Sprint 3 Steering Machine Operation

SYSTEM DESCRIPTION

The complete steering machine system is shown in Figure 1. It consists of three main components: the machine itself, the command module, and the battery/electronics box; plus cables from the “B/E box” to the vehicle battery, machine, command module, and data acquisition system, and a hex driver installation tool.

The machine is shown installed in a test vehicle in Figure 2. Normally it clamps to the vehicle steering wheel using the installation tool: but an adapter is provided for installation directly on the steering column. A cable connects the machine to the battery/electronics box containing batteries, battery charging DC/DC converters, signal conditioning, and programming. This “B/E Box” connects in turn to a hand-held command module and to the vehicle charging system. The command module contains pushwheel digital switches: hexadecimal program select; steering amplitude; direction of first turn; and program start speed.

MACHINE DESCRIPTION

The four spoke wood-rim "second steering wheel" is attached to the body of the motor/gearbox assembly, while the gearbox output plate is attached to the vehicle steering wheel by a "skate key" clamp assembly. The "second steering wheel" may be steered by the driver or mechanically "grounded". Grounding is accomplished by a plate running on bearings between the motor/gearbox assembly and the gearbox output plate, with two control rods fixed to the vehicle windshield by suction cups. Two solenoid friction brakes when energized connect this plate to the motor/gearbox assembly, preventing rotation of the "second steering wheel".

The handwheel is fitted with two thumb-operated momentary contact switches at the “10 and 2” positions. The ENERGIZE button controlled by the right-hand thumb activates a B/E-box relay to send 60 volts to the power amplifier, enables the PROGRAM button, and (after an amplifier self-check) releases a fail-safe motor brake. The PROGRAM button controlled by the left-hand thumb is used to start the program sequence counter when it is depressed, and inhibit the counter (pausing the program) when it is released. The program switch also energizes the solenoid grounding brake to lock the handwheel position.

The handwheel contains two additional momentary-contact switches: a red one for resetting the program before each run and a black one for adjusting the zero position of the handwheel. A rocker switch disables the entire system. Two panel meters are provided, to monitor vehicle speed and some other selected variable.

Two green ”klutzlights” indicate the direction of initial programmed turn, for drivers with short memories.

BASIC OPERATION

When the ENERGIZE button is not depressed, the vehicle is under manual control. The motor shaft is locked by the failsafe brake, the servo amplifier output stage is unpowered, and the PROGRAM button is disabled.

In operation, the ENERGIZE button is depressed first, to power the system. The failsafe brake is released, but since the servo commands zero angle between Handwheel and Driven Plate, normal driving is possible. Depressing the PROGRAM switch will ground the Handwheel and initiate the steer program. After this, releasing the Program button will immediately unground the Handwheel and stop the program counter, leaving the vehicle on manual control, but with the servo operational. Releasing the Energize button will immediately release the handwheel grounding brake, apply the failsafe brake, and unpower the servo, with whatever angular relationship exists at the time. Thus the effect of releasing either button produces approximately the same result.

COMMAND MODULE

The command module (Figure 2) is a hand-held box, which is intended to be placed within easy driver reach on the vehicle seat, dash, or floor. The Command Module contains pushwheel digital switches to select one of sixteen separate programs, the desired “maximum” programmed steer angle, and the sign (direction) of initial steer angle. The Command Module also contains a digital switch for setting the speed at which a program will start, if that automation function is used. The command module also has a RESET switch for zeroing the steer angle encoder module.

BATTERY ELECTRONICS BOX

The system is powered by five 12-volt, 5 amp-hour batteries that are connected in series for 60 volts; and a separate 12-volt battery. The batteries are kept charged to 13.6 volts by individual DC/DC converters, which provide galvanic isolation from the vehicle's 12-volt system. DC/DC converters also provide ±15 and +5 volts for signal conditioning. Charging occurs only when the servo is not activated.

The electronics section of the battery/electronics box has plug-in boards: for programming; for conditioning and scaling for the steer angle measurement; and for test automation. The front panel of the B/E Box (Figure 3) has switches for connection to the vehicle battery for charging, power-on for the 12 volt system power, and enable for the “Test Control” module functions. It also contains connectors to the steering machine, command module, and vehicle battery system, and for signal input/output, auxiliary EPROM output and a “data present” switch.

PLUG-IN MODULES

The B/E Box uses three plug-in modules: “Program”, “Steer Angle Encoder” and “Test Control”.

The Program Module generates the analog steer angle signal and feeds it to the Steering Machine. It contains the Program EPROM socket and a socket for an optional second EPROM (AuxROM). The 8-bit AuxROM has the same 18-bit address as the Program ROM: however, its output is brought out to the front panel for flags or other miscellaneous use. The AuxROM output is also fed to a digital/analog converter, in case a second programmed analog signal, synchronous with the steer signal, is desired. Figure 4 shows the Program Module with identification of principal components. Design details can be found in Section 11 of the Tech Manual.

The Steer Angle Module (Figure 5) converts the steer angle encoder signal to analog form and provides switched scaling for nominal settings of 800, 400, 200, or 100 degrees full scale (±10 volts out) as well as potentiometer scaling for any other full scale settings.

Figure 5 shows the Steer Angle Module with identification of principal components.

The Test Control Module utilizes Command Module signals, Auxiliary inputs (e.g., speed, roll rate, brakes), and Flag signals to provide additional automation to a test program. Scaling and offset (coarse and fine) pots are provided for auxiliary inputs along with “zero-crossing windows”. Figures 6A and 6B show the module with identification of the various switches and components. Flow charts and other design details can be found in Section 13 of the Tech Manual.

