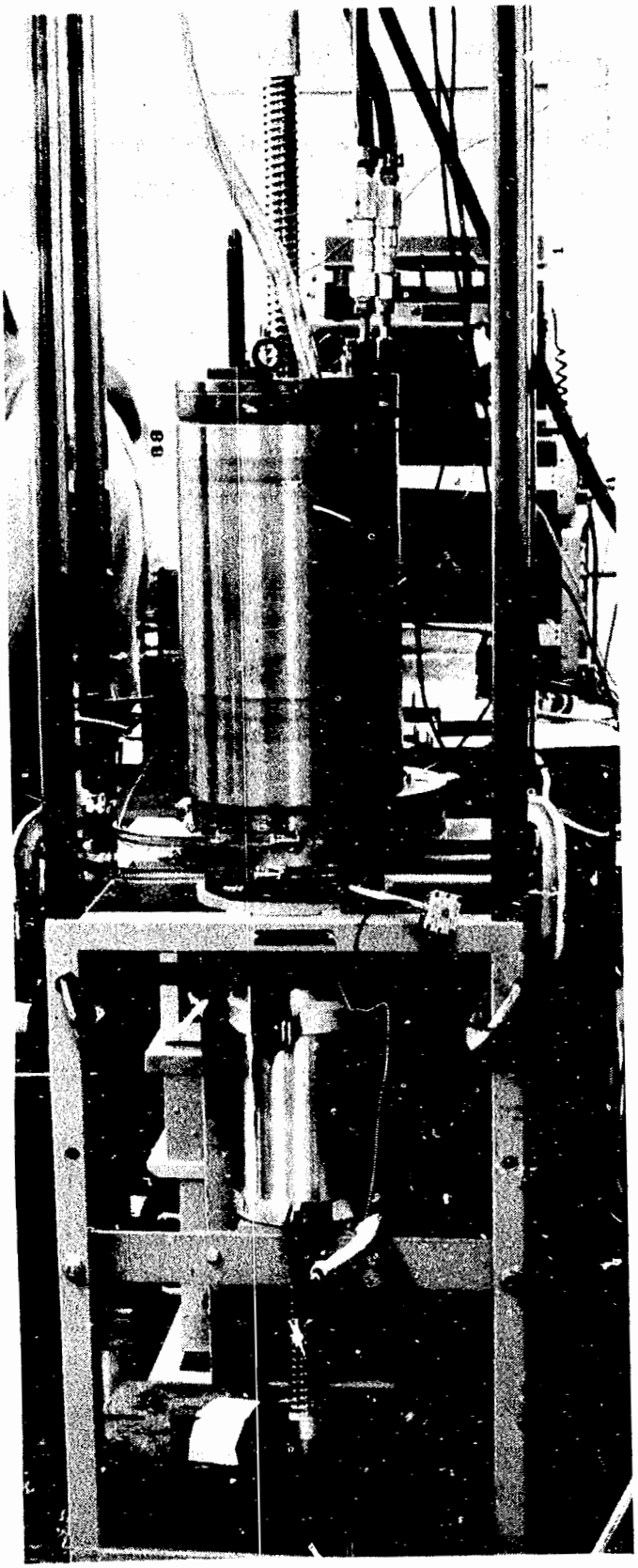

Figure 4. Air stand setup for weight versus current and speed test.

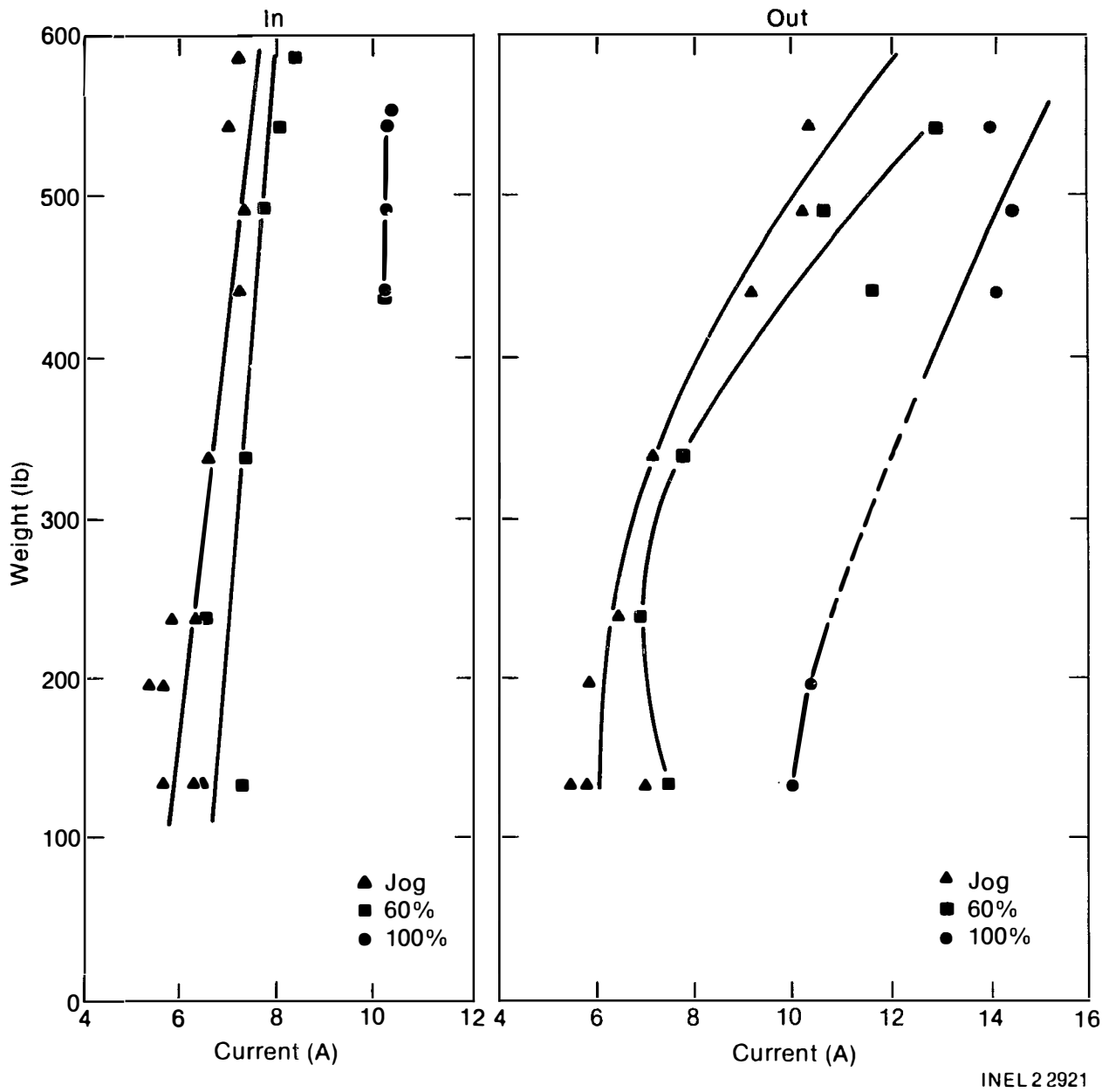

Figure 5. Current required to hold or move leadscrew as a function of speed and load.

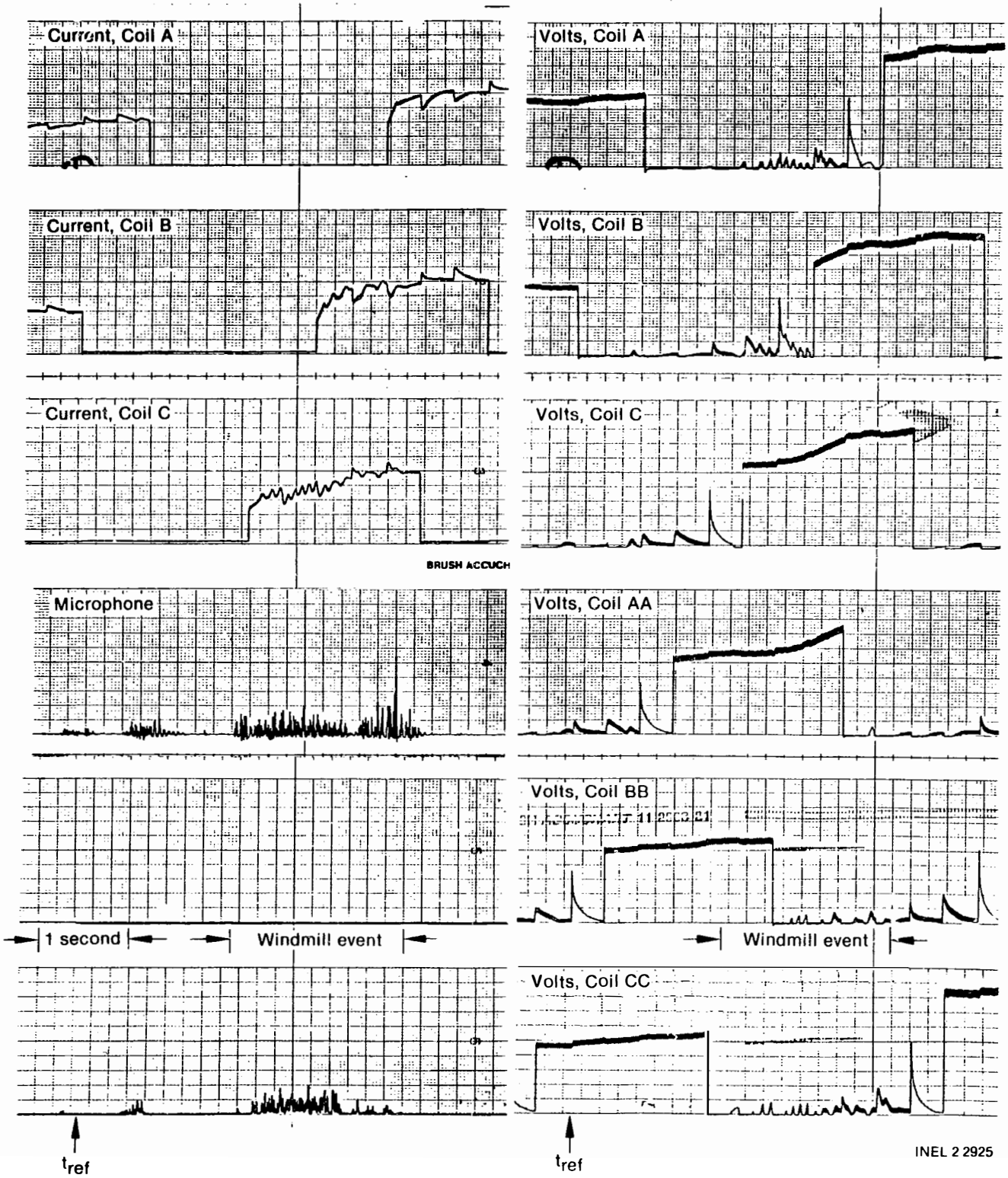

Figure 6. Typical windmill signatures.

