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Kevin E. Konno and Clifford R. Hausmann
Lewis Research Center
Cleveland, Ohio

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ROTATING RAKE DESIGN FOR UNIQUE MEASUREMENT

OF FAN-GENERATED SPINNING ACOUSTIC MODES

Kevin E. Konno and Clifford R. Hausmann
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

In light of the current emphasis on noise reduction in subsonic aircraft design, NASA has been actively studying the source of and propagation of noise generated by subsonic fan engines. NASA Lewis Research Center has developed and tested a unique method of accurately measuring these spinning acoustic modes generated by an experimental fan. This mode measuring method is based on the use of a rotating microphone rake. Testing was conducted in the 9 by 15 Low Speed Wind Tunnel. The rotating rake was tested with the Advanced Ducted Propeller (ADP) model built by Pratt & Whitney Division of United Technologies. This memorandum discusses the design and performance of the motor/drive system for the fan-synchronized rotating acoustic rake. This novel motor/drive design approach is now being adapted for additional acoustic mode studies in new test rigs as baseline data for the future design of active noise control for subsonic fan engines. Included in this memorandum are the research requirements, motor/drive specifications, test performance results and a description of the controls and software utilized.

INTRODUCTION

The fan noise generated by current and future aircraft engines is becoming an increasingly serious problem as the bypass ratio of these powerplants increases. The fan noise in the inlet and aft ducts of the engine propagates throughout the duct in the form of spinning modes. The identification and measurement of this acoustic phenomenon is the key to identifying its source mechanism, its propagation and attenuation within the duct, and its far-field radiation. Previous methods of mode measurement of fans involved too many microphones and ducts which were too long to be a useful study of real fan engines. Also, they could only measure a few modes simultaneously. A novel approach to mode measurement suggested by Sofrin (ref. 1) involves a continuously rotating radial rake holding a series of pressure transducers which are used as microphones. The rake's circumferential position must be slaved to the fan so that as the fan completes "X" many complete revolutions and arrives back at top-dead-center, the rake will have completed exactly one revolution and also arrived back exactly at top-dead-center, i.e., as if it were mechanically geared directly to the fan with a X:1 gear ratio. The value of X in this X:1 ratio can be any whole number within a certain research-defined range. In this case X was chosen to be 250. A precise angular positional tolerance is necessary in order to more accurately measure the higher fan tone harmonics. A tolerance of $\pm 1°$ positional accuracy on every rotation of the rake with respect to the fan is required for measurement in the region of the fundamental blade passing frequency (blade number*fan rev/sec). Two unique features of Sofrin's spinning rake method are:

(1) The circumferential mode order is directly determined by frequency. A Doppler shift is responsible for separating the various circumferential orders into different frequencies.

(2) The wake of the rake itself which is sliced by the fan blades creates noise which is only observed at one frequency by the rotating microphones. This frequency does not interfere with any mode measurements until the fan tip speed exceeds the speed of sound.

The remainder of this paper discusses the rake and support structure, the motor/drive mechanism components, the operating procedure, test performance results, and finally the concluding remarks.

GENERAL SYSTEM DESCRIPTION

The objective of the Rotating Acoustic Rake system was to design an instrumentation rake and drive system to be used in one phase of testing of the Pratt & Whitney ADP model in the 9 by 15 Low Speed Wind Tunnel at NASA Lewis Research Center. The model was tested up to Mach 0.2. This testing is documented in more detail by Woodward, et al. (ref. 2). The rotating rake measures fan noise using five pressure transducers pointing at the fan from the inlet plane of the model (figs. 1 to 3). The rake rotates around the inlet plane inside the ADP nacelle directly upstream of the fan. The rake velocity was 1/250th of the ADP fan velocity. This ratio was chosen based on the research fan speed range and the maximum allowable speed of the rake drive system. As the ADP fan rotates exactly 250 times at any test speed in the range of 8600 to 12 500 rpm the rotating rake will complete exactly one revolution in that timespan within $\pm 1°$. This speed and phase synchronization is necessary in order to accurately evaluate the data that is taken of the spinning acoustic modes. A more thorough description of the actual acoustic modes measurements and results thereof is available (refs. 3 and 4). The fan's speed is not constant, i.e., it wanders slightly because of the inherent turbine drive characteristics. Even so, this phase lock between fan and rake must be maintained over the entire test period (roughly 10 min) without any buildup of phase error. Thus the rake drive system must be slaved directly to the fan. This is accomplished by using the 30 pulse/rev signal and the 1 pulse/rev signal from the fan to drive the rake. These signals direct the position and velocity of a stepper motor via the closed loop control system. The motor in turn goes through a 5:1 gear reduction to spin the rake on a large externally-geared bearing around the inlet plane via a pinion gear. Thus, the rake becomes "electronically geared" to the fan through this control system. Real-time analysis of the fan and rake position signals allows the rake operator to correct for any discrepancy between their angular phase positions.

The following is a list of research and design requirements:

* Maximum fan speed: 12 500 rpm
* Maximum rake speed: 50 rpm at 1/250 engine speed
* Accuracy of "fan-following" rake speed: 250 rev of fan = 1 rev of rake $\pm 1°$ of rake revolution
* Test run duration: 10 min at each data point
* Number of pressure transducers needed per rake: 5
* Number of different fan inlet configurations: 3
* Maximum wind tunnel air speed: 175 mph = 257 fps
* Maximum flow velocity at fan inlet: Mach 0.6 = 670 fps
* Radio frequency telemetry system must be used to transfer signals from the rotating rake to the data acquisition system.

The Rotating Acoustic Rake System is shown in figures 1 to 3. The rake body bolts to one of three rake arms of varying lengths for use in the short, medium and long inlets, respectively. Figure 4 shows a block diagram of the motor/drive system. The 30 pulse/rev and 1 pulse/rev signals from the fan are converted into the proper pulse train to drive the rake at 1/250th of the fan speed. An optical sensor provides circumferential position data of the rake. This signal is used in the angular position correction sequence of the rake drive. The rake itself consists of five Endevco model no. 8507C–5 pressure transducers housed in a 304 Stainless Steel rake body with removable cover plate. The transducer signals were routed to a telemetry system on the rotating geared bearing, then transmitted and recorded on FM analog tape.

MECHANICAL SYSTEM DESIGN

Rake Body

The rake body material is 304 Stainless Steel and was cut from 3/8-in. plate. A profile of the rake body and attaching rake arm is shown in figure 3. The static stress analysis was accomplished using the COSMOS/M finite element analysis code. The loading on the rake body was due to the centrifugal loading at 50 rpm and the aerodynamic loading of Mach 0.6 air flowing over the rake body. A stress concentration of three was used in the weld fillet area of the base. A maximum Von Mises stress of 5950 psi was predicted at the base using this stress concentration factor. Since the overall static stress was relatively small, the rake design meets the Engineering Directorate's (E.D.) design criteria for static strength with a factor of safety of 4.5. The static analysis results were applied to the fatigue analysis for the rake body. The alternating load on the rake due to aerodynamic effects could not be well predicted and were assumed to be equal to 100 percent of the static stress level. This is a conservative approach. Results of the fatigue analysis showed a safety margin of 2.7 on stress for the rake body fatigue life.

A NASTRAN model of the rake was used for the dynamic analysis to determine the natural frequencies and mode shapes of the rake body design. The results indicate that the rake's second and third natural frequencies could be dynamically excited by the fan in the operating range of the ADP model, especially near speeds of 10 900 and 12 500 rpm. However, since the rake is not integral with the rotating ADP model and is well damped through the bearing and support structure interfaces, it was assumed that the rake could not be excited by the fan. To test this assumption, a rake prototype was strain gaged and tested in the wind tunnel with the ADP model running and with full tunnel air flow. Virtually no excitation was observed.

Because of the irregular shape of the rake body, it was decided that a prototype undergo flutter testing to qualify the rake for use upstream of rotating machinery. A rake failure could result in a catastrophic failure of the entire Pratt & Whitney ADP model. Mach 0.2 to 0.8 airflow from a 3.5-in. diameter free jet was directed at a prototype rake body outfitted with accelerometers. No excitation was detected for all flow speeds. The results of this flutter testing agree with the results of the flutter analysis, i.e., the rake as designed is aeroelastically stable throughout the air speeds experienced in actual wind tunnel testing.