EPROMS

Each EPROM contains 16 steer programs, selectable by a thumbwheel switch on the Command Module. Programs may be made up of mathematical functions (steps, ramps, sinusoids, etc.) or from previously recorded steer data (manual-steer lane changes, etc.). A program is composed on a personal computer with Windows software and transferred to the EPROM. The hardware, software and detailed instructions are supplied with each machine.

A selected EPROM is installed in the “ZIF (zero insertion force) socket” in the E/Box Program module.

STOCK EPROMS

"Stock" programs are a significant aid in producing consistent vehicle dynamics databases. The most prominent current example is in rollover testing, in which a steering machine is necessary for repeatable and reproducible results. However, most standard test protocols will benefit from automation, to simplify the test itself and to eliminate driver variability and inadvertent changes in the test program. Examples are SAE J266, ISO 7401, and NHTSA NCAP.

EXAMPLE OF STOCK EPROMS - NHTSA NCAP

NHTSA NCAP testing requires measurement of the handwheel angle required for lateral acceleration of 0.3g in a "slowly increasing steer" test, then using steering angles 6.5 and 8 times this for their Road Edge Recovery and J-Turn tests. Steer programs for the "slowly-increasing steer" test may be segmented in different ways according to the available test area: but once determined there is no reason for change. Preparation of new EPROMS as a result of the 0.3g determination is not necessary — it only requires selecting a stock EPROM and program address number within that EPROM for each test.

Analysis indicates that at 0.3g the range of steer inputs will be 30 to 60 degrees. This can be covered in two EPROMs: 30–45 and 45–60 degrees. In order to include extremes, three EPROMs might be used with ranges 20–35, 35–50, and 50–65 degrees.

A 30–45 degree EPROM for a Road Edge Recovery test will have the following programs:

Program Address	Steer Angle Degrees
0	30 x 6.5 = 195
1	31 x 6.5 = 201.5
2	32 x 6.5 = 208
3	33 x 6.5 = 214.5
4	34 x 6.5 = 221
5	35 x 6.5 = 227.5
6	36 x 6.5 = 234
7	37 x 6.5 = 240.5

Program Address	Steer Angle Degrees
8	38 x 6.5 = 247
9	39 x 6.5 = 253.5
A	40 x 6.5 = 260
B	41 x 6.5 = 266.5
C	42 x 6.5 = 273
D	43 x 6.5 = 279.5
E	44 x 6.5 = 286
F	45 x 6.5 = 292.5

If the steer at 0.3g is found to be 37 degrees, then the 30–45 degree Road Edge Recovery EPROM would be selected and set for program address 7.

A required set of EPROMs can be prepared with little trouble. In fact, Heitz will supply 3-EPROM sets for Road Edge Recovery and J-Turn tests at no charge. The ROMsteer programs for these tests can also be downloaded from our website at: http://www.atiheitz.com/download.htm

COMMAND MODULE STEER ANGLE SETTING

Each steer point programmed into the EPROM is actually a percentage of the angle set on the command module. Therefore, the steer angle selected on the command module by the *driver* is the *nominal* maximum steer angle for the program. The programmer uses a “maxsteer” command to set the nominal maximum steer as a reference angle. When the program is compiled, all angles in the program are ratioed to that number. For example, if the maxsteer is 360 degrees, a point in the EPROM will be “50 percent” for 180 degrees. No ratio can be greater than 100%, so the maxsteer must be greater than or equal to the largest angle used in the program.

When running the program in the machine, the steer angle on the command module must be set to the same as the programmed maxsteer in order to achieve the programmed angles. If the command module is set to a higher or lower number, then the resulting steer angles (and rates) will be proportionally higher or lower.

For example: A program uses maxsteer of 360 degrees and a ramp steer from 0 to 180 degrees in 0.3 seconds (600 deg/s). The command module steer angle must be set to 360 in order to get the desired angle. If the command module were set to 180 degrees, then the result would be a 0 to 90 degree ramp in 0.3 seconds (300 deg/s). Similarly, if the command module were set to 720 degrees, then the result would be a 0 to 360 degree ramp in 0.3 seconds (1200 deg/s).

Maxsteer is completely arbitrary as long as it is greater than or equal to the largest angle used in the program (up to 999). Each program in the EPROM can have a different maxsteer value, but in order to reduce possible driver error, we recommend that all programs in an EPROM (or set of EPROMs) use the same value for maxsteer. For example: In our program sets for the NCAP J-Turn and Road Edge Recovery, the maxsteer for all programs is 600, which is a convenient “round” number greater than the highest expected steer of 520 degrees (65 deg x 8 for the J-Turn).

The maxsteer value may be selected so that it is the same for all programs used by an organization.

SYSTEM INSTALLATION

DO NOT INSTALL THE STEERING MACHINE ON A VEHICLE UNLESS THE AIRBAG IS FIRST REMOVED.

STORAGE BOXES

The system is stored in two polyethylene cases. One case contains the Steering Machine, with two steel "red boxes" below and the plate for direct mounting to the steering column below them. One red box contains components for direct mounting, and the other contains tools. The second case contains the Battery/Electronics Box, the Technical Manual, and four red boxes. One red box contains the hand-held Command Module and system cables; the second contains the struts and suction cups for mechanical grounding the Slip Ring Plate; the third contains EPROMS and programming equipment, and the fourth is intended for miscellaneous items.