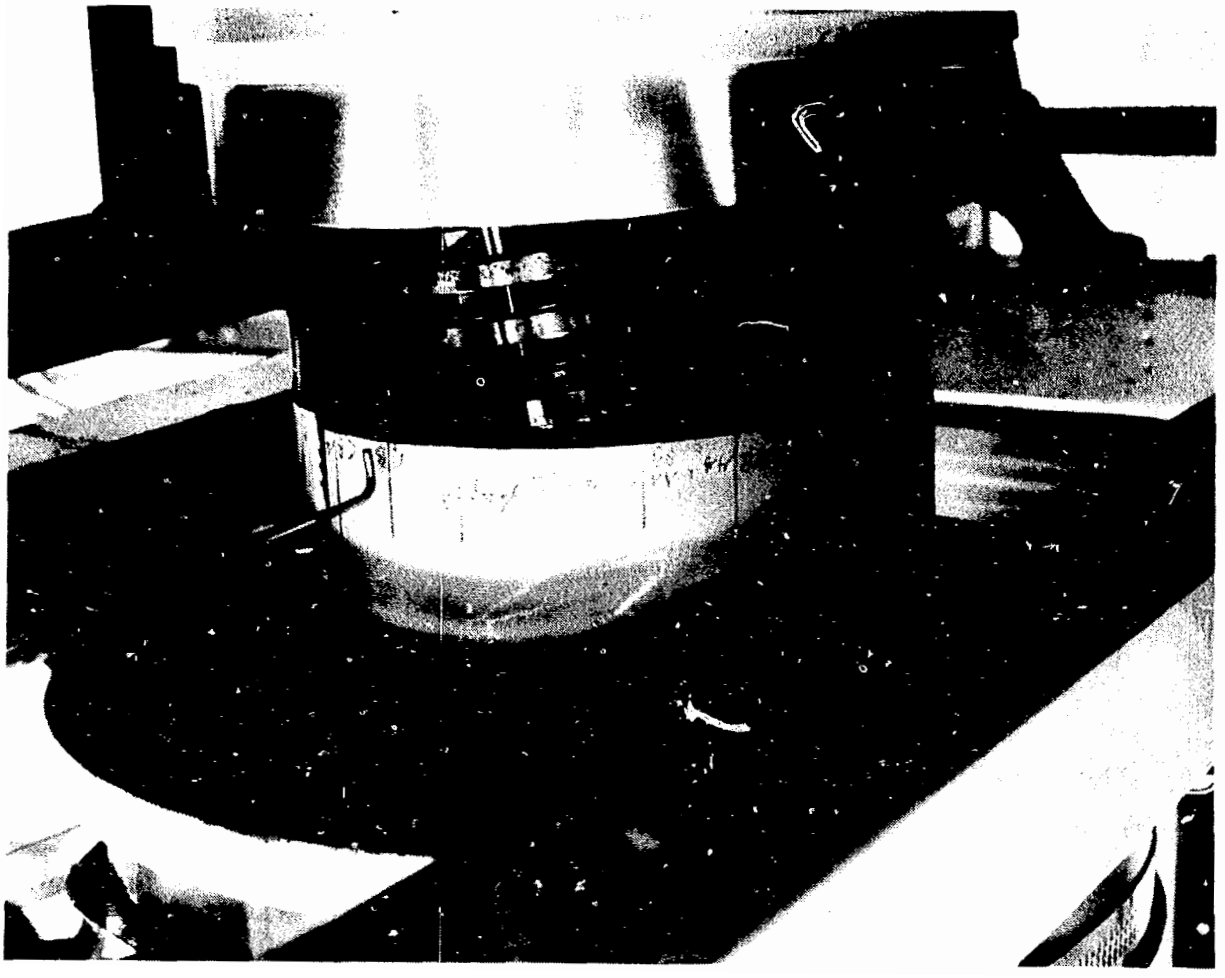

Figure 7. Air stand setup showing roller nuts with indicator for latch and rotation test.

For reference purposes, typical voltage and current patterns for jog speed without motion artifacts are presented in Figure 8. Typical latch and roll signatures are shown in Figures 9 through 12. Typical expanded acoustic analysis plots from the magnetic recordings for latch, and latch and roll signatures, are shown in Figure 13.

Pole Slip Test

The purpose of this test was to acquire electrical transients and acoustic signatures associated with pole slip. The test was conducted with the leadscrew portion in the simulated reactor environment and the mechanism housing filled with water (a normal reactor condition) and empty (a postulated TMI-2 condition). Figure 14 shows the autoclave facility. The mechanism was operated to stop against both upper and lower limits at single-step and jog speeds. Typical signatures obtained during testing are shown in Figure 15.

Run Signature Test

The purpose of the run signature test was to acquire electrical transients and acoustic signatures associated with various speeds of operation of the mechanism with the leadscrew in a simulated reactor environment and the mechanism housing filled with water, and dry. Figure 16 shows a typical signature set.

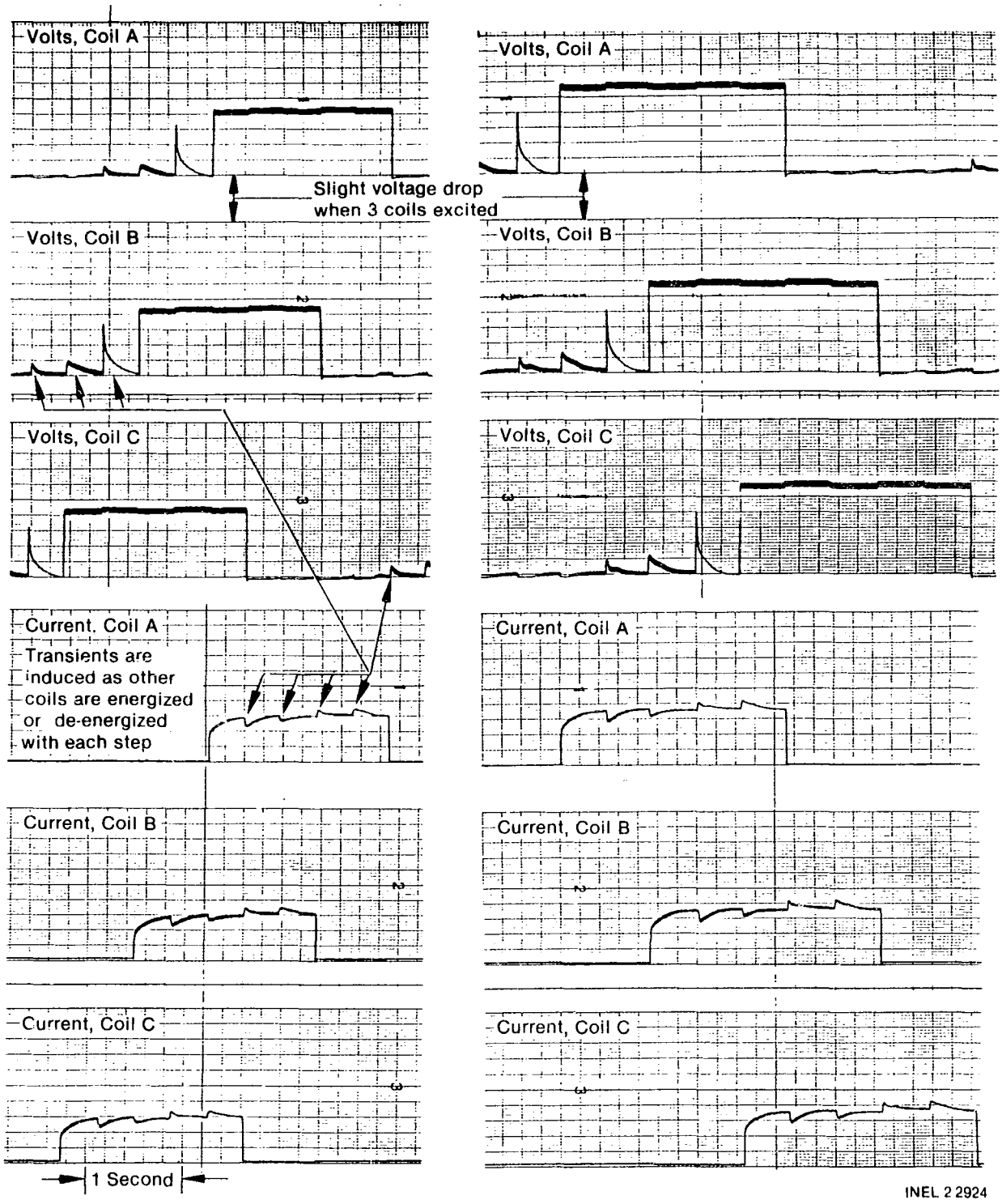

Figure 8. APSR stator voltage and current patterns at jog speed.

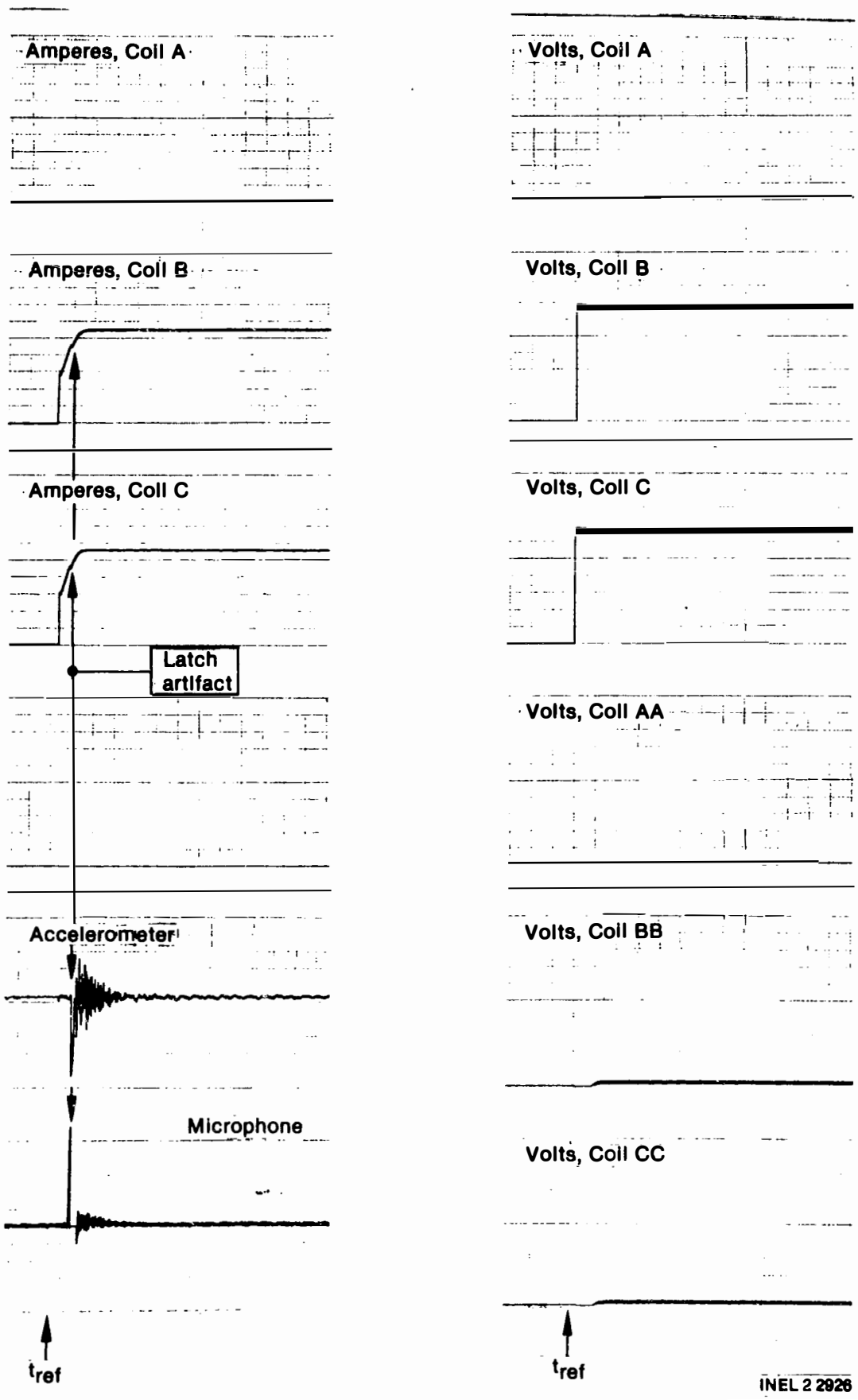

Figure 9. Latch signature at 197 lb and zero degrees misalignment.