It is normal practice at NASA Lewis to qualify prototype rakes and probes used upstream of rotating machinery with a vibration test. However, extensive vibration testing was done on the ADP model and the rotating rake drive system which showed that nothing could excite the rake body near the excitation levels used in this qualification test. Thus an alternate series of analysis and testing were conducted on the rake body using lower excitation levels which gave more realistic yet conservative dynamic loading conditions. The modified qualification test results indicated that the rake was safe for operation directly upstream of rotating machinery as designed.

To summarize, the rake body design was analyzed and/or tested for static stress, fatigue, dynamic response, vortex shedding and flutter. The rake body is lightly loaded giving large factors of safety for static stress and fatigue. An extensive battery of tests was conducted on the rake body and ADP model to insure that the rake would be safe from any vibratory or aeroelastic excitation which could have led to a catastrophic failure of the rake and ADP model.

Support Structure

A structural vibration analysis was conducted of the entire support structure which supports the rake and drive assembly from the floor and ceiling of the tunnel. The first natural frequency was a horizontal first bending mode of the cantilevered structure at 4.1 Hz. The second natural frequency was a vertical bending mode at 21 Hz. Since the rake is revolving at 0.5 to 1 Hz frequency, there is no source for exciting these lower modes of the structure. A static stress analysis was performed on the components of the support structure. The structure is lightly loaded having large margins of safety on yield and is sufficiently rigid so as not to bind the ring gear. It was observed in previous ADP operation testing that the ADP model characteristically shifts down and to the left slightly and vibrates during operation. The acoustic rake rotates around the cavity of the inlet fairing within 0.25 in. of the fairing skin and spinner body. To avoid the possibility of the rake rubbing, the rake was tied to the ADP such that the rake and ADP move as one body. A series of turnbuckles were used to tie the ADP casing to the rake support structure (fig. 5). Four load cells were integrated in line with these turnbuckles as a diagnostic tool to detect any unsafe overloading in the ADP casing. The turnbuckles were then tightened so that a tensile preload was applied to each of them. This firmly locked the ADP casing to the rake support. These load cells were closely monitored during all rake testing.

ELECTRICAL SYSTEM DESIGN

Motor Drive/Controller

The precise angular position requirement dictated a motor/drive system capability which quickly responded to torque and/or speed command changes while providing a stable closed-loop positioning response. A closed-loop stepper system was chosen for this project. The drive's speed command utilized a pulsed, variable frequency input supplied by an indexer/stepper type of controller.

The control approach chosen was that of a master/slave motor control system (ref. 5). A compatible indexer and stepper motor drive system was designed to accelerate the rake to the current fan velocity and maintain its position relative to a control point at a pre-programmed fraction of the fan's velocity. The positional information would be determined from a physical point (1 pulse/rev signal) on the fan housing's circumference. The system operation would convert the fan's 30 pulse/rev signal for use as an input speed command to the motor control system. The fan speed would be variable but the driven rake would always rotate at 1/250th of the instantaneous fan velocity. In addition the rake would be synchronized to a marker point on the fan housing via an optical sensor signal (phase position). The general description of the motor control system and its operation would be that of follower or "electronically geared" system. The rake would "follow" the master fan's rotation. The curves in figure 6 illustrates the trapezoidal motion profile and motor torque/speed relationship typical for the system.

The motor and controller system was programmable using a standard user-friendly software design approach. A dedicated manufacturer's software programming approach was utilized. It was preferable to use a generic PC to run the software rather than a special hardware terminal or programming device.

Electrical Equipment Description

The rotating acoustic rake is driven by a Compumotor CPH106–220 stepping motor with a Compumotor Plus drive. Control is provided by a Compumotor 500–FOL single axis controller/indexer.

Figure 4 shows a block diagram of the rake drive system which uses the 30-pulse/rev signal from the ADP to direct the motor/drive system. A photoelectric sensor is used to detect the phase position of the rake and directs the operator to correct the phase synchronization of the rake to the ADP (via the operator control panel) by speeding or slowing the rake's angular velocity momentarily.

Parameters used in sizing the motor:

* Rotek 2100 Econtrak ring gear bearing startup torque: 1000 oz-in.
* Rotek Bearing required running torque: 200 oz-in.
* Required load-to-motor inertia ratio: $\leq$10:1
* Maximum motor speed required (using 5:1 gearbox): 28.7 rev/sec

CPH106-220 Motor specifications (using 5:1 gearbox):

(1) Motor torque at startup: 5500 oz-in.

(2) Motor torque at 30 rev/sec: 900 oz-in.

(3) Load to motor inertia ratio: 9.3:1

(4) Maximum motor speed: 45 rev/sec

The stepper motor drive and indexer (fig. 4) provides power and control to a 1.8° hybrid stepper motor (refs. 5 and 6). An integral brushless resolver is similar in rotor and stator materials makeup to the stepper motor. This resolver has the same number of poles as the motor and is always properly aligned with the motor. The equipment combination provides a brushless, digital, closed-loop positioning system with:

* High torque to inertia ratio for responsive acceleration rates.
* Velocity and position loops with PID (proportional, integral, and derivative gain settings).
* A standard RS-232 interface plus a step and direction interface (from an indexer controller).

The drive is an amplifier with a built-in power supply, low EMI filtered outputs, and optically isolated user inputs. Power required is 120 Vac single-phase. The on-board controller is based on the Motorola 68000 16 bit microprocessor. The Compu-motor Plus drive hardware has an internal resolution of 12 800 steps/rev. A software command to the drive can be used to set the motor/drive resolution equal to the indexer resolution.

The control panel (fig. 7) illustrates the operator interface controls.

The indexer is a single-axis controller that is directly compatible with the Compumotor Plus drive (ref. 5). It provides step and direction inputs to the drive. The power required is 120 VAC single phase. The Compumotor 500-FOL indexer uses the 30 pulse/rev signal as an input to its incremental encoder port for following motion commands. The indexer uses the motor encoder feedback signal as an input to its absolute/incremental encoder port for position information and maintenance. Specific software commands effect the desired "follower" performance.

Servo Operation/Tuning

The servo/drive and motor utilizes the output of the controller/indexer as an input command to position or move the acoustic rake in a certain direction and at a controlled velocity (ref. 6). Motor shaft positional information is sensed by a built-in resolver feedback device. This feedback generates an error value based on commanded versus actual positions and is used to calculate the proper motor velocities. The control equation is generated by a discrete-time PID (proportional, integral, and derivative) network (fig. 8). The system operates on digitally-sampled data instead of continuous analog data. A high sample rate, 300 μsec, provides good dynamic response.

The current velocity equation is shown below:

$$Vc = (Pg \times Pe) + (Ig \times \Sigma Pe) + (Dg \times \Delta Pe)$$

where

Vc	is command motor velocity
Pg	is proportional gain
Pe	is positional error
Ig	is integral gain
Σ Pe	is sum of all previous positional errors
Dg	is derivative gain
Δ Pe	is the difference between the last two positional errors

The velocity term determines the system responsiveness. The proportional term determines system stiffness and accuracy. The integral term determines position error compensation and final position accuracy. The derivative term determines settling time and dynamic response. All the terms (gains) are interactive and require set point experimentation in obtaining the correct value combinations for the best overall system performance. Tuning values for these gains are set either via the drive's front panel pushbuttons or over the RS-232 link.

Program Commands

Compumotor's X-language software commands are programmed over a standard RS-232 channel (refs. 5 and 7). High level commands such as GOTO, GOSUB, IF/THEN/ELSE, WHILE, REPEAT/UNTIL are utilized. A command summary list includes: Status request, following, motion, set up, memory and sequence control, homing, and I/O (Input/Output) commands. Software commands are stored or entered in the following format:

[Device Address] [Command] [Parameters] [Delimiter]

where the Device Address is a number from 1-16; the Command is made up of ASCII characters (A-Z); the Parameters are made up of ASCII digits (0-9), binary values (0 or 1), or hexadecimal digits; the Delimiter is a space bar character or a carriage return. The delimiter indicates that the command is complete. Refer to the acoustic rake motion control software flowchart in figure 9.