SYSTEM INSTALLATION

The Steering Machine is designed to attach directly to the vehicle steering wheel, with "mechanical-ground" struts attached to the vehicle windshield or similar structural hard-point to provide a torque reaction for the Machine output. The grounding struts have suction cups on the windshield end, and spherical rod-ends at both ends.

STEERING WHEEL OFFSET

Many steering wheels are offset from the steering column in the vertical direction, and may be asymmetrical in the vertical direction. Centering the Steering Machine on the steering column may therefore require a compensatory offset of the Machine on the vehicle steering wheel.

The "Skate Key" clamping system on the Steering Machine has self-centering synchronous clamps in the horizontal direction, and independently adjustable clamps in the vertical direction (Figure 7).

OPTIONAL DIRECT MOUNTING ON STEERING COLUMN

The vehicle steering wheel is removed and is replaced by a Grant Products splined hub with holes for 3 attaching bolts. One or more Grant spacers are bolted to the hub, and the Heitz adapter is attached to the spacer. The Skate Key clamps may be used with the adapter plate, or the clamping system may be removed from the Driven Plate and the Machine attached directly to the Heitz adapter. With the Skate Key brackets removed, the Adapter can be attached directly to the Driven Plate.

SAFETY STOP

The safety stop limits rotation of the Driven Plate to approximately ±200 degrees. In practice, we know of no one who has ever used it; but since it was described in the original SAE Paper we feel obligated to supply it.

The stop is not functional until a rubber-cushioned pin is installed, through the bottom of the Driven Plate. No Machine disassembly is required (Figure 8).

The limit stop "clapper" slotted disk is driven by a protrusion on the gear/bearing plate (Figure 9). Without the rubber-cushioned drive pin installed a noise (clap) will be heard whenever the freely rotating disk hits the protrusion. If this noise is bothersome the disk may be removed by removing the Driven Plate for access to the disk-retaining snap ring.

CABLING

The 12-volt power-in cable is plugged into the Battery/Electronics Box. The red wire connects to battery positive, the black wire to battery negative or chassis ground, and the green wire to chassis ground. The green wire connects to the cable shield, and carries no current.

The Steering Machine cable is installed. The 37-pin connectors have enough friction that hold-in screws are not necessary on the Machine end.

The 15-pin cable is installed between the Electronics Box and the hand-held Command Module.

CONNECTORS FOR INPUT/OUTPUT DATA SIGNALS

A nine-pin "D-Sub" connector in the Battery/Electronics Box feeds a five-signal cable, each with BNC connectors.

PIN	FUNCTION	COLOR
1	AUX 3 – Optional	Red
2	AUX 2 – Roll Rate In	Green
3	AUX 1 – Speed In	Blue
4	Torque Out	Gray*
5	Angle Out	Black*

*Some early cables used different colors for pins 4 and 5 (e.g. 4=Black and 5=White).

FRONT-PANEL BNC CONNECTOR

The front panel of the Battery/Electronics Box has a BNC connector that is connected to the yellow ON/OFF switch on the Machine Slip Ring plate.

For early Sprint 3 machines: When that switch is ON, 12 volts at approximately 200 milliamps appears at the BNC connector. It is open-circuit when OFF. The return for this signal is Power Common.

For current Sprint 3 machines: When that switch is ON, the BNC tip is switched to Signal Common (which is connected to the BNC shield). It is open-circuit when OFF.

SIGNAL FILTERING

It is assumed that the System will interface with some type of data acquisition system, and that data acquisition system will have anti-aliasing filters appropriate to the data sampling rate. For that reason the Torque Out and Steer Angle Out signals are very lightly filtered.

The Torque Out signal is inherently very noisy because it is obtained from a 30 kHz pulsewidth-modulated square wave. Early units have two single-pole rolloffs at about 80 Hz. In later models these were reduced to about 10 Hz. Noise pickup in the slip rings and cabling is filtered by an 800 Hz rolloff consisting of a 200 ohm series resistor on the machine PC board shunted to ground by a 1 microfarad capacitor located on the Steer Angle module in the B/E box. The data acquisition system should therefore have an input impedance of at least 20,000 ohm.

The Steer Angle signal has only a 200 ohm series output resistor shunted to ground by a 1 microfarad capacitor, but the resistor is inside the feedback loop for low amplifier output impedance.

PROGRAM

System 12-volt power must be OFF when changing EPROMS,

SYSTEM OPERATION

INITIAL TURN-ON

If the system has not been used for several months the internal batteries may be partially discharged. In this case, when the Power-In switch is turned on the system may draw as much as 40 amps for 20-30 minutes, before slowly dropping back to 2-3 amps as the batteries reach full charge.

When the system has been in use, when turned on it will draw high current for only a few seconds before settling back.

Whenever the 60-volt output of the system is energized for servo operation, it draws less than 7 amps.

The system behaves in this way because the battery-charging DC/DC converters are regulated at 13.6 volts; and until the surface charge of the batteries reaches 13.55 volts the converters will put out their maximum overload current. The current draw by the servo amplifier when energized pulls the batteries below this point, and so the converters for the five batteries making up the 60V output are cut out during servo operation to avoid loading the vehicle alternator. The DC/DC converter for the sixth battery, which supplies 12V system power, remains on.

CENTERING THE HANDWHEEL

Depressing the black momentary-contact switch at the center of the Handwheel releases the motor's failsafe brake, so that the Handwheel can be lined up with the vehicle steering wheel. Since in doing so the motors and the motor encoder rotate, the RESET switch must be depressed after each centering operation.