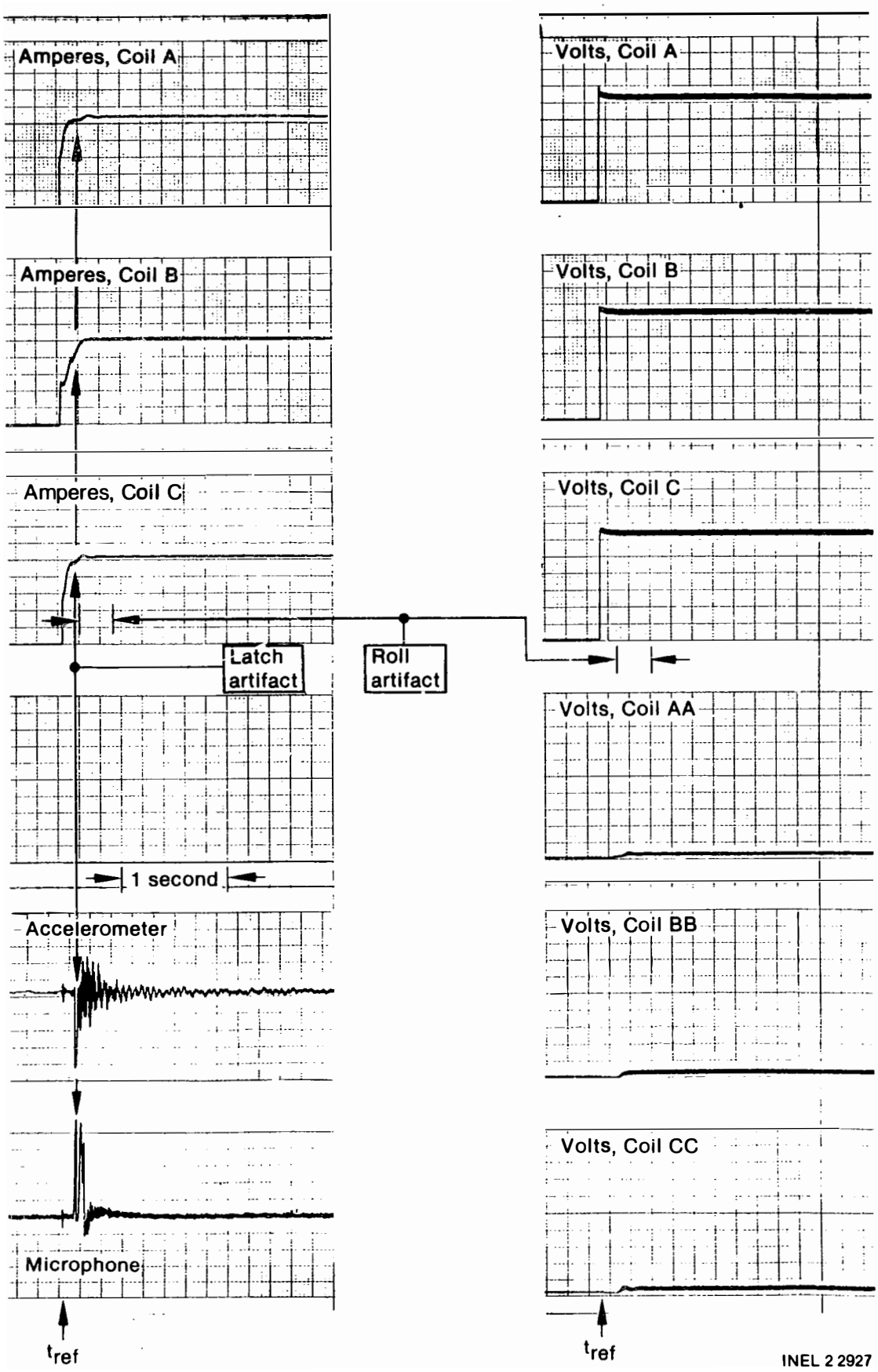

Figure 10. Latch signature at 197 lb and 15 degrees misalignment.

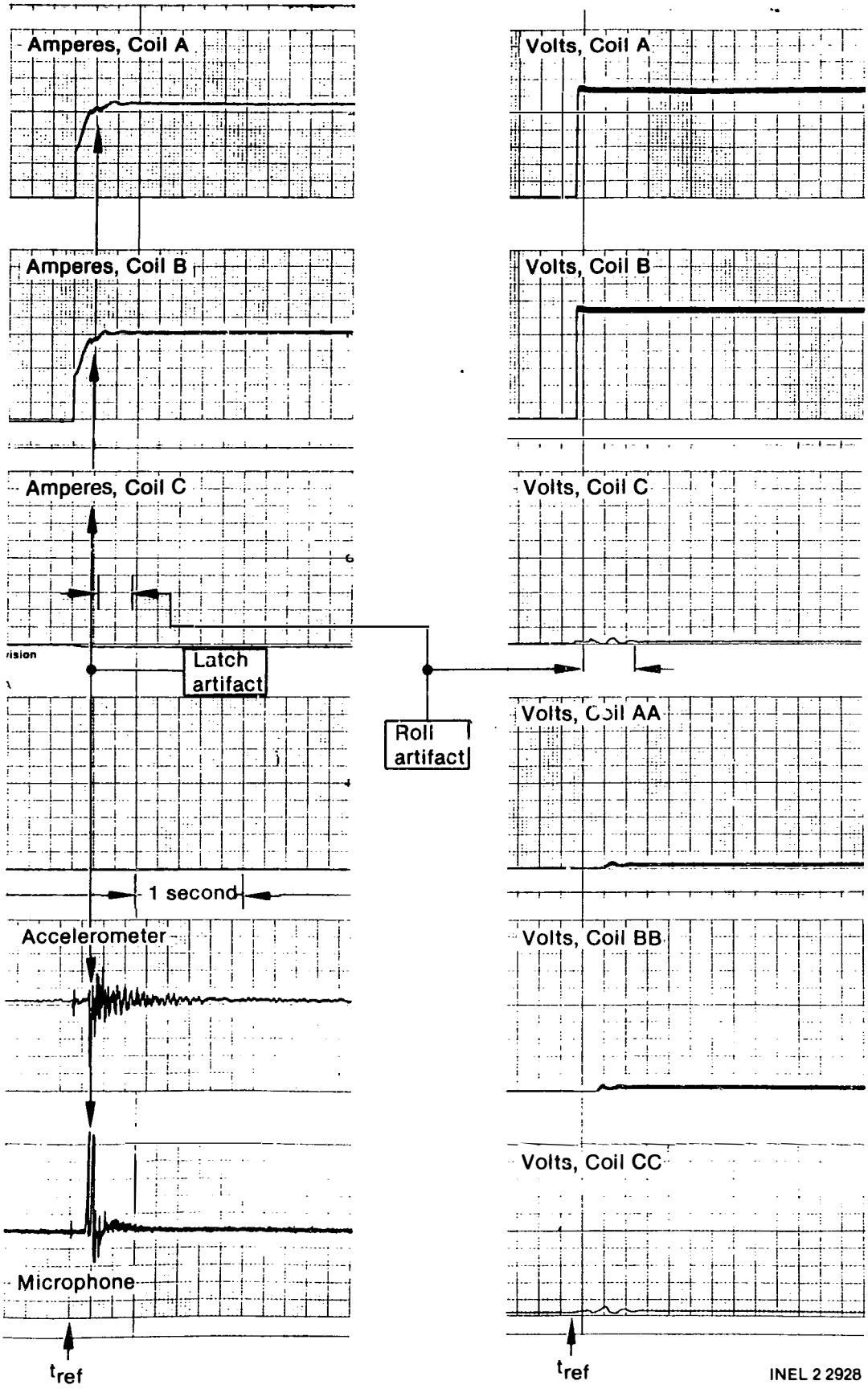

Figure 11. Latch signature at 197 lb and 30 degrees misalignment.

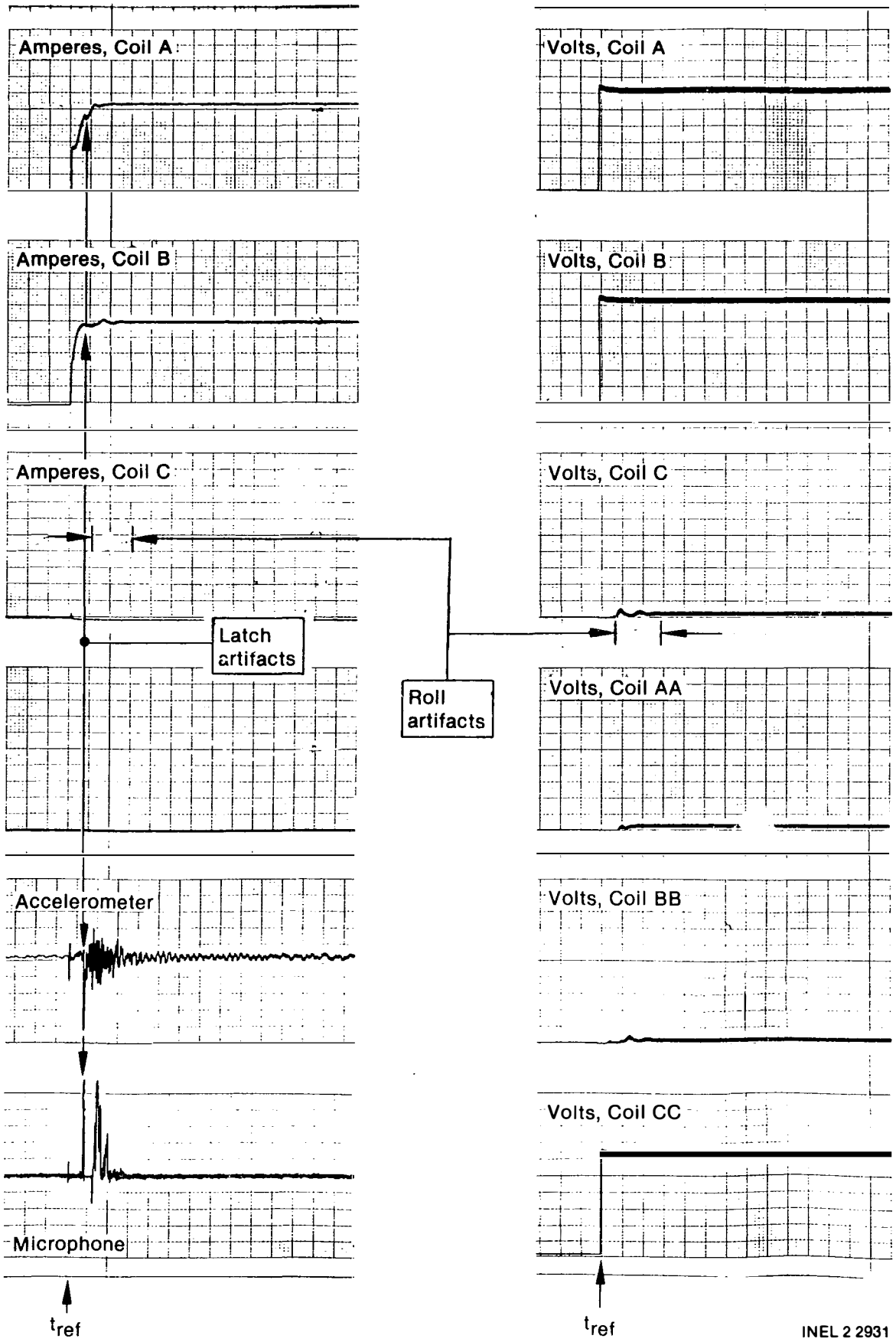

Figure 12. Latch signature at 197 lb and 45 degrees misalignment.