Indexer Software Calculations

(1) Rotating rake rev per (250) revolutions of the fan is achieved as shown below (refs. 5 and 7). Refer to figure 10:

$$\begin{aligned} \text{Fan signal} &= 30 \text{ pulses/rev (or 30 ppr)} \\ \text{250 fan revs} &= 30 \text{ pulses/rev} \times 250 \text{ fan revs} \\ &= 7500 \text{ pulses} \end{aligned}$$

The 500 follower controller (indexer) output pulses (drive and motor step pulses) = Fan pulses X FOL X FOR X (Correction)

where

(Correction) = 1, i.e., the correction in output pulses is done manually via the oscilloscope phase measurement and the synch. pushbuttons on the control panel.

FOL is the Following Percent. This indexer software command establishes a percentage of the indexer's encoder input frequency and is used in conjunction with the Following Ratio (FOR) command to produce the step output frequency.

FOR is the Following Ratio. This software command configures the motor resolution to the following encoder resolution ratio used to make the indexer's step output frequency.

Let the 500-FOL step pulses to the compumotor plus motor/drive amp = Pd

$$\text{Pd} = \text{Fan Pulses} \times \text{FOL} \times \text{FOR} \times 1$$

where

$$\begin{aligned} \text{FOL} &= 25 \text{ (2500 percent from the acoustic rake program)} \\ \text{FOR} &= 2.20 \text{ (motion ratio from the acoustic rake program)} \end{aligned}$$

So

$$\begin{aligned} \text{Pd} &= 7500 \times 25 \times 2.20 \times 1 \\ &= 412\,500 \text{ pulses (to the drive) or } 412\,500 \text{ pulses/250 fan revs} \\ &= 165 \text{ pulse/rev (to the drive)} \end{aligned}$$

MR is the Configure Motor Resolution command. This software command configures the number of pulses the drive requires to make one revolution of the motor.

$$\begin{aligned} \underline{\text{MR}} &= 12000 \text{ pulses/rev} \\ &= 1/12000 \text{ revs/pulse (from the Acoustic Rake Program)} \end{aligned}$$

$\underline{Rm}$ = drive motion command to motor (as shown in fig. 10)

$= 1/MR \times Pd$

$= 1/12000$ revs/pulse $\times$ 412,500 pulses

$= 34.375$ revs

And these revolutions translated through the 5:1 gearbox result in:

$34.375 \times (1/5) = 6.875$ revs (of the drive gear)

And translated through the 110:16 gear system gives:

$6.875 \times (16/110) = 110/110 = 1$ rev of rake/250 fan revs

Hardware Specifications

Compumotor Plus drive and motor (ref. 6):

Relative accuracy (any load)	±0.15°
Continuous torque	1100 oz-in.
Peak torque	1400 oz-in.
Maximum continuous speed	3600 rpm
Electrical I/O—	
Input	100 to 130 vac, 1 ph.,47 - 66 Hz., 6.0 A continuous
Output	170 Vdc, 8 A
Maximum input step rate =	640 kHz
Minimum step pulse width =	500 ns
Environmental considerations—	
Drive operating temperature	0 to 50 °C
Motor operating temperature	100 °C, maximum
Storage temperature	−40 to 85 °C
Humidity	0 to 95 percent, noncondensing

Motor resolution is programmable from 200 to 25 600 steps/rev. The drive utilizes an internal 12 800 steps/rev. The drive input control signals are optically isolated.

Compumotor 500 indexer/follower (ref. 5):

A standard RS-232 interface is used. The discrete (13) inputs are optically isolated and the (8) programmable outputs are open collector.

There are (1) incremental and (1) absolute/incremental encoder interfaces.

Two outputs are set for pulse and direction.

There is (8K) bytes of battery-backed RAM memory available to store up to (99) motion control sequences.

There is a position command/position error update every (1) msec.

Stepping accuracy	+0 steps from preset total
Velocity accuracy	+0.02 percent of maximum rate above (1) rps
Velocity repeatability	+0.02 percent of maximum rate
Motor resolutions	25K or 5K steps/rev
Position range	+0 to 99,999,999 steps
Velocity range	
for 25K steps/rev	0.01 to 20 rps.
for 5K steps/rev	0.01 to 100 rps
Acceleration range	
for 25K steps/rev	0.01 to 999.9 rps ^{2}
for 5K steps/rev	0.05 to 4999.9 rps 2
Maximum encoder input frequency	80 kHz; minimum pulse width is 500 nsec.
Electrical I/O—	
Input	90 to 240 vac, 50 to 60 Hz, single phase, < 1.3 amps
Programmable discrete Inputs	5 to 30 Vdc
Output	
Step, direction,shutdown	+3.0 Vdc minimum/60 ma low signal
Fault Normally open or closed	2 A/120 va relay contact
Programmable discrete outputs	Open collector 5-30 Vdc/300 ma maximum sink
Environmental considerations --	
Operating temperature	32 to 122 °F
Storage temperature	-22 to 185 °F
Humidity	0 to 95 percent, noncondensing

TEST RESULTS

The performance of the rotating acoustic rake was quantified by measuring the variation of the time difference (or time Delta) between every 250th fan 1 pulse/rev (1 PPR) signal and the rake 1 PPR signal. A perfect system would have the fan's 250th 1 PPR signal lagging in time behind the rake's 1 PPR signal at exactly the same fraction of a second for each and every revolution of the rake. This time lag, or "Delta," can in fact be quantified by counting the number of recorded fan 128 PPR signals that occur during this Delta. This is easily done since all signals are recorded together on FM tape. As the data shows (see tables I to III), Delta is the absolute phase difference between the rake and fan expressed in total number of fan 128 PPR signals which elapse during this time. However, the real error in the system is the difference of the Delta from revolution to revolution. This would be due to the imperfections and overall jitter of the rake drive system which keep it from running perfectly smoothly. This error is expressed as the standard deviation in tables I to III. The average error for all test speeds was 0.0835°, which is much better than the required tolerance of 1.0°. There were a few isolated instances in which the rake experienced slightly irregular spinning at maximum speed. These instances were isolated to only a few revolutions of the respective test runs. The spinning may have been caused by strain in the motor/drive at these high speeds coupled with larger rig deflections as the rake/model structure swayed more and loaded the bearing more as well. Even though these test run perturbations in rake performance had occurred, the rake motion tolerance stayed within 0.3°.

CONCLUDING REMARKS

Spinning acoustic modes generated from the fans of subsonic engines have been measured using a unique fan-synchronized rotating acoustic rake. The phase position tolerance between the rake and fan of 0.0835° has been achieved in this first application. The versatile control software allows for acoustic mode measurements of this type on a wide range of test engine configurations. The hardware itself can be easily adapted to different machines since it is not mechanically coupled to the test engine. Efforts are already underway to begin further study of these spinning acoustic modes. This is being accomplished by adapting this rake technology to both existing and new fan models. These studies will lay the groundwork for the design of active noise control devices in the subsonic engines of the future.

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7. Compumotor Model 500 Indexer Software Reference Guide. Compumotor Division/Parker Hannifin Corp., 1989.

TABLE I.—SHORT INLET ACOUSTIC RAKE TEST

Trial	Fan speed, rpm	Average Delta, fan signals	Delta, rake degrees	Standard deviation, rake degrees
1	6 600	70.892	0.798	0.0898
2	8 400	67.629	.761	.0366
3	9 600	66.682	.750	.0416
4	10 800	66.787	.751	.0472
5	10 000	69.684	.784	.0516
6	11 400	64.209	.722	.0562
7	12 000	53.683	.604	.2946
8	11 400	71.893	.851	.0557
			Average error	0.0842

TABLE II.—MID-LENGTH INLET ACOUSTIC RAKE TEST

Trial	Fan speed, rpm	Average time differential—rake to fan, fan signals	Delta, rake degrees	Standard deviation, rake degrees
1	9 600	73.158	0.823	0.0582
2	9 600	66.737	.750	.0414
3	11 400	73.970	.831	.2130
4	11 400	66.631	.749	.0766
5	12 000	73.158	.823	.0586
6	12 000	67.421	.758	.0648
7	12 000	51.010	.574	.2798
8	12 000	65.274	.734	.0715
			Average error	0.108

TABLE III.—LONG INLET ACOUSTIC RAKE TEST

Trial	Fan speed, rpm	Average time differential—rake to fan, fan signals	Delta, rake degrees	Standard deviation, rake degrees
1	9 600	66.236	0.745	0.0386
2	10 800	67.526	.759	.0690
3	10 800	64.680	.727	.0653
4	11 400	65.684	.739	.0596
5	11 400	66.842	.752	.0525
6	12 000	66.684	.772	.0583
7	12 000	66.136	.746	.0650
			Average error	0.0583