STEER ANGLE ZERO

The System 12-volt (Yellow) switch must be ON. It does not matter whether the system is Energized. The vehicle must be driven in a straight line while the STEER ZERO switch located on the Hand-held Command Module is momentarily depressed.

Steer angle is measured between the Driven Plate/vehicle steering wheel and "mechanical ground". Zero is not dependent in any way on servo operation. It is normally necessary to perform the Steer angle Zero procedure only once, before the first test run. Since the power must be turned off in order to change EPROMs, it may be necessary to re-zero the steer angle then.

TESTING PROCEDURE

1. The driver selects the “max steer” amplitude, the steering program, and the direction of the initial turn using the hand-held command module.
2. The RESET switch is momentarily depressed to reset both the program counter and motor encoder counter.
3. The ENERGIZE switch is depressed, to power the system. The failsafe brake is released, but since in the absence of a program there is a zero angle command and the torque gradient is high, normal driving is possible.
4. Upon reaching the test location and speed the PROGRAM switch is depressed to initiate the program. Depressing the PROGRAM switch will also ground the handwheel.
5. Upon completion of the program, the PROGRAM and ENERGIZE switches are released to restore the system to completely manual control and recharge the batteries.

If the “start at speed” function is used, the driver will select the speed at which the steer program will start. He will bring the vehicle to 3-5 mph above the start speed, then release the throttle and depress the PROGRAM switch. The program will start when the vehicle slows to the set speed.

DEAD MAN SWITCHING

Releasing the ENERGIZE switch at any time unlocks the ground brakes, locks motor shaft, and shuts off the servo amplifier. The system is then on manual control at whatever steer angle that was in effect at the time of disengagement.

Releasing the PROGRAM switch alone unlocks the ground brakes and pauses the program. The vehicle is then on servo control, with whatever steer command that was in effect at the time of disengagement – the same situation as releasing the ENERGIZE button.

OPTIONAL DEAD MAN SWITCHING

As an option, with a different "GAL" chip on the Program Module, releasing the PROGRAM switch *resets* the program instead of *pausing* it. As a result, the vehicle steering wheel will immediately attempt to return to zero angle with respect to the machine handwheel, with the driver supplying reaction torque as ground. Although it is considered "bad" from a human factors standpoint, some test drivers prefer this option.

STEER PROGRAM STARTING IMMEDIATELY WHEN START PROGRAM SWITCH IS DEPRESSED, ROLL RATE FEEDBACK OFF

CHECK

1. Power-In (green B/E Box) switch	ON
2. System 12-volts (yellow B/E Box) switch	ON
3. Test Control (red B/E Box) switch	OFF

B/E BOX SWITCH SETTINGS

1. START PROGRAM JUMPER (Program Module)	OFF
2. SPEED ENABLE	OFF
3. ROLL PAUSE ENABLE	OFF
4. ROLL PAUSE FLAG ENABLE	OFF
5. BRAKE FLAG ENABLE	OFF
6. ROLL 2 ENABLE	OFF

PROCEDURE

1. Select program and direction;
2. Depress RESET switch;
3. Bring vehicle to speed;
4. Depress ENERGIZE switch;
5. Observe Klutzlights to confirm direction of initial turn;
6. Depress START PROGRAM switch;

Program will start immediately when START PROGRAM switch is depressed.

STEER PROGRAM STARTING IMMEDIATELY WHEN START PROGRAM SWITCH IS DEPRESSED, ROLL RATE FEEDBACK ON

CHECK

1. Power-In (green B/E Box) switch	ON
2. System 12-volts (yellow B/E Box) switch	ON
3. Test Control (red B/E Box) switch	ON
4. Roll rate signal present	

B/E BOX SWITCH SETTINGS

1. START PROGRAM JUMPER (Program Module)	OFF
2. SPEED ENABLE	OFF
3. ROLL PAUSE ENABLE	ON
4. ROLL PAUSE FLAG ENABLE	ON
5. BRAKE FLAG ENABLE	OFF
6. ROLL 2 ENABLE	OFF

PROCEDURE

1. Select program and direction;
2. Depress RESET switch;
3. Bring vehicle to speed;
4. Depress ENERGIZE switch;
5. Observe Klutzlights to confirm direction of initial turn;
6. Depress START PROGRAM switch;

Program will start immediately when START PROGRAM switch is depressed. Steer will go to the level at which the Roll PauseFlag is set, and will remain there until roll rate goes through zero, at which time the steer program will continue.

STEER PROGRAM STARTING AT A SET SPEED, ROLL RATE FEEDBACK OFF

CHECK

1. Power-In (green B/E Box) switch	ON
2. System 12-volts (yellow B/E Box) switch	ON
3. Test Control (red B/E Box) switch	ON
4. Vehicle-speed signal present	

B/E BOX SWITCH SETTINGS

1. START PROGRAM JUMPER (Program Module)	OFF
2. SPEED ENABLE	ON
3. ROLL PAUSE ENABLE	OFF
4. ROLL PAUSE FLAG ENABLE	OFF
5. BRAKE FLAG ENABLE	OFF
6. ROLL 2 ENABLE	OFF

PROCEDURE

1. Select program, direction, and speed;
2. Depress RESET switch;
3. Bring vehicle to speed;
4. Depress ENERGIZE switch;
5. Observe Klutzlights to confirm direction of initial turn;
6. Bring vehicle to a speed at least 3 km/h higher than test speed;
7. Depress START PROGRAM switch;
8. Release throttle.