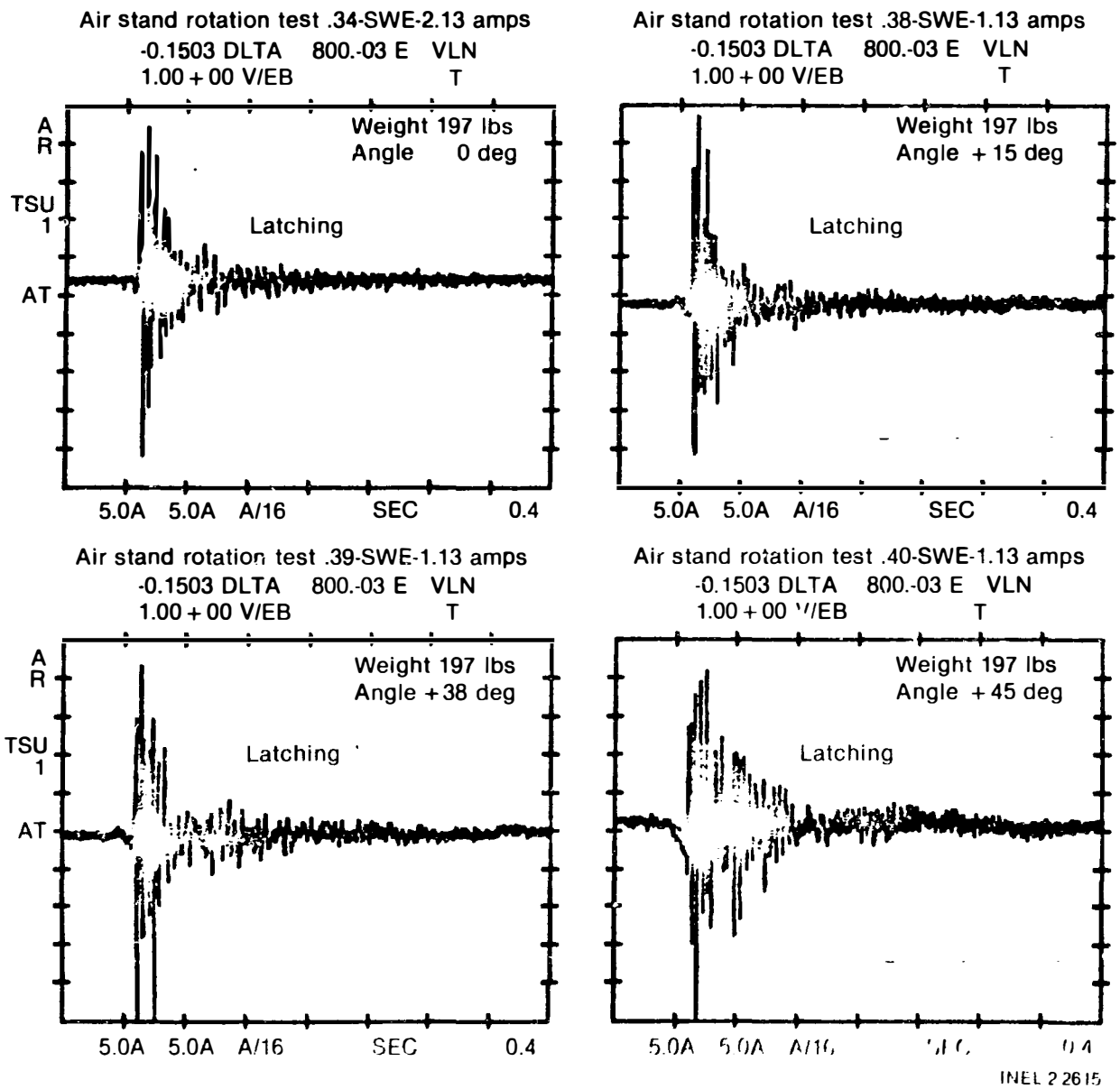

Figure 13. Typical expanded acoustical analysis plots for latch and latch and roll signatures.

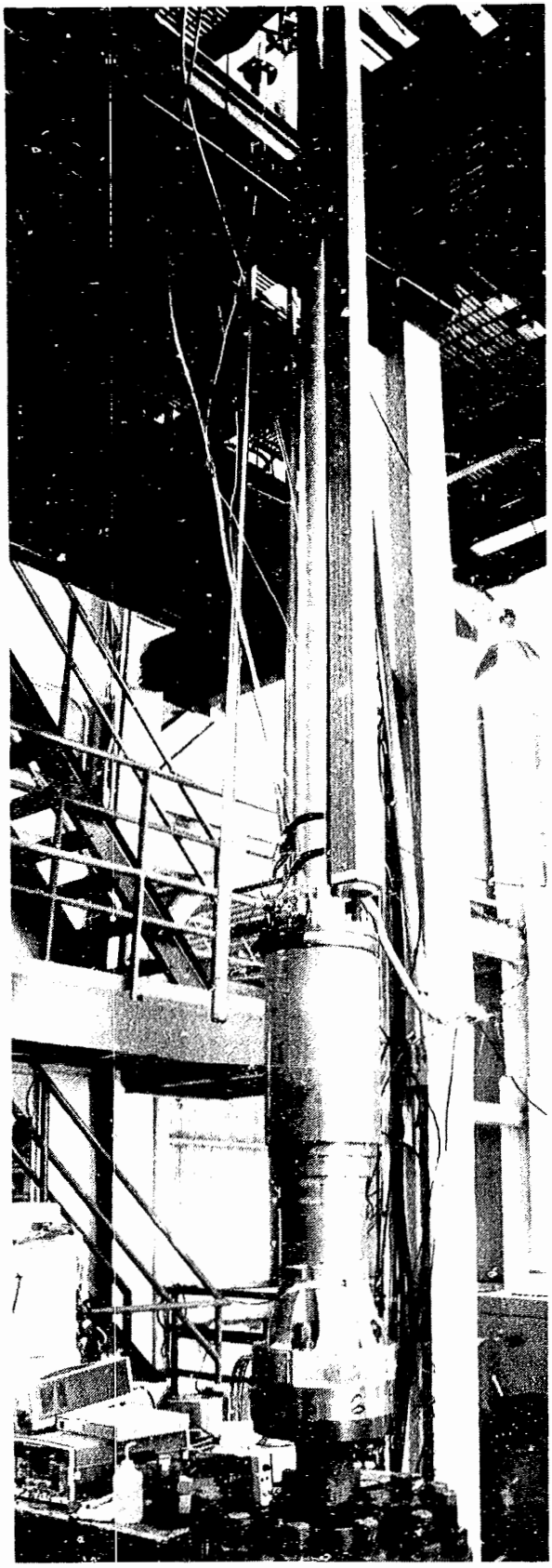

Figure 14. Autoclave facility showing absolute position indicator.

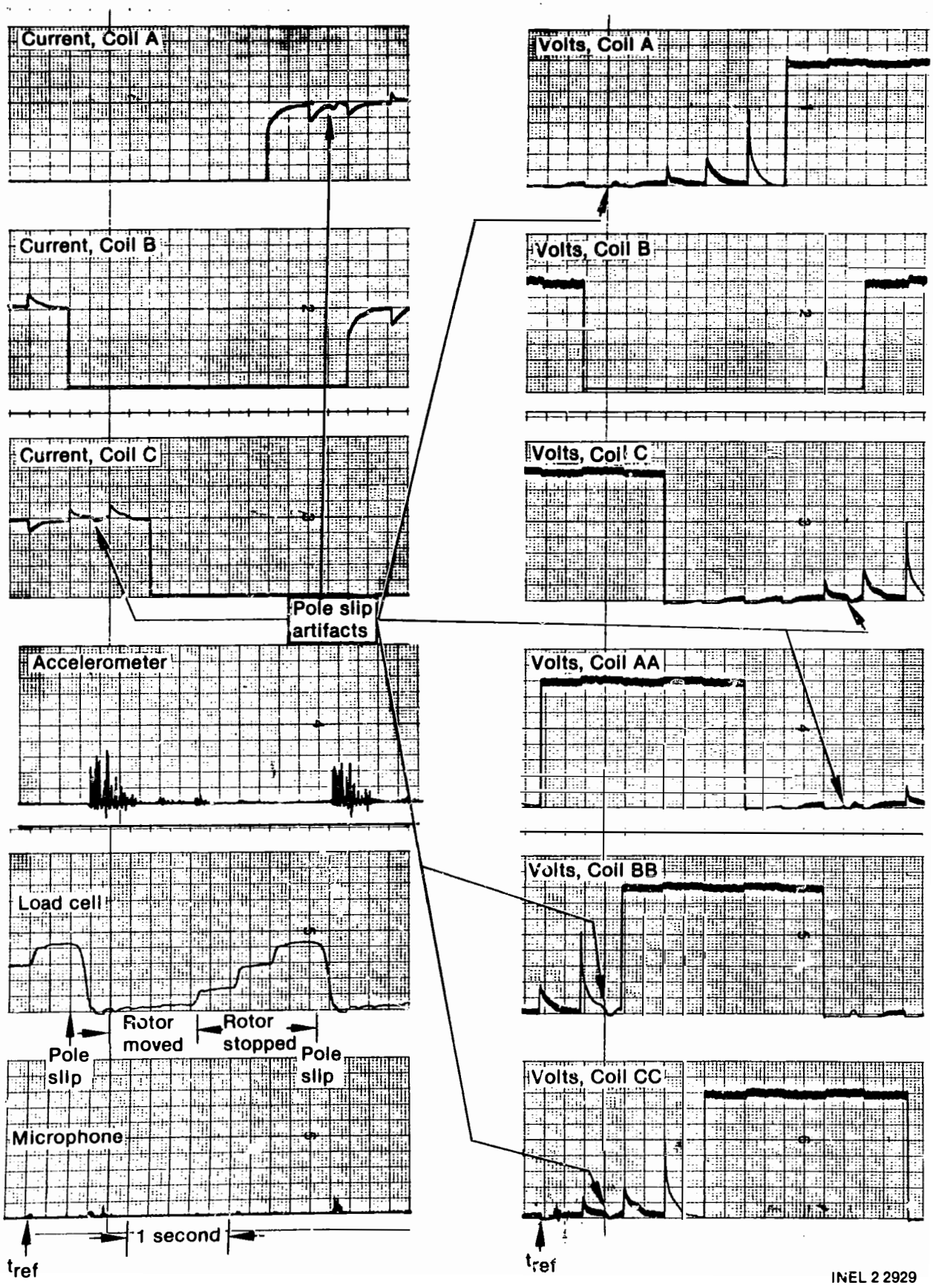

Figure 15. Typical signatures for pole slip at obstruction.