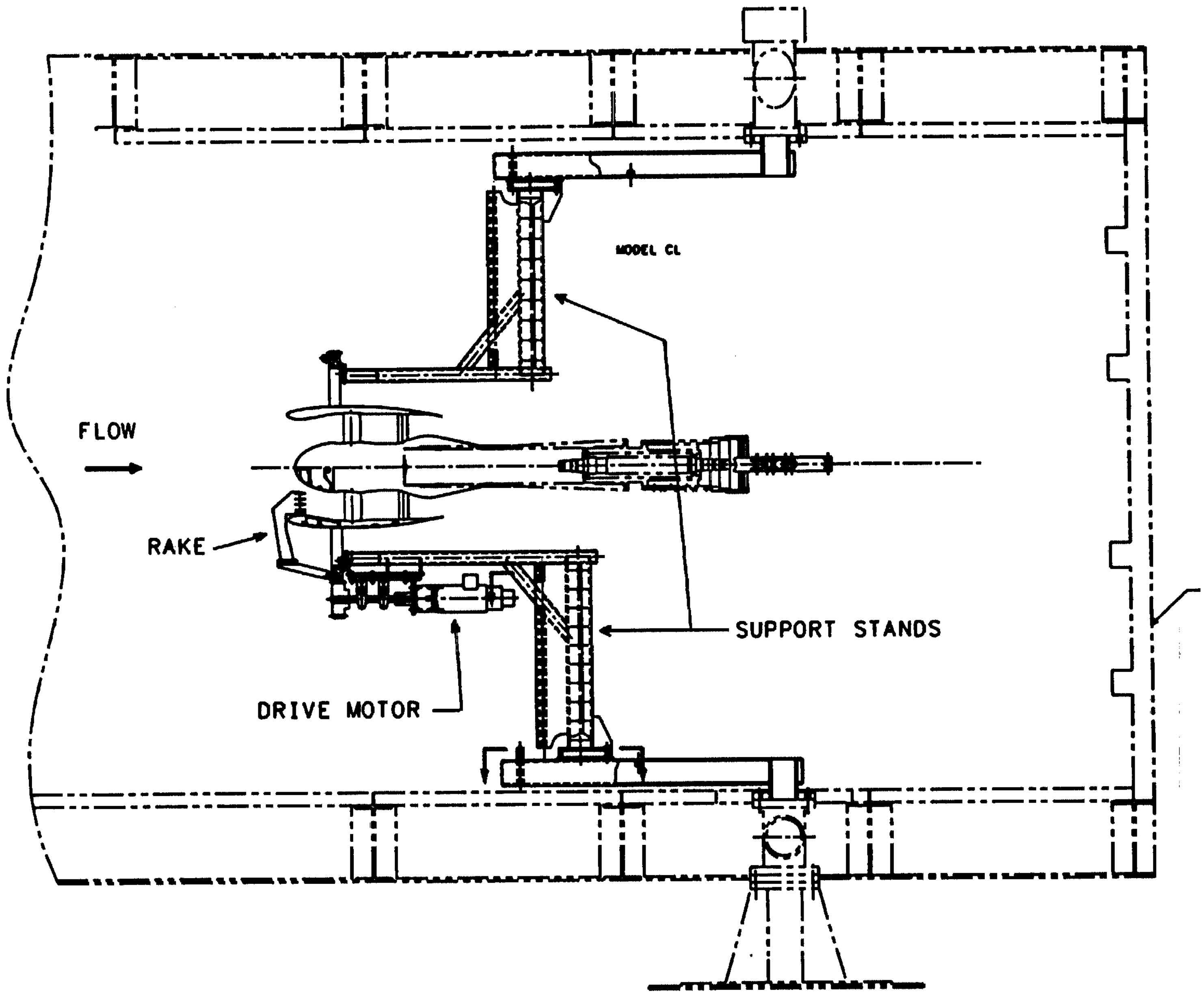


Figure 1.—Rake assembled with ADP model in 9 by 15 wind tunnel.

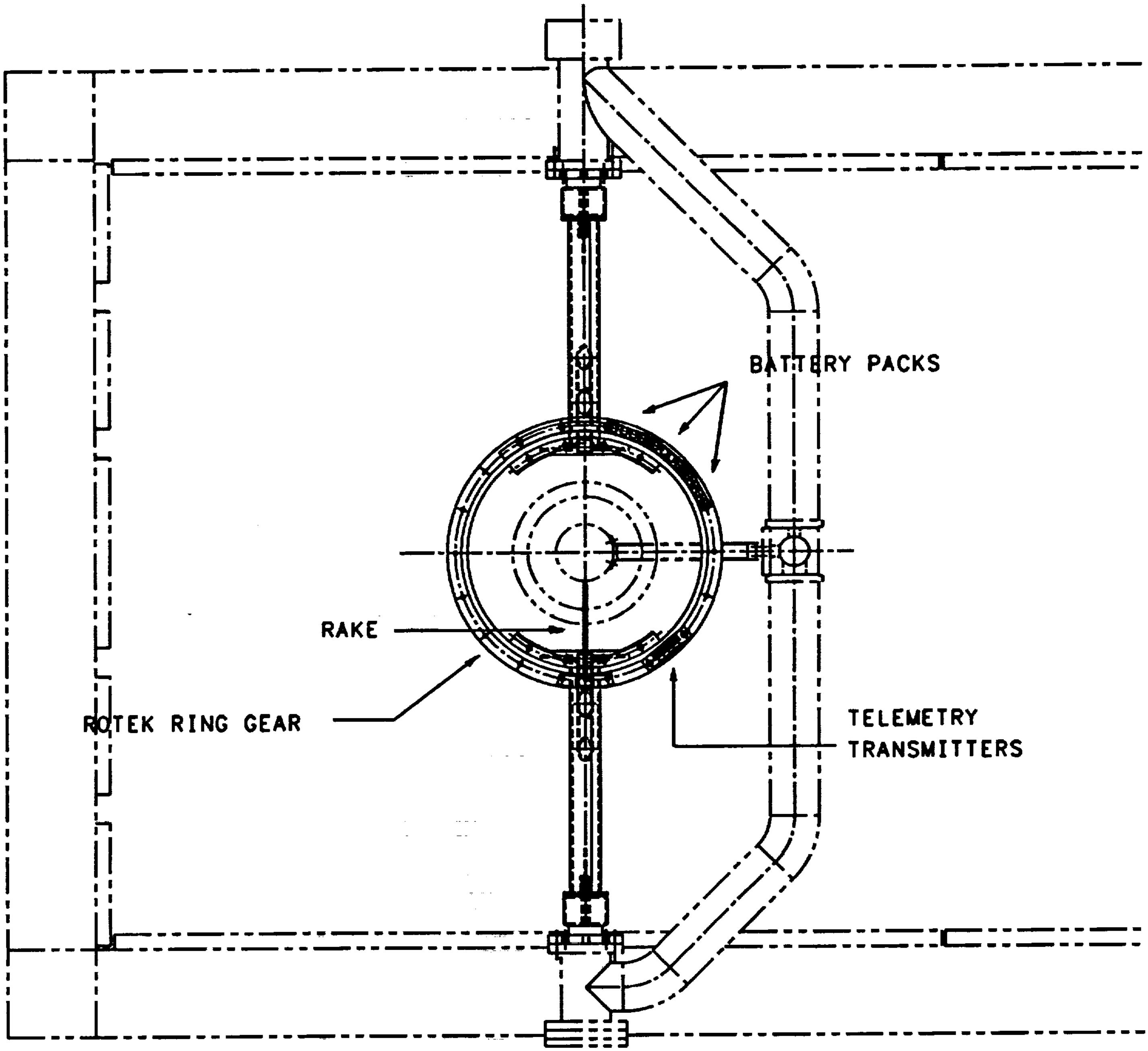


Figure 2.—Rotating rake assembly—end view.