Program will start when vehicle speed equals set speed. Subsequent increase in speed to above set speed will not effect the continuing program.

STEER PROGRAM STARTING AT A SET SPEED, WITH ROLL RATE FEEDBACK

CHECK

1. Power-In (green B/E Box) switch	ON
2. System 12-volts (yellow B/E Box) switch	ON
3. Test Control (red B/E Box) switch	ON
4. Vehicle speed and roll rate signals present	

B/E BOX SWITCH SETTINGS

1. START PROGRAM JUMPER (Program Module)	OFF
2. SPEED ENABLE	ON
3. ROLL PAUSE ENABLE	ON
4. ROLL PAUSE FLAG ENABLE	ON
5. BRAKE FLAG ENABLE	OFF
6. ROLL 2 ENABLE	OFF

PROCEDURE

1. Select program, direction, and speed;
2. Depress RESET switch;
3. Bring vehicle to speed;
4. Depress ENERGIZE switch;
5. Observe Klutzlights to confirm direction of initial turn;
6. Bring vehicle to a speed at least 3 km/h higher than test speed;
7. Depress START PROGRAM switch;
8. Release throttle.

Program will start when vehicle speed equals set speed. Steer will go to the level at which the Roll Pause Flag is set, and will remain there until roll rate goes through zero, at which time the steer program will continue.

STEER PROGRAM STARTING AT A SET SPEED, WITH ROLL RATE FEEDBACK FOR STEER REVERSAL AND ROLLBACK-BRAKING

CHECK

1. Power-In (green B/E Box) switch	ON
2. System 12-volts (yellow B/E Box) switch	ON
3. Test Control (red B/E Box) switch	ON
4. Vehicle speed and roll rate signals present	

B/E BOX SWITCH SETTINGS

1. START PROGRAM JUMPER (Program Module)	OFF
2. SPEED ENABLE	ON
3. ROLL PAUSE ENABLE	ON
4. ROLL PAUSE FLAG ENABLE	ON
5. BRAKE FLAG ENABLE	ON
6. ROLL 2 ENABLE	ON

PROCEDURE

1. Select program, direction, and speed;
2. Depress RESET switch;
3. Bring vehicle to speed;
4. Depress ENERGIZE switch;
5. Observe Klutzlights to confirm direction of initial turn;
6. Bring vehicle to a speed at least 3 km/h higher than test speed;
7. Depress START PROGRAM switch;
8. Release throttle.

Program will start when vehicle speed equals set speed. Steer will go to the level at which the Roll Pause Flag is set, and will remain there until roll rate goes through zero, at which time the steer program will continue. When the program sets the Brake Flag, the brakes are applied. After a program-set period the Brake Flag is reset, but the brakes remain applied until the next zero-crossing of the roll rate signal. At this point the brakes are released.

DESIGN DETAILS

GROUNDING DISK

The grounding disk is fitted with ears for the strut attachment to the vehicle windshield, and a steering wheel angle encoder that is driven by a gear on the driven plate.

When the solenoid "calipers" are energized the rotor is squeezed between rubber "pucks" on the solenoid shafts and rubber crescents in the lower half of the motor plate sandwich. This locks the grounding plate to the upper/lower sandwich plates, and thereby locks the handwheel through the struts and suction cups to the vehicle windshield.

The encoder measures the angle between the grounding disk and the driven plate. Since the grounding disk is clamped to the windshield and the driven plate is clamped to the vehicle steering wheel, the encoder reads the steering wheel angle.

BATTERIES

Five batteries are in series for servo amplifier power. The motors require 35.3 volts for back EMF at 1800 degrees/second, and 45 amps of motor current for 50 N-m at the driven plate at 1800 degrees/second. A current of 45 amps requires 20.3 volts across their 0.45 ohm terminal resistance (motors plus series inductances). The power amplifiers require 4 volts of overhead. The required total is therefore 60 volts. The internal impedance for 5 batteries in series is about 0.085 ohms when they are charged to 13.5 volts, so charged battery output is 63 volts at 45 amps. Maximum torque and maximum speed seldom occur simultaneously: however, the batteries can provide 56-60 volts at 50 amps to the amplifier terminals for short periods under usual test conditions, as might be required for fast ramps or maximum sinusoids.

PROGRAM CIRCUITRY

A crystal oscillator provides the basic 32 kHz clock frequency, which is divided down to form the EPROM address clock frequencies of 2048, 1024, 512, and 256 Hz. The address clock frequency used is selected by two EPROM output lines, and can be changed "on the fly" during a program.

The EPROM has a 18-bit address input. The lower 14 bits are controlled by a counter driven by the address clock, and the upper four bits by the PROGRAM SELECT function of the Control Module. Thus, sixteen separate programs are available, each having 16384 steps at rates of 2048 down to 256 steps per second, in program lengths from 8 seconds to 64 seconds.

The EPROM output has sixteen bits. The lower 12 bits are used in a D/A converter to generate an analog control command signal. The first two upper bits are used to select the address clock frequency. The third is used to inhibit the program counter at any desired point so that it will not begin to repeat if the driver fails to release the PROGRAM switch. The fourth Flag is used as a PAUSE flag for use in feedback functions such "wait for roll angle peak".

The lower twelve EPROM data bits are fed to a multiplying D/A converter. Here the digital EPROM signal is multiplied by the amplitude/sign signal from the control module. Scaling is ±9.99 volts at ±999 degrees from the Control Module, so an "ALL-ONES" EPROM signal commands a negative 180 degrees steer signal if the Control Module is set at -180.