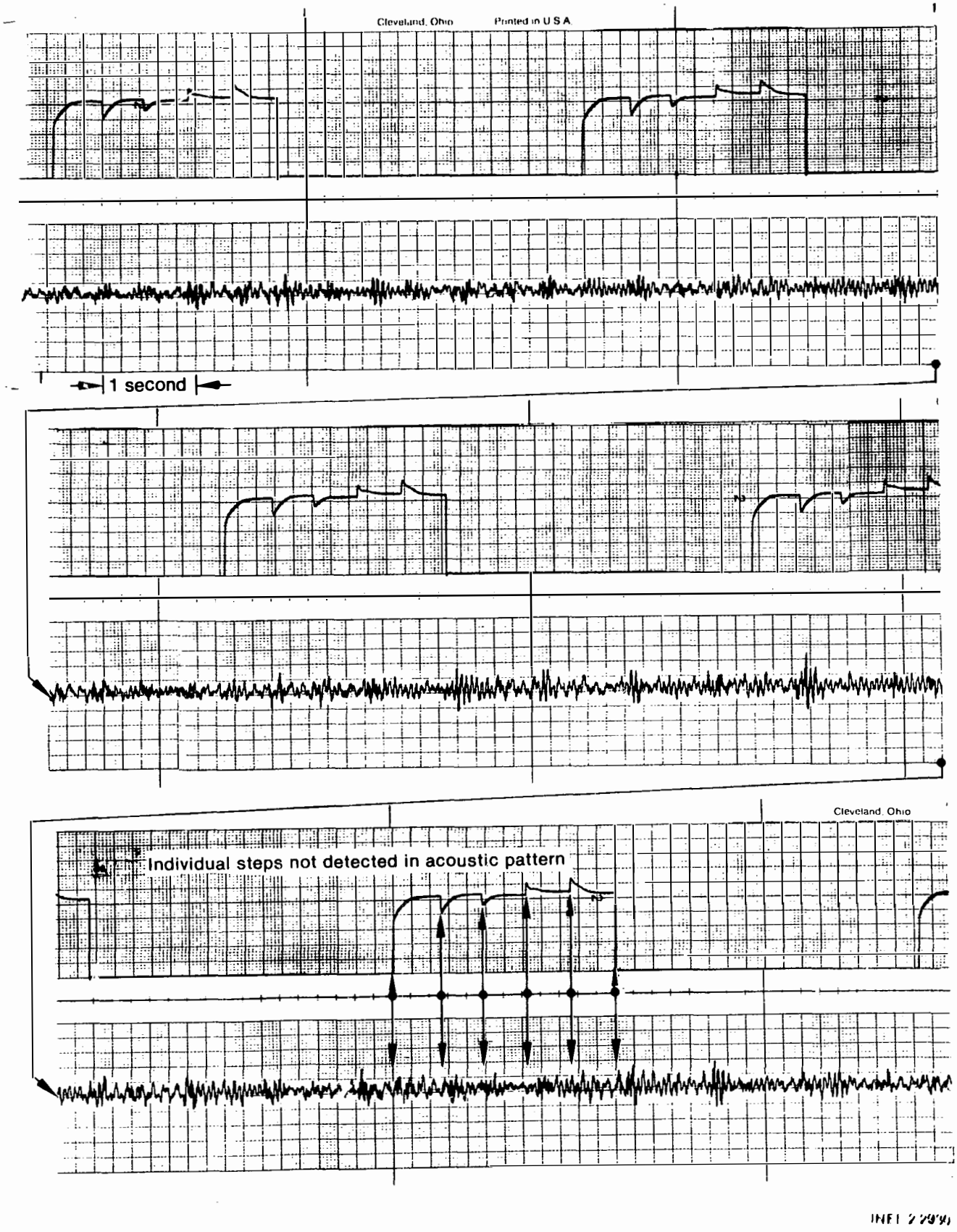

Figure 16. Typical acoustic signature while running at jog speed.

STATIC TESTS

Measurements of certain APSR characteristics unrelated to actual motion were made for three purposes. It was necessary to determine the elapsed-time limit for energizing a stator without cooling water so that the safe temperature for the mechanism would not be exceeded during the planned evolution at TMI-2. It was considered desirable to energize and latch in a field orientation aligned with present rotor position so that all movement would be under positive control, and no initial movement would occur at the time of latch. A test was performed to determine if rotor position could be determined on the basis of static inductance measurements of the stator windings. Finally, it was considered necessary to determine if acoustic data for other than mechanism-induced noise could be obtained.

Stator Heat Up Test

Using calculations based on stator winding resistance, the current and voltage relationship for a winding at the published safe limit of 82.2°C[1] was established. Tests were performed with two and then three coils energized while monitoring the temperature and the current and voltage relationship. Results for this test are shown in Figure 17.

On the basis of these results, a limit of 30-min elapsed time from energizing the service power supply was developed as a backup to actual temperature (thermocouple) readings.

Inductance Measurements Test

The purpose of performing inductance measurements was to determine if rotor position could be determined on the basis of variations in the inductance of stator coils aligned with the rotor pole as compared to non-aligned coils. See Figure A-1, Appendix A, a functional diagram of the rotor and stator relationship.

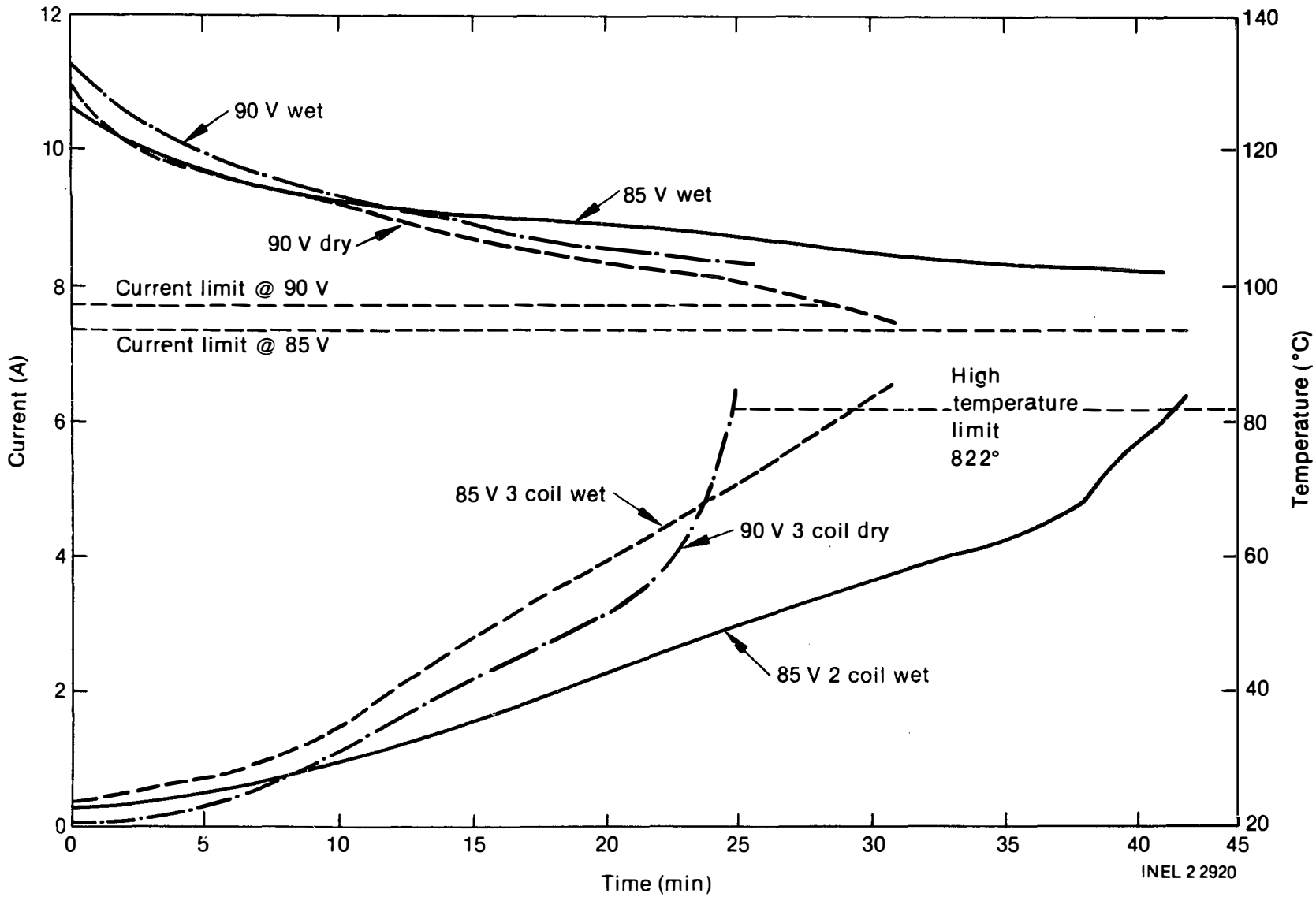

Figure 17. Stator heat up indicating temperature and current, temperature and voltage relationship.

The inductance was measured on each stator coil for each of 12 normal rotor alignment positions 15 degrees apart. The measured results are shown in Table 1.

Development of a predictive technique involves manipulation of the raw data to a common baseline, in this case to relate the values to a common average. It is obvious that the average measured value of C and CC coils is higher than the average of others. A set of normalized values is presented in Table 2. Also shown in Table 2 are the results of predictions based on the following criteria:

- A single distinct minimum value (at least 2 less than the next higher value) indicates alignment to the center of a three-pole configuration with the minimum at the pole.

- A pair of close (separation less than 2) minimal values indicates alignment with a two-pole configuration.

The success ratio for the test stator is 87.5%. When applied to the limited data obtained from the eight APSRs during in situ static testing, it is judged that a success probability for prediction is approximately 70%.

Acoustic Impact

With a fully assembled drive mechanism and full-length leadscrew suspended in the air from an overhead crane, a pendulum of 0.203 lb was allowed to impact the leadscrew bayonet coupling from various angles about 12 ft below the motor housing, imparting 0.1 ft-lb, 0.25 ft-lb and 0.5 ft-lb of energy. Acoustic pickups were mounted in several places on the stator and near the top of the motor tube about 12 ft above the stator. The results indicate a sensitivity defined by the APSR impact signal to running signal noise ratio equal to 17 dB for a 0.25 ft-lb impact acting on the leadscrew bayonet. This is believed to be very good sensitivity and any object fall- ing into contact with this structure, or a similar acoustically coupled structure, should be heard.