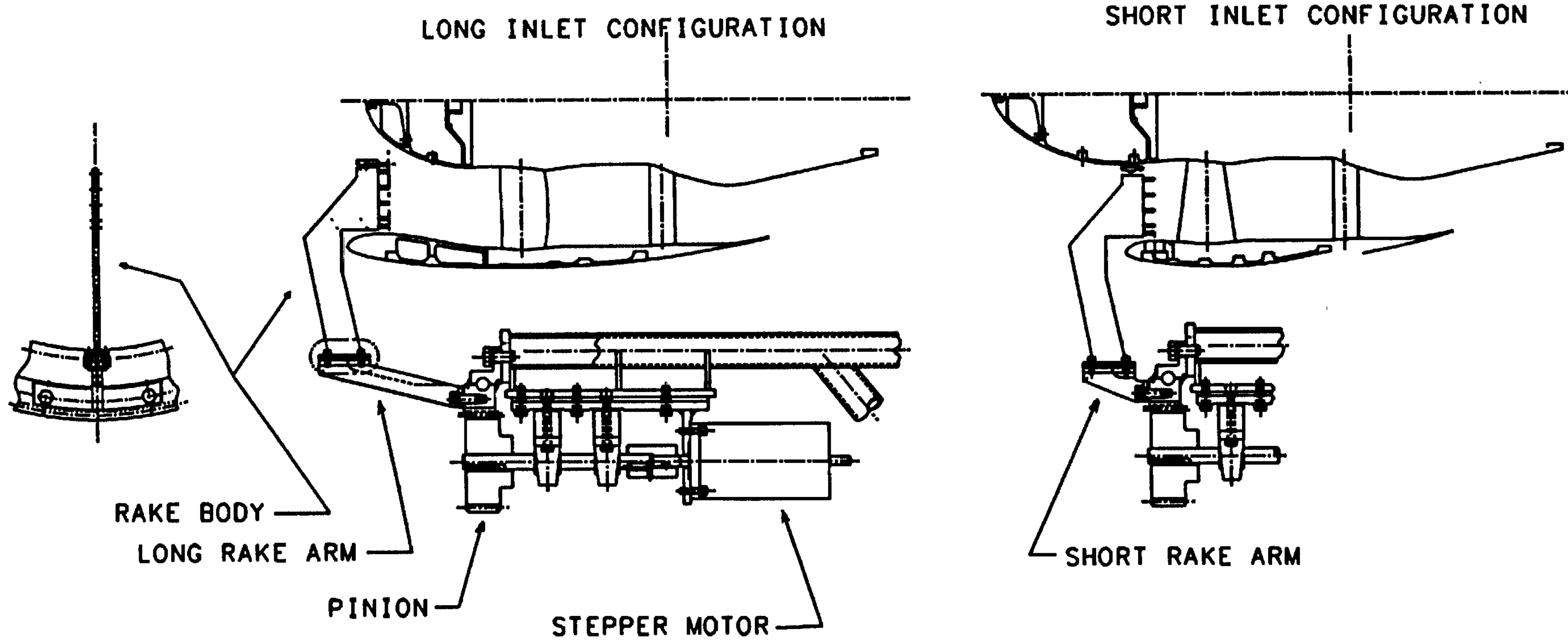


Figure 3.—Rake shown in two different inlet configurations.

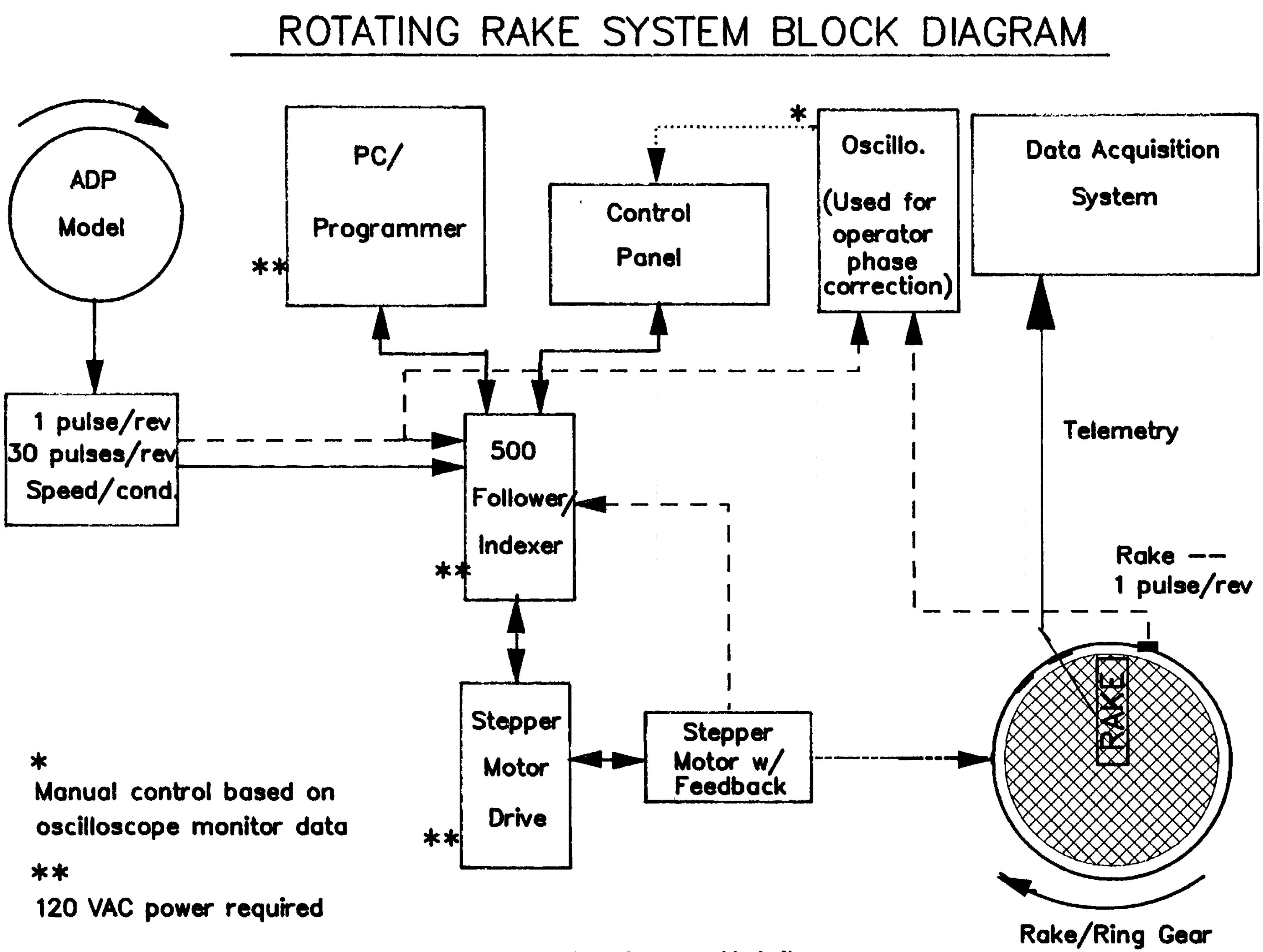


Figure 4.—Rotating rake system block diagram.