A second EPROM is included on the Program Module to provide external control signals. It has the same 18-bit address, and an 8-bit output which is buffered and brought out to the front panel as external Flag signals, for turning recording instruments on or uncaging gyros, or operating throttle or brake servos. The external Flags may be programmed as individual ON/OFF signals, as duty-cycle modulated analog signals, in multibit words, or alternatively, as a single analog signal thru an on-board 8-bit D/A converter.

FEEDBACK CIRCUITRY

The 200-count motor encoder is fed thru a 4X quadrature counter and a 16-bit D/A converter to provide a motor resolution of 0.45 degrees, which yields 0.03 degrees at the Driven Plate. This voltage is summed with the PROGRAM COMMAND signal to form the servo error voltage. This signal is PID (proportional/integral/derivative) equalized before being sent to the power amplifier.

POWER AMPLIFIERS

The two pulsewidth modulated power amplifiers (one for each motor) are Elmo “Violin”, Model 15-100. They are designed for supply voltages between 20 and 96 volts. Internally-limited peak current capacity is 30 amps, reducing to 15 amps continuous current capacity after 2.7 seconds at an average (rms) current of 30 amps. The amplifiers are self-protected against short-circuit, overvoltage, and overheating. They are operated in current mode, in which motor current is proportional to servo error regardless of motor speed.

TORQUE DATA SIGNAL

The current in a permanent-magnet motor is an accurate measure of motor output torque. A precision 0.05 ohm resistor is placed in series with the motor leads. The voltage drop across this resistor is a reliable measure of motor current. This voltage is amplified in an isolation amplifier, corrected for motor friction, and made available to the data system. The circuit is located on the Motor Encoder card.

The friction torque from motor brushes, bearing seals, and gear meshes, amounting to about 2 percent of full-scale, creates hysteresis in any attempt to measure torque by measuring motor current. In theory, a signal equal to the total friction torque can be subtracted out from the current signal, leaving only the load torque signal. To correct for friction the output of a motor direction flip-flop is conditioned, gain-controlled, and subtracted from the torque signal out of the current isolation amplifier. With the motor running slowly and freely, the "friction signal" is adjusted to produce a zero torque signal output.

STEERING ANGLE MEASUREMENT

The steering angle resolution is determined by that of the encoder (360 counts/revolution, multiplied by X1 or X4) and the gearing (440/44 gear teeth) between it and the driven plate. Resolution is ±0.025 degrees at 4X and ±0.1 degrees at 1X. A 16-bit D/A converter with a binary-gain instrumentation amplifier produces a switch-selected full-scale output of 800, 400, 200, or 100 degrees.