TABLE 1. INDUCTANCE MEASURED AS A FUNCTION OF POLE ALIGNMENT (mH)

	Rotor Alignment (15 degrees apart)											
Coil	CC-A-B	A-B	A-B-C	B-C	B-C-AA	C-AA	C-AA-BB	AA-BB	AA-BB-CC	BB-CC	BB-CC-A	CC-A
A	194	195	198	198	198	197	196	198	199	199	198	196
B	198	197	196	197	199	200	199	197	199	199	199	199
C	201	202	203	202	200	202	203	204	203	201	200	202
AA	194	195	198	198	198	196	196	198	199	199	198	196
BB	198	197	196	197	200	201	200	198	197	199	200	200
CC	201	202	203	202	200	202	203	208	202	201	200	202

TABLE 2. NORMALIZED DATA AND PREDICTIONS FOR SUCCESS

	Rotor Alignment											
Coil	AA-A-B	A-B	A-B-C	B-C	B-C-AA	C-AA	C-AA-BB	AA-BB	AA-BB-CC	BB-CC	BB-CC-A	CC-A
A	195.067	196.025	199.089	199.089	199.089	198.083	197.078	199.089	200.095	200.095	199.089	197.078
B	198	197	196	197	199	200	199	197	199	199	199	199
C	197.342	198.323	199.305	198.323	196.36	198.323	199.305	200.287	199.305	197.342	196.36	198.323
Alignment Prediction/ Criterion[a]	A/1	A-B/2	B/1	B-C/2	C/1	C-AA/2	AA/1	B/1	BB-CC/2	BB-CC/2	CC/1	CC-A/2
Success[b]	S	S	S	S	S	S	S	F[c]	F	S	S	S

	Rotor Alignment											
Coil	AA-A-B	A-B	A-B-C	B-C	B-C-AA	C-AA	C-AA-BB	AA-BB	AA-BB-CC	BB-CC	BB-CC-A	CC-A
AA	195.145	196.151	199.168	199.168	199.168	197.156	197.156	199.168	200.174	200.174	199.168	197.156
BB	197.663	196.665	195.667	196.665	199.66	200.658	199.66	197.663	196.665	198.667	199.66	199.66
CC	197.101	198.081	199.062	198.081	196.12	198.081	199.062	203.965	198.081	197.101	196.12	198.081
Alignment Prediction/ Criterion	A/1	A-B/2	B/1	B-C/2	C/1	C-AA/2	AA/1	AA-BB/2	BB-CC/2	BB-CC/2	CC/1	CC-A/2
Success	S	S	S	S	S	S	S	S	F	S	S	S

a. 1 = a single distinct minimum value (at least 2 less than the next higher value) indicated alignment to the center of a 3-pole configuration with the minimum at the pole; 2 = a pair of close (separation less than 2) minimal values indicated alignment with a 2-pole configuration.

b. Success ratio is 21/24 or 87.5%.

c. Failure.

IN SITU DYNAMIC TEST PLAN

On the basis of the results of the various tests, a plan for dynamic testing and positioning of the APSRs at TMI-2 was developed and tested at Diamond Power. Shown as a flowpath in Figure 18, the plan embodies the following principal functions and their verification:

- Initial latch and resulting motion, if any
- Initial motion up, out of the core, to establish that the drive mechanism operates and to remove ambiguity regarding non-operation due to possible obstruction to IN, or down, movement
- Initial slow motion to verify ability to move in the IN direction
- Run IN at 3 in. per minute until bottomed or obstructed and no further motion possible
- Acoustical monitoring of mechanism response, especially pole slip and external impacts
- Time and temperature monitoring of excited stator.

This plan was eventually developed into and implemented as Procedure 007 007 076, Job Ticket C 9631.[a]

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a. During the actual In Situ Dynamic Test at TMI-2, an additional sequence was added to attempt further motion once repeated pole slip at maximum current was achieved. This sequence involved repeated reversal of motion and unlatch and relatch steps.

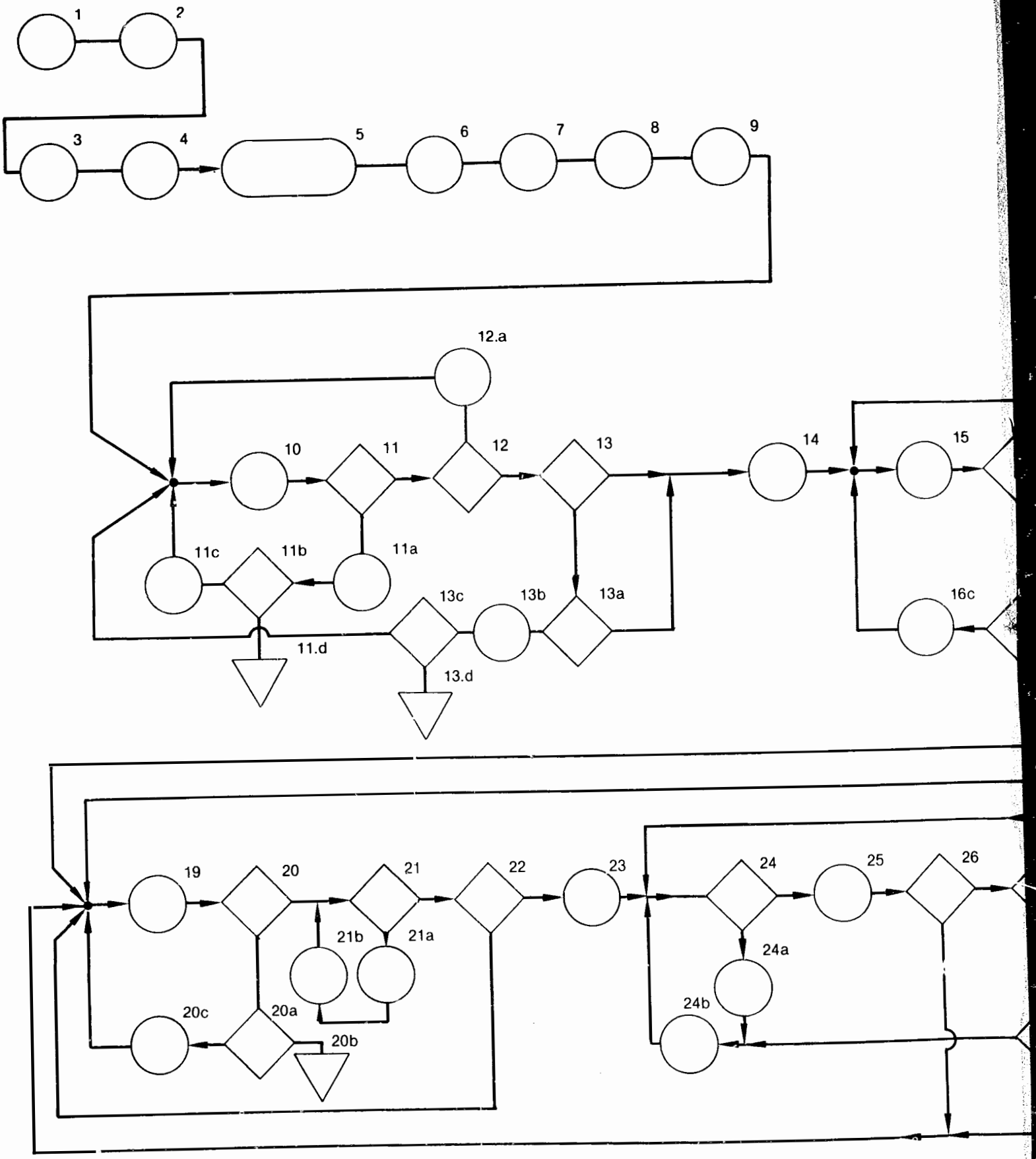
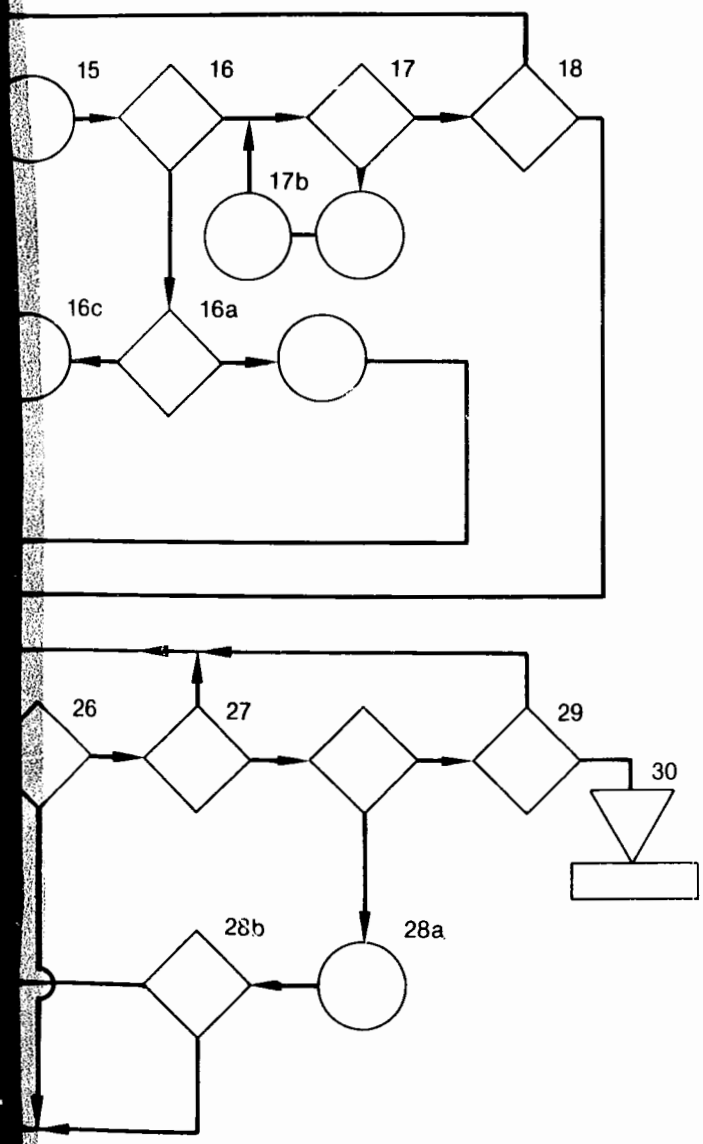


Figure 18. Flowpath for dynamic testing and posi



1. Install acoustic monitors
2. Calibrate acoustic monitors
3. Predict rotor position
4. Select latch current
5. Preset service power supply (SPS) controls
   Power off
   Select stator current
   Jog speed
6. Connect SPS to APSR
7. Connect instrumentation
8. Connect service power to SPS
9. Turn on instrumentation
10. Turn on SPS
11. Confirm latch (yes or no)
11a. Turn off SPS
11b. Is current set to maximum (yes or no)
11c. Increase current by 1 amp
11d. Stop
12. Check stator temperature (OK or high)
12a. Turn off SPS for ___ hr.
13. Did rotor move when latched? (yes or no) (Acoustic signature)
13a. Was movement more than 3/32 in. (yes or no)
13b. Turn off SPS
13c. Does API indicate rod at bottom (yes or no)
13d. Stop: test complete
14. Reduce current to 9 amp
15. Single step up
16. Is pole slip detected (yes or no)
16a. Is current set to maximum? (yes or no)
16b. Reduce current to 9 amp
16c. Increase current by 1 amp
17. Check stator temperature (OK or high)
17a. Turn off SPS for ___ hr
17b. Turn on SPS
18. Has rotor moved 6 steps? (yes or no)
19. Single step down
20. Is pole slip detected? (yes or no)
20a. Is current set to maximum (yes or no)
20b. Stop
20c. Increase current by 1 amp
21. Check stator temperature (OK or high)
21a. Turn off SPS for ___ hr
21b. Turn on SPS
22. Has rotor moved 12 steps? (yes or no)
23. Operate SPS in job mode
24. Check stator temperature (OK or high)
24a. Turn off SPS for ___ hr
24b. Turn on SPS
25. Continue (or resume) jog
26. Is pole slip detected in excess of 2? (yes or no)
27. Has rotor moved 48 steps? (yes or no)
28. Has API changed? (yes or no)
28a. Turn off SPS
28b. Does acoustic data show motion (yes or no)
29. Does API indicate bottom (yes or no)
30. Stop: test complete

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and positioning of APSRs at TMI-2.