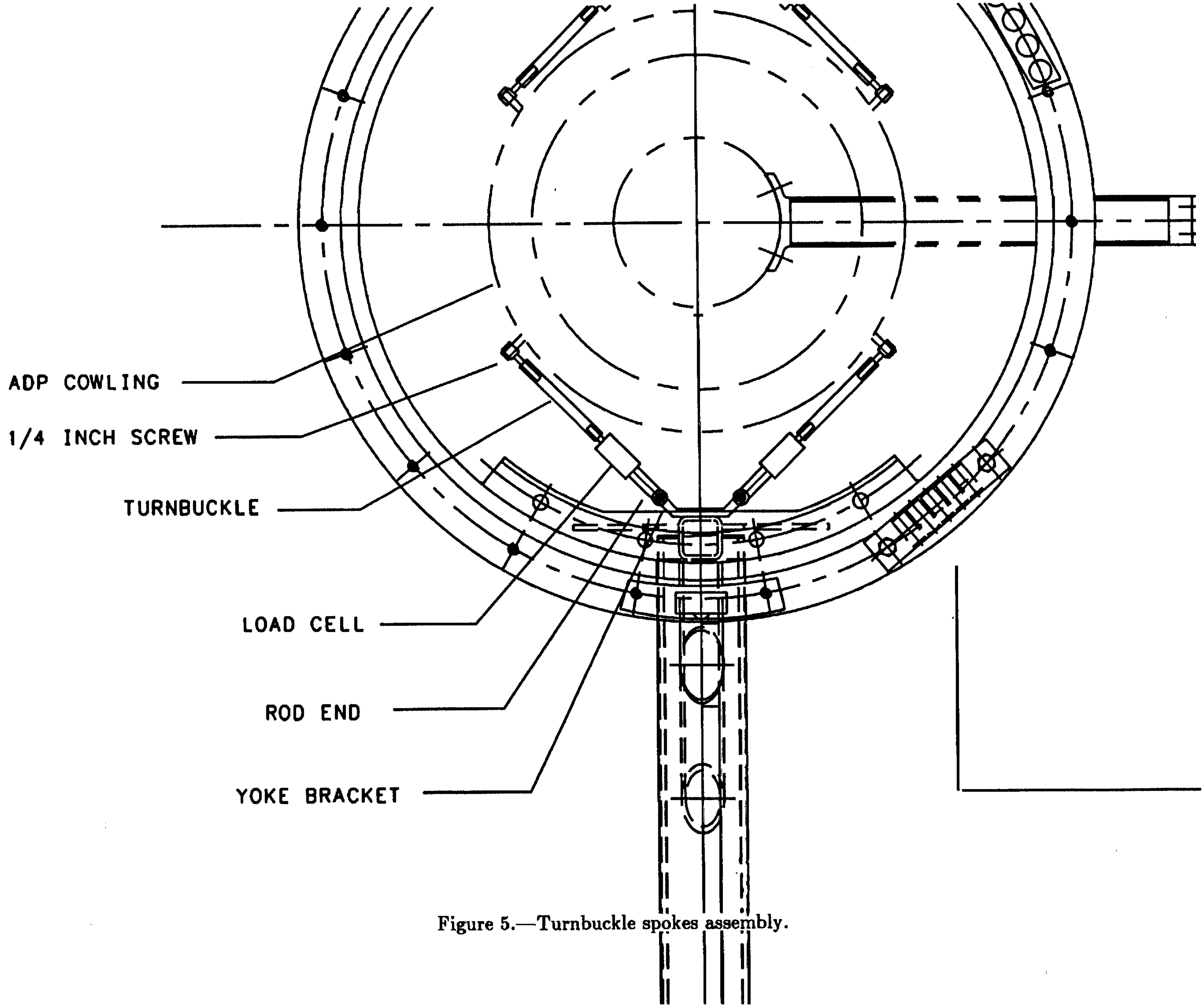
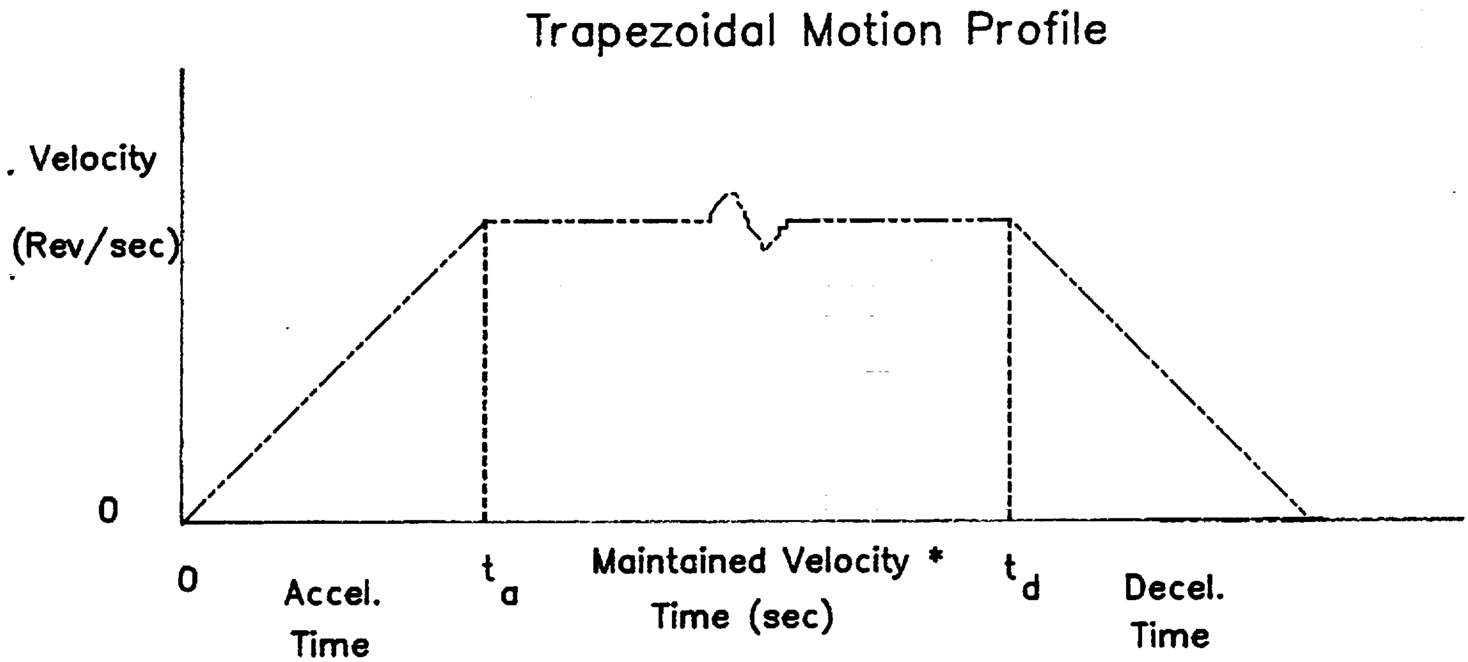


Figure 5.—Turnbuckle spokes assembly.



* The velocity always equals 1/250th of the fan's velocity. This occurs whether the fan's velocity is constant or fluctuating during the run time interval.

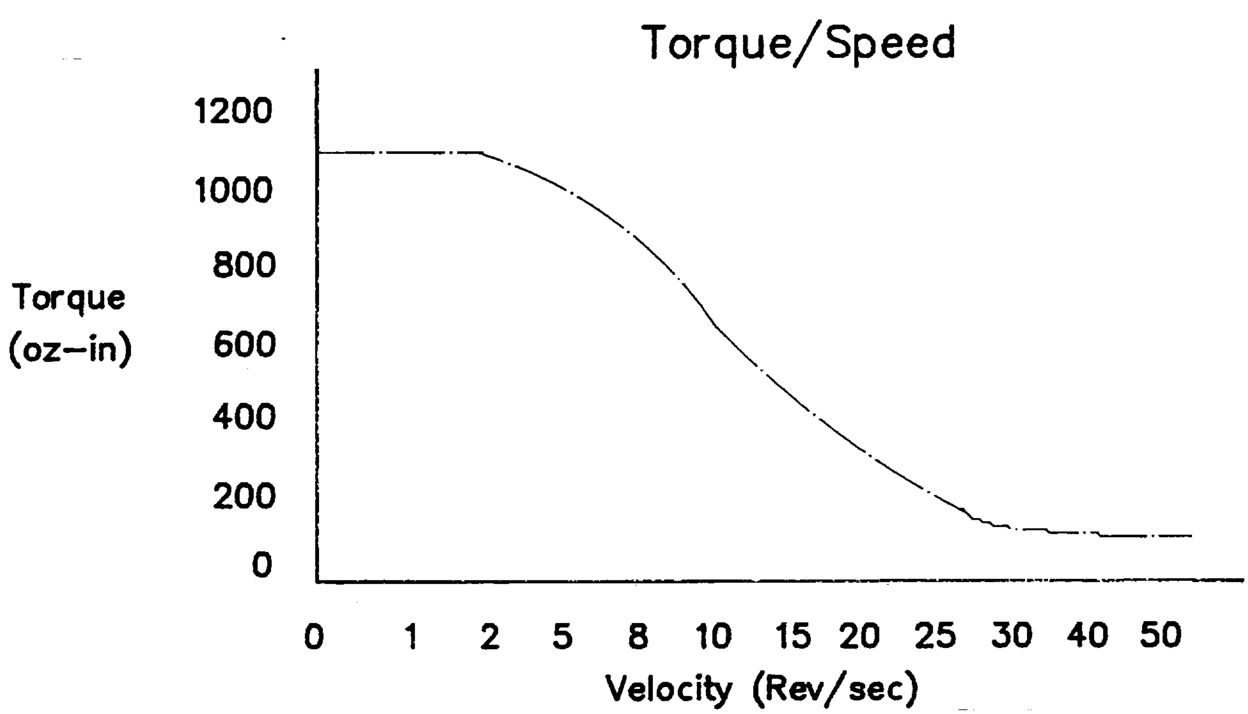


Figure 6.—Trapezoidal motion profile and torque/speed curve.