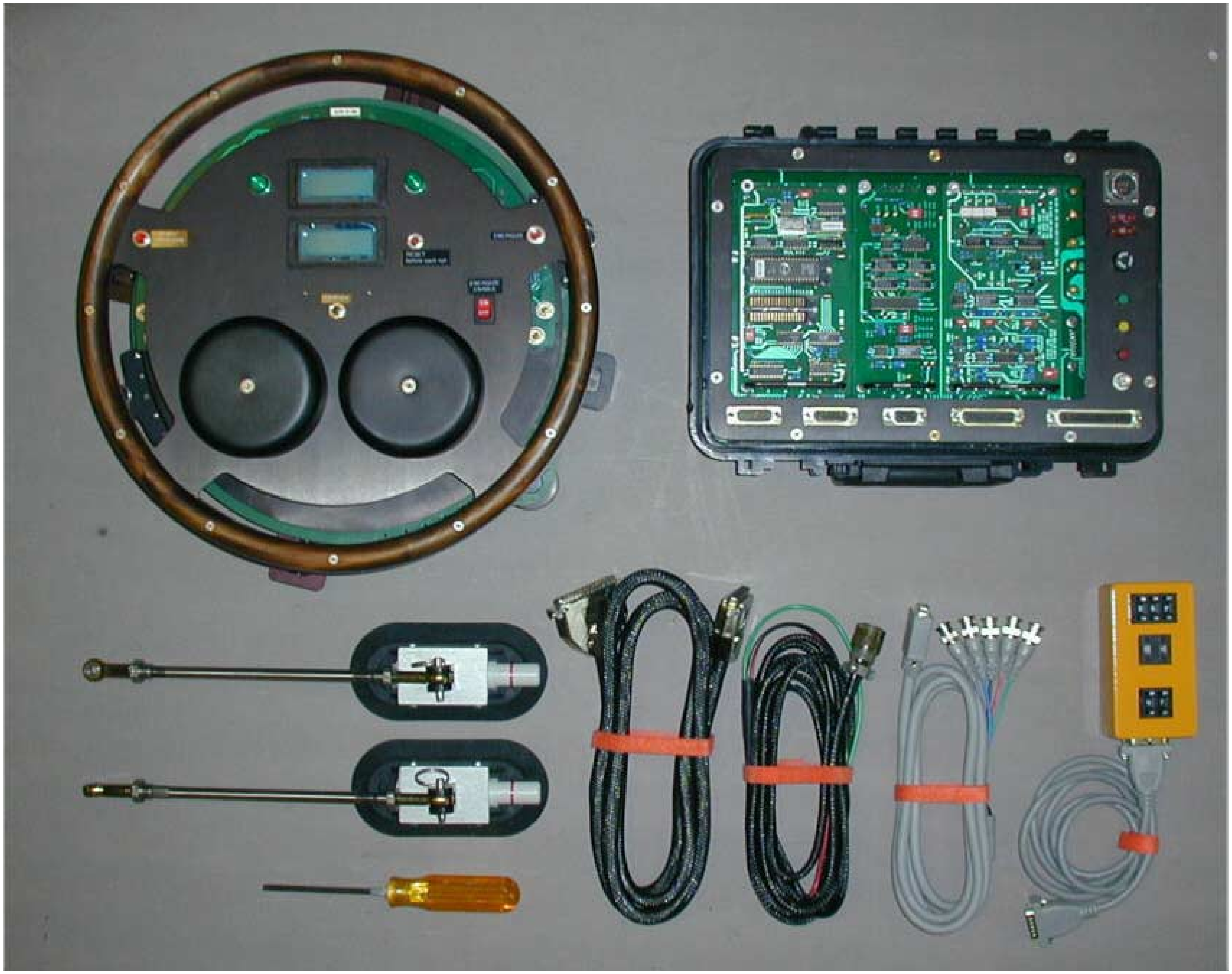

Figure 1: Sprint 3 system

Figure 2: Sprint 3 machine and Command Module installed in vehicle.

Figure 3: Sprint 3 Steering Machine Electronics Box Connections

1. 12V POWER IN: 3-pin Pygmy connector. The supplied cable terminates in 3 wires (red for vehicle battery "+"; Black for battery "-"; Green for shield (chassis ground).

2. Fuse for 12V input: 30 amp ATO blade type. (Tech manual page 10-2)

3. Fuse for system 12V output: 10 amp ATO blade type. (manual page 10-2)

4. Fuse for 60V output to Machine: 20 amp high-voltage ceramic cartridge type. (manual page 10-2)

5. Input Power Switch. Must be on to charge batteries and/or operate machine.

6. System Power Switch. System electronics are powered when this is on.

7. Test Control Switch: The test control module has no effect unless this switch is on. See Tech manual section 13.

8. The signal at this BNC connector is normally open-circuit and is switched to Sig Com by a solid-state relay when the yellow (push-on, push-off) button on the machine slip ring is depressed (on). It is not used by the machine, so it is available for user applications. See Tech manual page 2-3.

9. Machine Connector: This is a 37-pin connector interface to the steering machine. A custom-made cable is used.

10. Test Control Connector: This is a 25-pin connector interface to additional test automation components. It is not used for steer-only operation. No cable is supplied.

11. Signal In/Out connector: This 9-pin connector is used for input and output of signals to/from an external data acquisition system. The return for each of these signals is signal common. The supplied cable separates the signals into 5 separate colored BNC cables identified as follows (also see Tech manual page 2-3):

    1. Red   Aux3 – Throttle In. Not currently used for steer-only test control.
    2. Green   Aux2 – Roll Rate In. Used for reversing steer at peak roll angle.
    3. Blue   Aux1 – Speed In. (Top LCD display). Also used for beginning program at set speed.
    4. *Gray   Torque Output
    5. *Black Angle Output

    * Note that these colors may not be correct as they vary in different cables.
    (e.g. one other available cable has 4=Black and 5=White)

12. Command Module connector: This 15-pin connector interface to the Command Module. The supplied cable is a standard off-the-shelf cable except that pin 10 has been cut out. Pin 10 on the connector is blocked as a key to avoid accidentally in plugging an AuxRom cable.

13. AuxRom Output connector: This 15-pin connector is available for outputs from the Auxiliary EPROM for custom use. No cable is supplied. Pin 12 of this connector is keyed (blocked) to prevent accidentally plugging in the Command Module. Some pins may also be used for external monitoring of the program command voltage and the Start Program signal.

14. Steer EPROM socket: This is a 40-pin ZIF (zero insertion force) socket. A programmed Steer EPROM must be inserted for operation. System power must be OFF when changing EPROMs. The EPROM is inserted so that pin 1 is to the left as shown in the picture.

15. Aux EPROM socket: This is a 32-pin ZIF socket. A programmed Auxiliary EPROM may be inserted if it is used for additional test automation function. This is not necessary for steer-only control. System power must be OFF when changing EPROMs. The EPROM is inserted so that pin 1 is to the left as shown in the picture.