CONCLUSIONS

The tests were concluded with positive answers to all of the original objectives. A test was devised for conduct at TMI-2 that would positively determine APSR operability, and if operable, drive the APSRs to the lower limit. The procedure to determine absence of shaping rods was not included in the recommended TMI-2 dynamic test because it necessitates driving the APSRs at maximum speed in both the IN and OUT directions while decreasing drive current and noting at what current level pole slip occurred. It was judged that this would impose too great a risk to the accomplishment of the primary objective, which was to place the rods in the uncoupling position.

There is a good chance for successful remote indication of latch and roll rotor movements, pole slip, and structured noise. There is a 70% chance of predicting rotor position for initial energizing without movement. A time limit of 30 min for operation of an uncooled mechanism has been established.

REFERENCE

1. Instrumentation Manual for Axial Power Shaping Rod Drive Mechanism 706392-3051, Diamond Power Specialty Corporation, Lancaster, Ohio.

APPENDIX A

APSR DESCRIPTION AND PRINCIPLES OF OPERATION

APPENDIX A

APSR DESCRIPTION AND PRINCIPLES OF OPERATION[a]

The Axial Power Shaping Control Rod Drive Mechanism is an electromechanical device consisting of: an electrically driven, rotating nut assembly (rotor) within a pressure vessel; a 4-pole, 6-phase stator; a translating leadscrew that converts rotary motion of the nut to linear travel of the leadscrew and control rod; and a brake that prevents motion of the leadscrew control rod assembly when power is interrupted to the stator.

When power is off or interrupted, the rotor assembly segment arms pivot until contact between buttons on the lower end of the segment arms contacts a rotationally fixed cylinder (motor tube). Contact of the buttons with the tube prevents complete disengagement of the roller nuts from the leadscrew while imparting a friction force that prevents rotor movement and thus leadscrew translation.

The control system provides a direct current, sequentially programmed input to the 4-pole, reluctance drive motor that incorporates a 6-coil, star-connected winding. The stator coils are sequentially energized in a unique 3-2-3-2 progressive manner producing a rotating magnetic field around the rotor assembly as shown in Figure A-1.

When power is applied to the stator, the magnetic field established by energizing the stator assembly acts as a magnetic coupling through the motor tube wall to pull the upper portions of the rotor segment arms outward. Due to the pivoting action, the lower portions of the segment arms move inward, causing the brake buttons (friction screws) to lose contact with the motor tube and the roller nuts to complete engagement with the leadscrew.

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a. This section contains information derived from Instruction Manual for Axial Power Shaping Control Rod Drive Mechanisms, see Reference 1 main text.

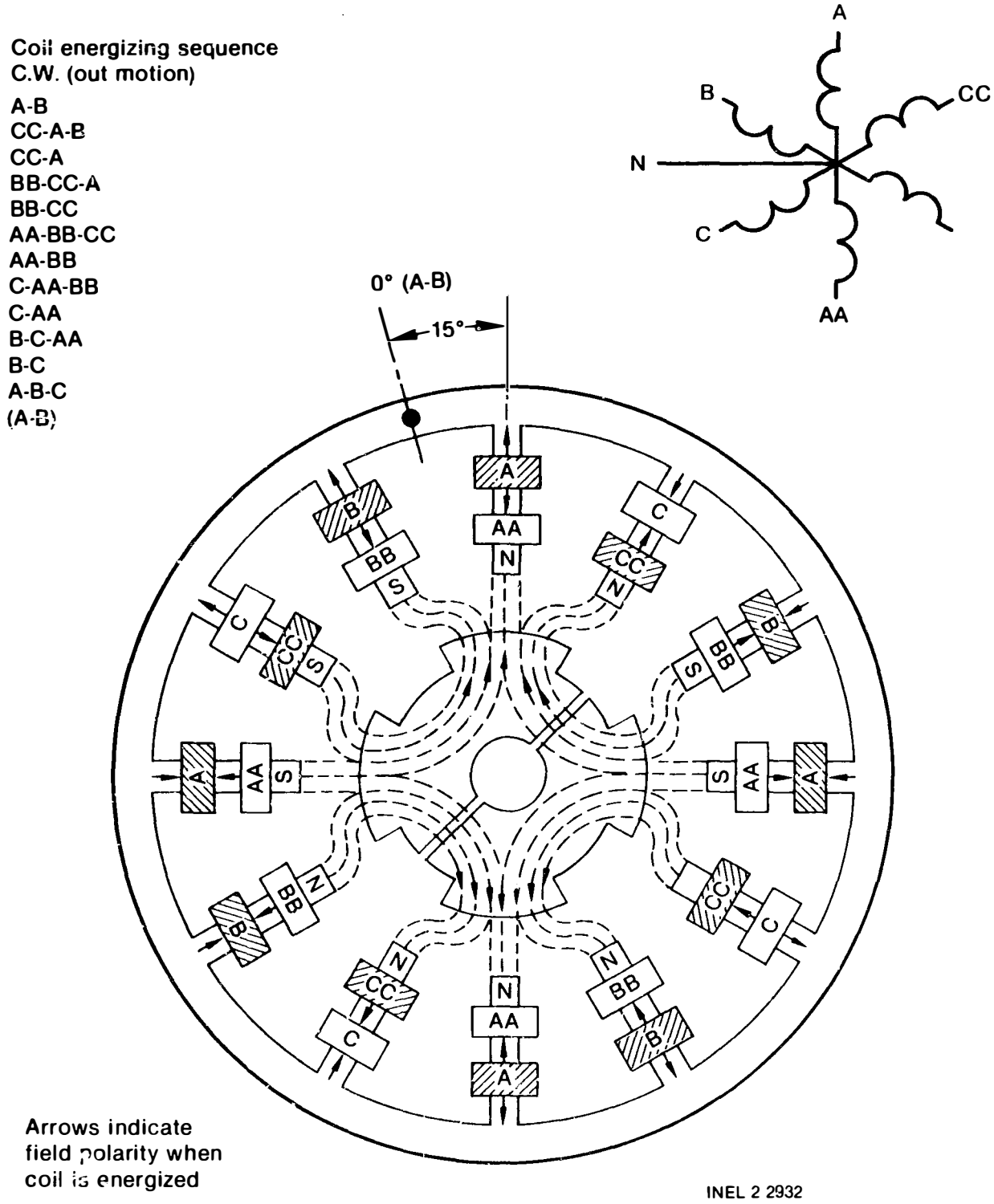

Figure A-1. Rotor positions with three windings (CC-A-B) energized.

As the stator coils are progressively energized, the rotor rotates (steps) to orient itself to the new positions. The programmed supply of overlapping sequential coil currents results in 12 mechanical steps, 15 degrees each, for each electrical cycle. Two electrical cycles result in one revolution of the rotor. One rotor revolution results in 3/4-in. leadscrew and control rod translation.

The direction in which the rotor rotates determines the direction of leadscrew movement. Viewing down on the drive, clockwise rotation of the rotor assembly translates the leadscrew in the OUT direction. Figure A-2 is a cross section of the rotor, stator, and leadscrew assembly.

Five Basic Drive Functions

Latch

The latching action releases the brake and completes engagement of the rotor assembly rollers in the leadscrew threads to permit subsequent positioning of the control rod. To accomplish a latching operation, the leadscrew may be in any stroke position, and a current capable of producing a magnetic field of sufficient strength to overcome the opposing force of the segment arm springs and friction must be applied to the stator assembly. When the magnetic field attracts the upper ends of the segment arms radially outward, the lower ends of the arms below the pivot pins pivot inward causing the brake to release and the roller nuts to complete engagement with the leadscrew. Latch and roll is the response when the rotor is not initially aligned with the stator coil group being energized.

Hold

The control rod may be held stationary by placing the control system in the HOLD condition. A HOLD condition is achieved by stopping the coil voltage at some point with the drive operating in either the RUN or JOG mode. The rotor maintains the alignment with the stationary magentic vector in the stator. The drive is capable of maintaining a HOLD condition indefinitely.

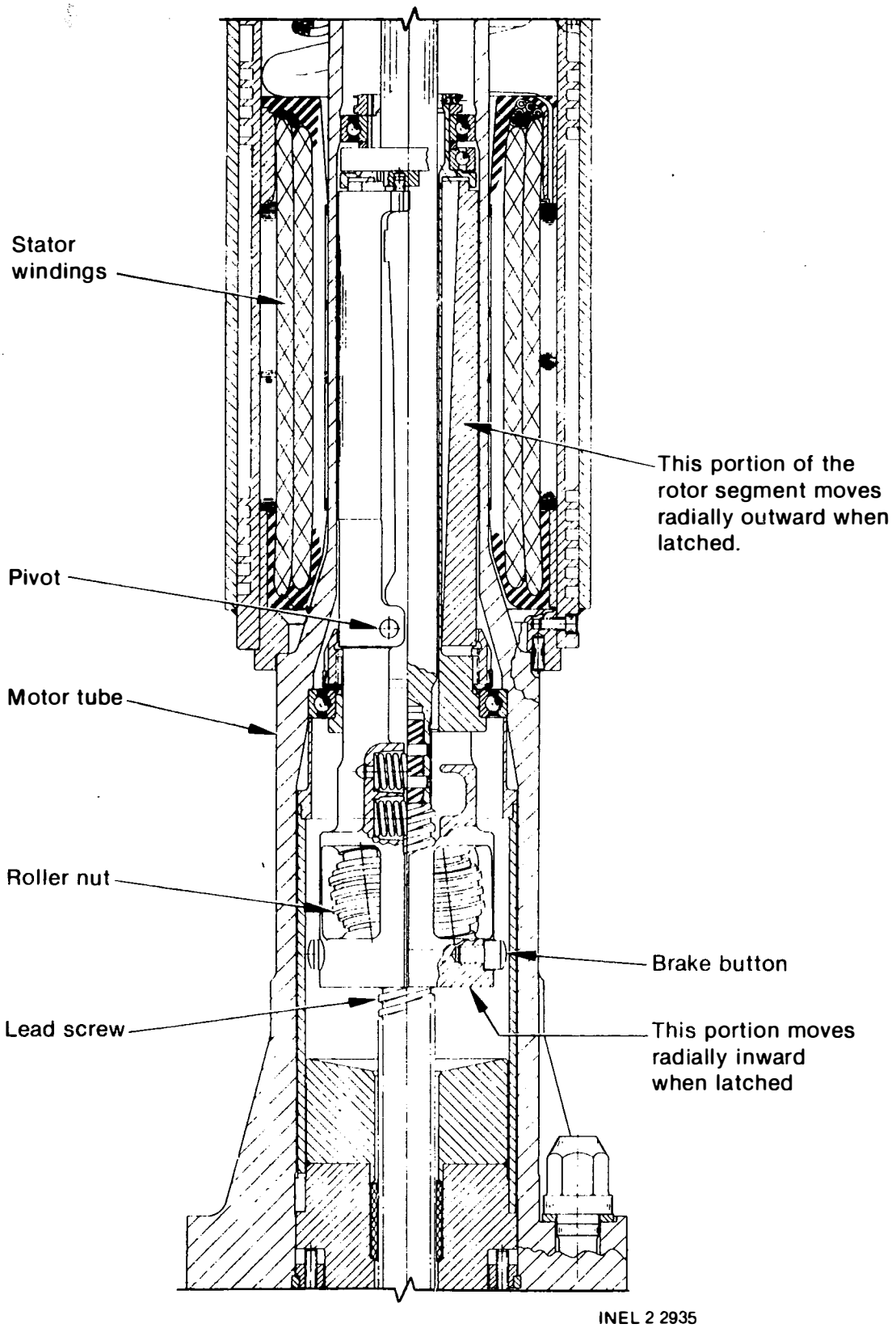

Figure A-2. Cross section of the rotor, stator and leadscrew assembly.