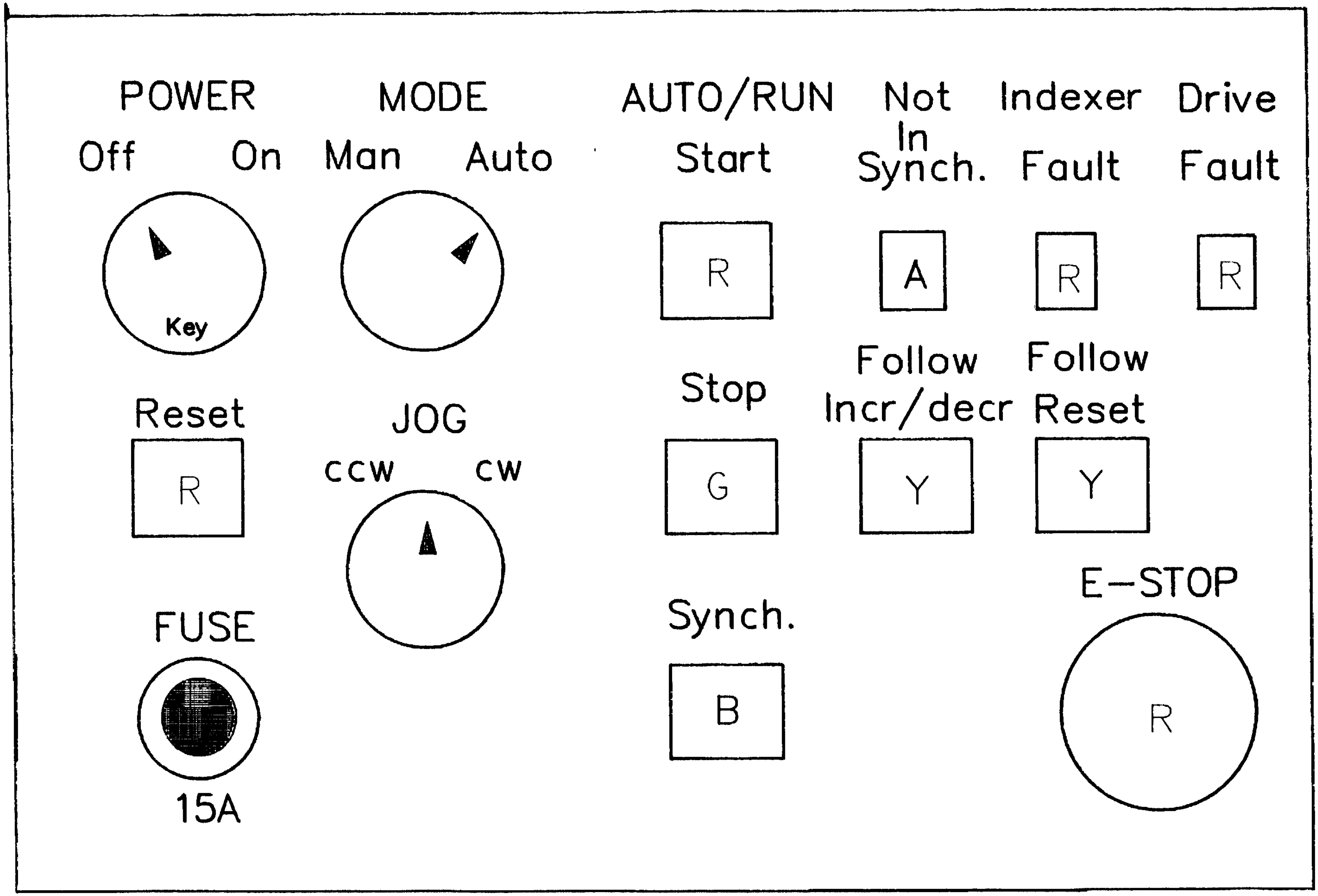


Figure 7.—Indexer/rake control panel.

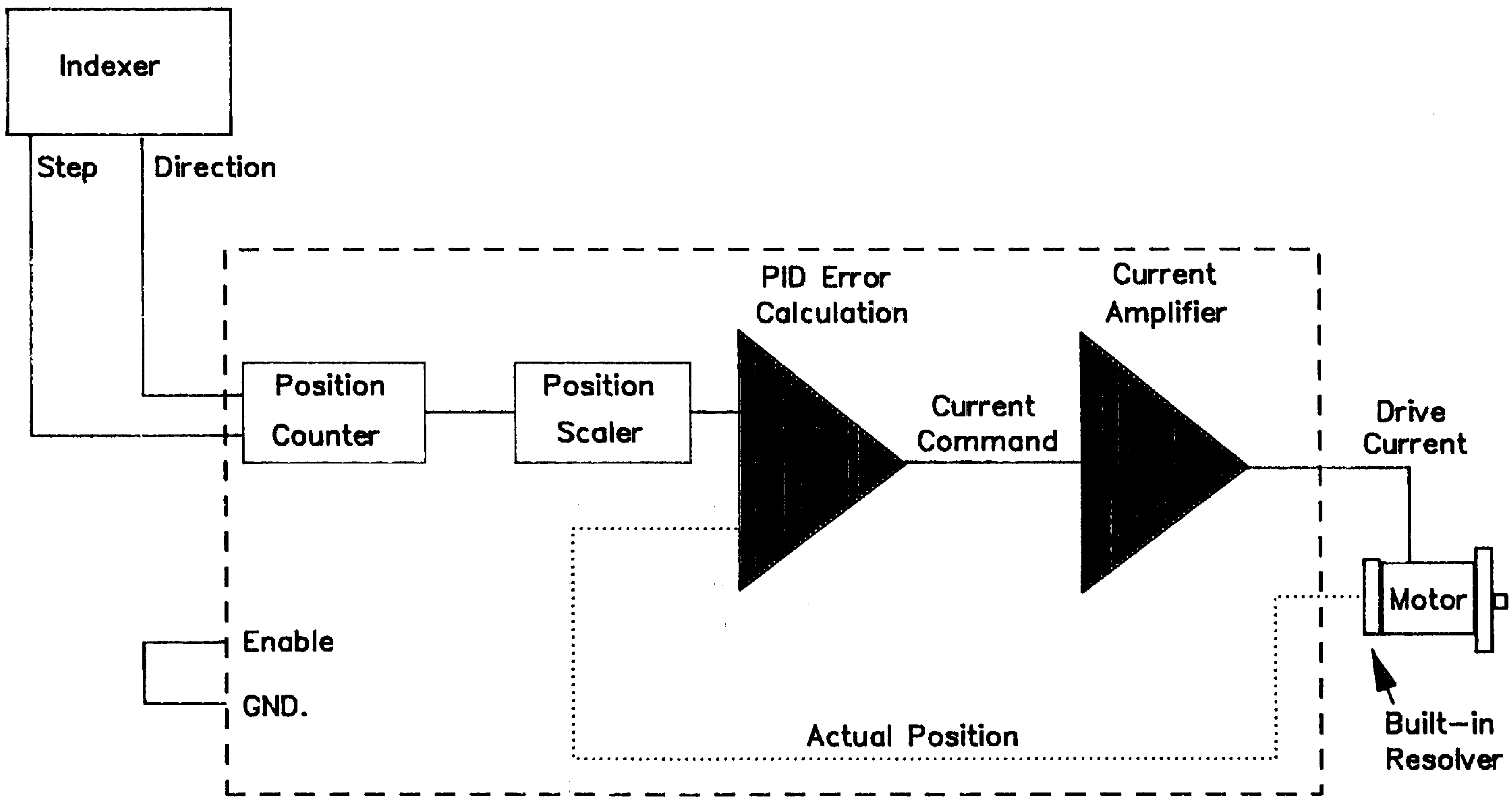


Figure 8.—Compumotor Plus drive loop.