Run

The RUN mode is performed by the drive after it has been latched to move the leadscrew and control rod to a new position. When the drive is running at 100% speed, the leadscrew and control rod are translated at a rate of 30 in. per minute in either the IN or OUT direction. Under actual operating conditions, selection of the RUN mode is made at a Control Board.

Jog

The JOG mode is performed by the drive to move the leadscrew and control rod to a new position. When the drive is running at JOG speed, the leadscrew and control rod are translated at a rate of 3 in. per minute in either the IN or OUT direction. Selection of the JOG mode is normally made at a Control Board. For service or maintenance purposes, momentary operation of the coil current sequencing programmer causes a single change in the coil sequence that is called a single-step.

Brake

A brake action is initiated by the interruption of power to the stator. With current interruption, the magnetic field decays permitting the segment arm springs to force the lower end of the segment arms radially outward (see Figure A-2). The buttons (friction screws) on the lower end of the segment arms contact a rotationally fixed cylinder (thrust bearing spacer). Contact of the buttons with the cylindrical thrust bearing spacer prevents complete disengagement of the roller nuts from the leadscrew while imparting a frictional force that prevents rotor movement and thus leadscrew translation.

Related to the basic functions is a mechanism response to continued sequential energizing after obstruction to leadscrew translation has been encountered. Called pole slip, this response is a rotational movement in the reverse of the applied sequence as the rotating field approaches from "behind" the stalled rotor to within 45 degrees of alignment.

Rotor

The rotor assembly when actuated through magnetic coupling by the stator is the component that engages, holds, and positions the leadscrew. The rotor is pictured in Figure A-3. The rotor assembly is mounted inside the motor tube and is normally immersed in primary coolant.

The rotor tube is the central structure of the rotor assembly and is equipped with bearing journals at each end. It is hollow to allow passage of the leadscrew. Pivot-pin holes located near the lower end of the rotor tube are for mounting the segment arms.

The magnetic stainless steel segment arms are mounted on the rotor tube by four pivot pins, two per segment arm, allowing them to rotate with and pivot on the rotor tube. The upper portion of the segment arms forms a 4-pole, collapsible rotor. The lower portion of the segment arms is a collapsible split nut designed to latch, drive, unlatch, and brake the leadscrew. A friction screw is mounted on the lower end of each segment arm and limits the motion of the segment arms by contacting the inner surface of the thrust bearing spacer, thus ensuring that the roller nuts do not completely disengage the leadscrew.

Four compression springs, located below the segment arm pivot pins, hold the friction screws out against the thrust bearing spacer. To complete engagement of the roller nuts to the leadscrew and release the brake, a force greater than the spring force must be applied to the segment arms above the pivot pins by the stator's magnetic field.

The four rollers located in the lower portion of the segment arms are angular contact bearings with grooved outer races. Two rollers, mounted on spindles, are assembled in each segment arm. When latched to the leadscrew, the rollers are mounted 90 degrees apart and form a roller nut. When unlatched, the roller nut is slightly loosened but is not disengaged from the leadscrew thread.

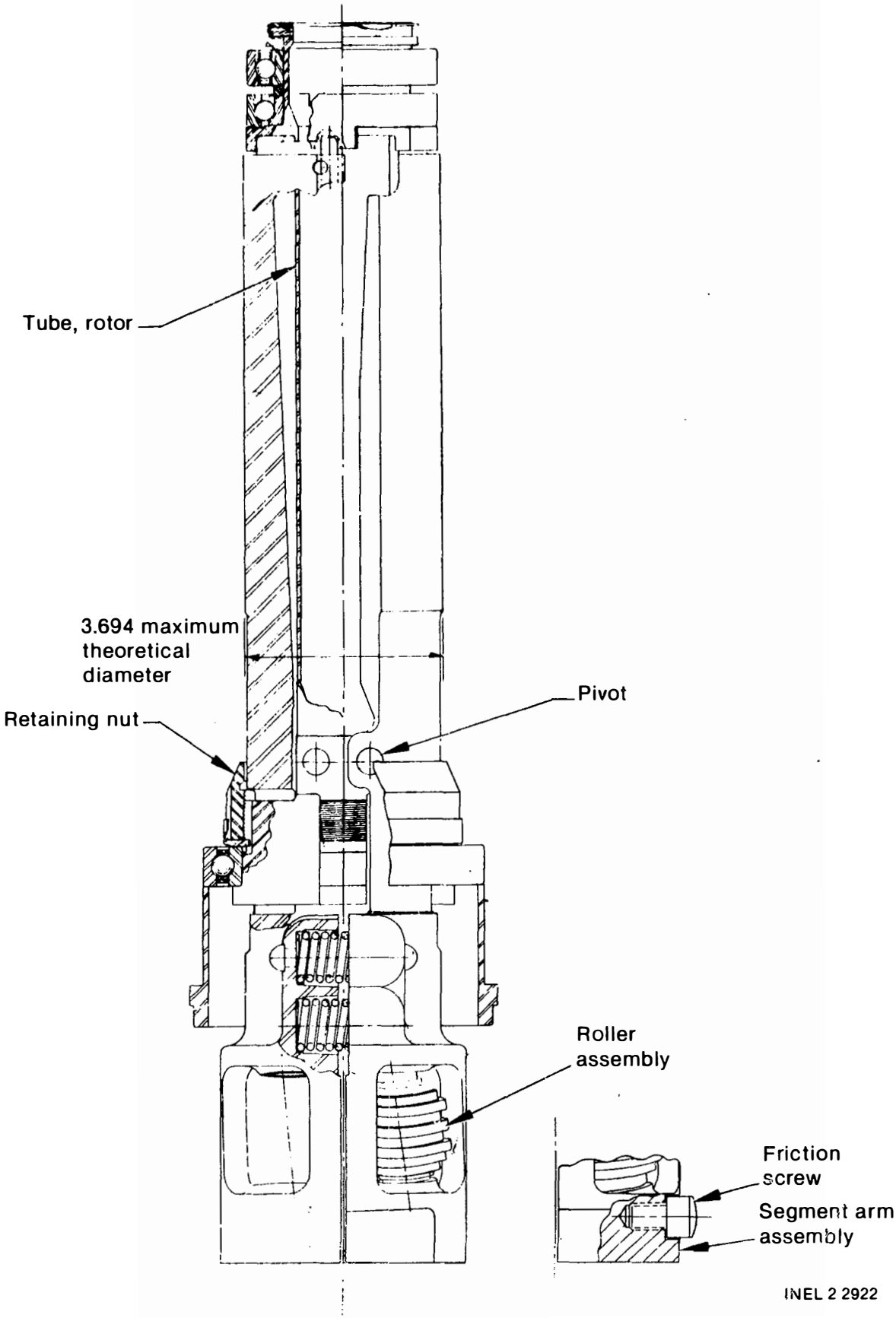

Figure A-3. Cross section of rotor assembly mounted inside motor tube.

Leadscrew

The leadscrew assembly is the connecting link between the rotor assembly and the control rod. When the rotor assembly rotates, the leadscrew assembly is kept from rotating by keying it to the torque tube assembly through the torque taker. The leadscrew assembly travels along the vertical centerline of the drive.

Torque Tube

The torque tube, as shown in Figure A-4, is a cylinder approximately 151 in. long with a 3-3/8 in. diameter. A full length key is attached to the inside diameter of the torque tube to keep the leadscrew assembly from rotating.

The torque taker is coupled directly to the leadscrew assembly. The torque taker rides on the torque tube key preventing rotary motion of the leadscrew. As the rotor assembly rotates, the torque applied to the leadscrew is transmitted to the torque taker and, since the torque taker cannot rotate, vertical translation of the leadscrew and torque taker results.

A magnet is mounted in one side of the torque taker to operate the reed switches in the position indicator (PI) assembly. As the magnet travels vertically with the leadscrew, the reed switches in the PI are closed and opened in sequence, indicating the position of the magnet, and thus, the leadscrew within the drive.

Position Indicator

The position indicator assembly is used to determine the absolute position of the leadscrew within the drive. As the leadscrew translates within the drive, the torque taker and magnet travel with it. As the magnet travels vertically, the equally spaced reed switches in the position indicator close whenever the magnet is in the immediate vicinity. When the magnet passes the reed switch, the reed switch returns to its normally open condition.

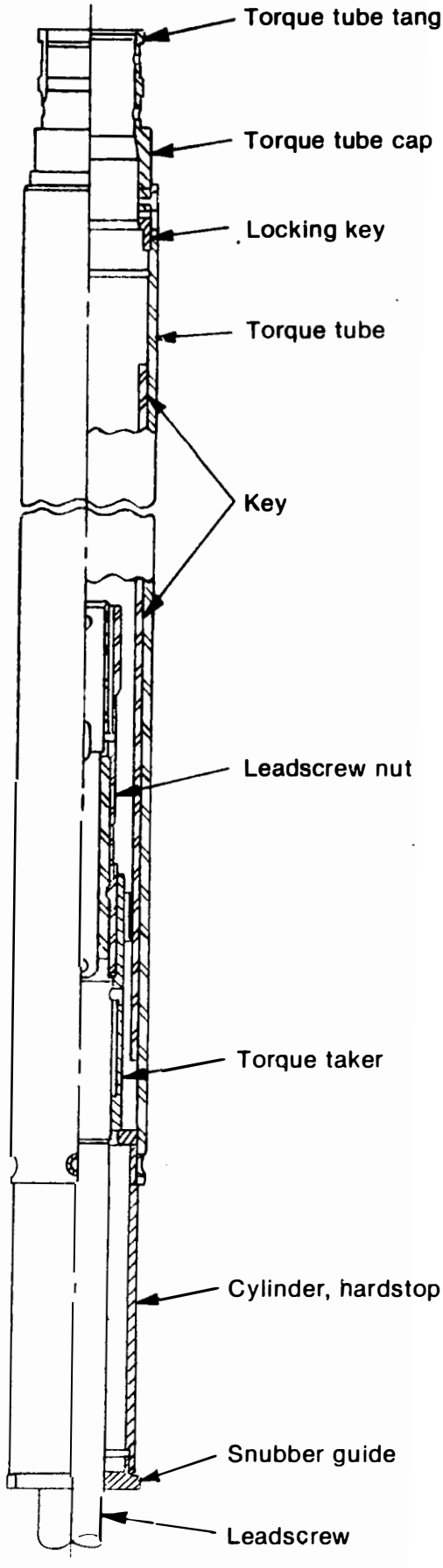

Figure A-4. Cross section of torque tube assembly.

Direct current power is applied to a reed switch-resistor network for providing an analog position indication. The analog output, when properly "mixed" at the measuring point, results in a single voltage, which indicates leadscrew position throughout leadscrew travel. When the leadscrew is in the tripped position, the analog output is zero volts. As the leadscrew is withdrawn, the analog output increases until the leadscrew is in the full OUT position, at which time, the analog output reaches a maximum voltage. The output voltage increases in a step pattern of approximately 1% per step; therefore, 0% represents a position from 0 to approximately 0.5%; 1% represents 0.5 to 1.5%, etc.

Indicator switches of interest are the in-limit switch (ILS) and 0% switch. The ILS provides a switch closure whenever the leadscrew is 0.12 to 1.0 in. above the tripped position. The 0% switch provides a switch closure 1.5 in. above the ILS. These switches are adjustable over the first 2 in. of leadscrew out motion travel.