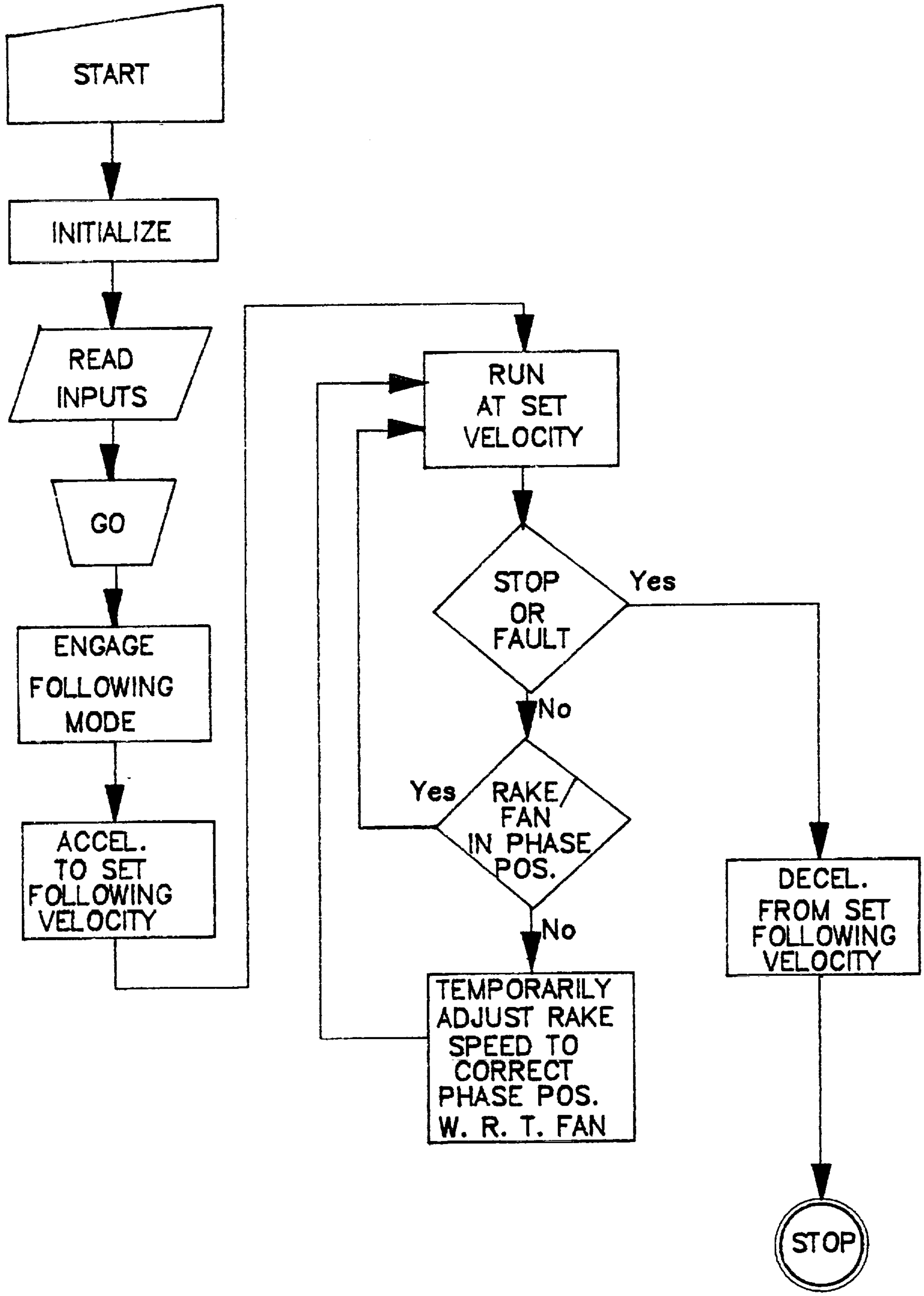


Figure 9.—Acoustic rake motion control software flowchart.

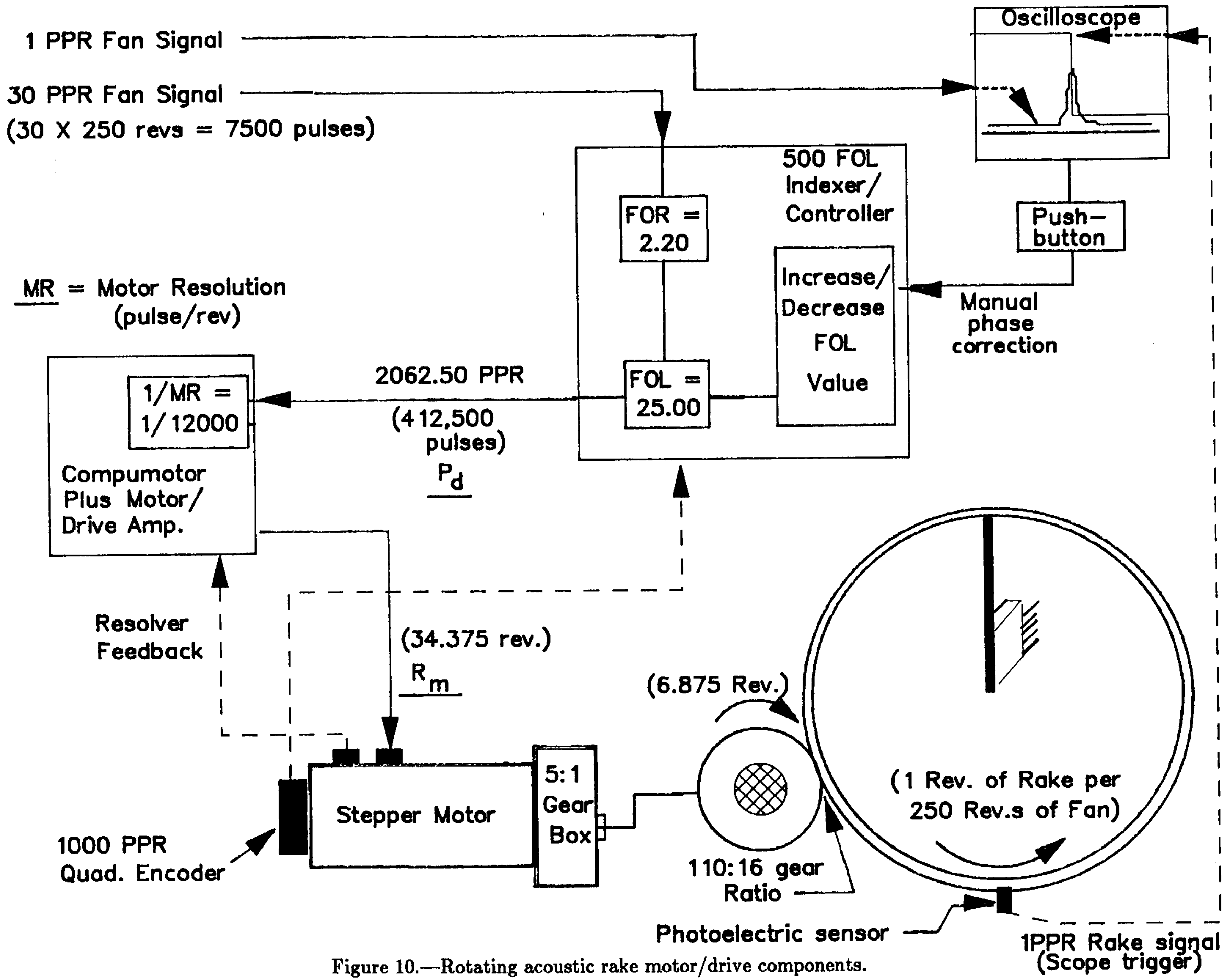


Figure 10.—Rotating acoustic rake motor/drive components.

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Kevin E. Konno and Clifford R. Hausmann

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13. ABSTRACT ***(Maximum 200 words)***
In light of the current emphasis on noise reduction in subsonic aircraft design, NASA has been actively studying the source of and propagation of noise generated by subsonic fan engines. NASA Lewis Research Center has developed and tested a unique method of accurately measuring these spinning acoustic modes generated by an experimental fan. This mode measuring method is based on the use of a rotating microphone rake. Testing was conducted in the 9×15 Low-speed Wind Tunnel. The rotating rake was tested with the Advanced Ducted Propeller (ADP) model built by Pratt & Whitney division of United Technologies. This memorandum discusses the design and performance of the motor/drive system for the fan-synchronized rotating acoustic rake. This novel motor/drive design approach is now being adapted for additional acoustic mode studies in new test rigs as baseline data for the future design of active noise control for subsonic fan engines. Included in this memorandum are the research requirements, motor/drive specifications, test performance results and a description of the controls and software involved.

14. SUBJECT TERMS
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