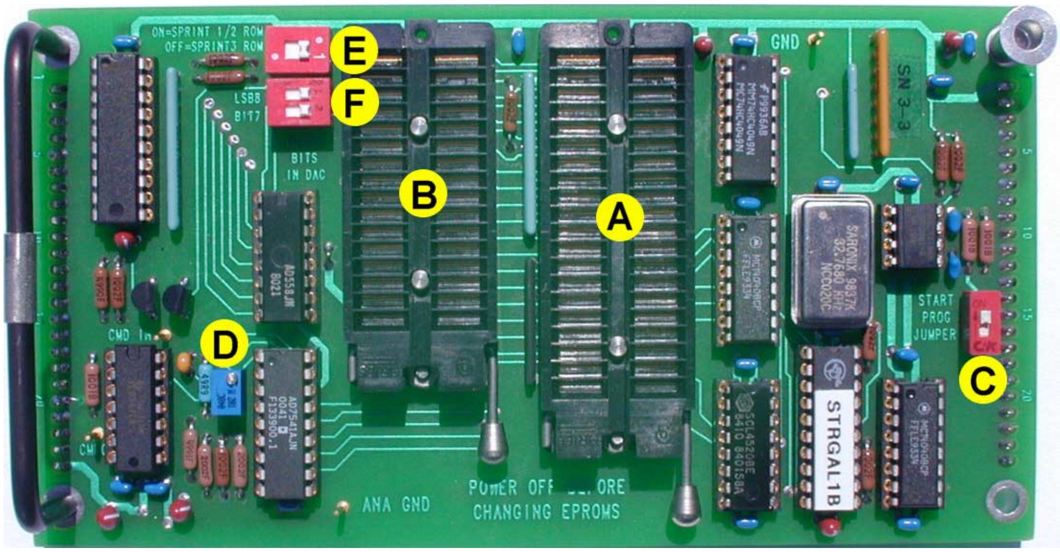

Figure 4: Program module

A: Steer program EPROM socket
B: Aux EPROM socket.
C: Start Program switch
D: Command output offset adjustment potentiometer
E: Compatibility switch to enable use with Sprint 1 and Sprint 2 EPROMs
F: Aux DAC "lsb" switches

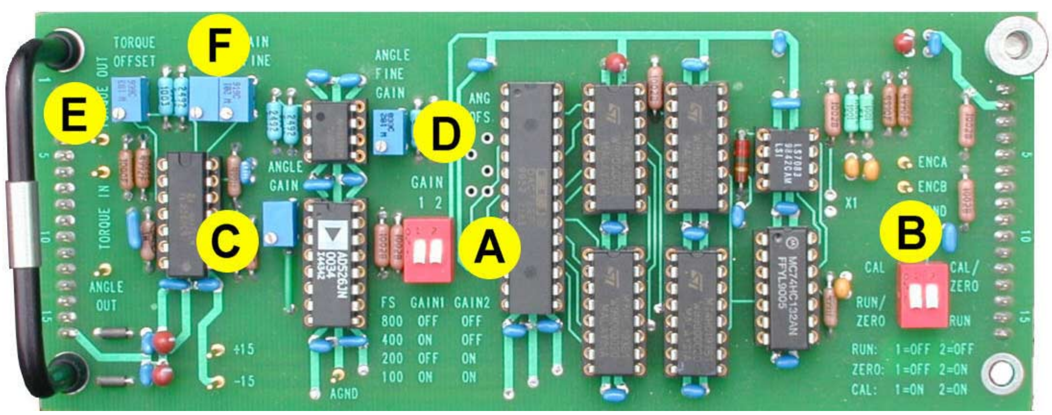

Figure 5: Steer Angle Module

A: Steer angle Gain switches
B: Zero/CAL switches
C: Steer angle coarse Gain potentiometer
D: Steer angle fine Gain potentiometer
E: Torque offset potentiometer
F: Torque fine and coarse gain potentiometers

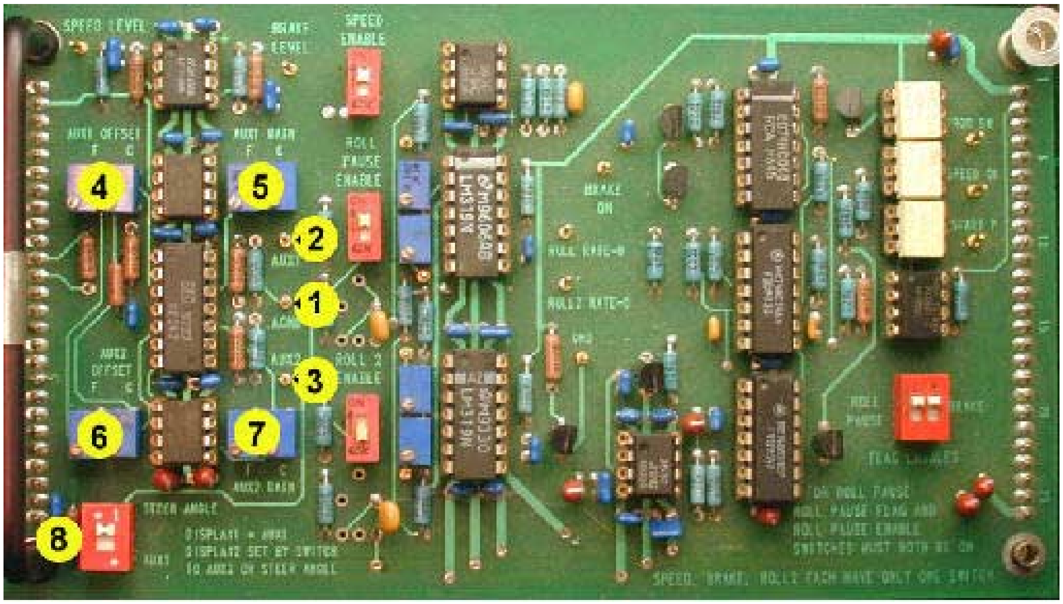

Figure 6A: Test Control Module with Aux1 and Aux2 controls identified.

1: Test point for Analog Ground. This is the reference ground for analog signals.

2: Test point for Aux1 voltage output to display and test control circuit.

3: Test point for Aux2 voltage output to display and test control circuit.

4: Aux1 offset adjustment potentiometers (fine and coarse).

5: Aux1 gain adjustment potentiometers (fine and coarse).

6: Aux2 offset adjustment potentiometers (fine and coarse).

7: Aux2 gain adjustment potentiometers (fine and coarse).

8: Switch that selects either steer angle (↑) or Aux2 (↓) for display on the lower handwheel LCD display.

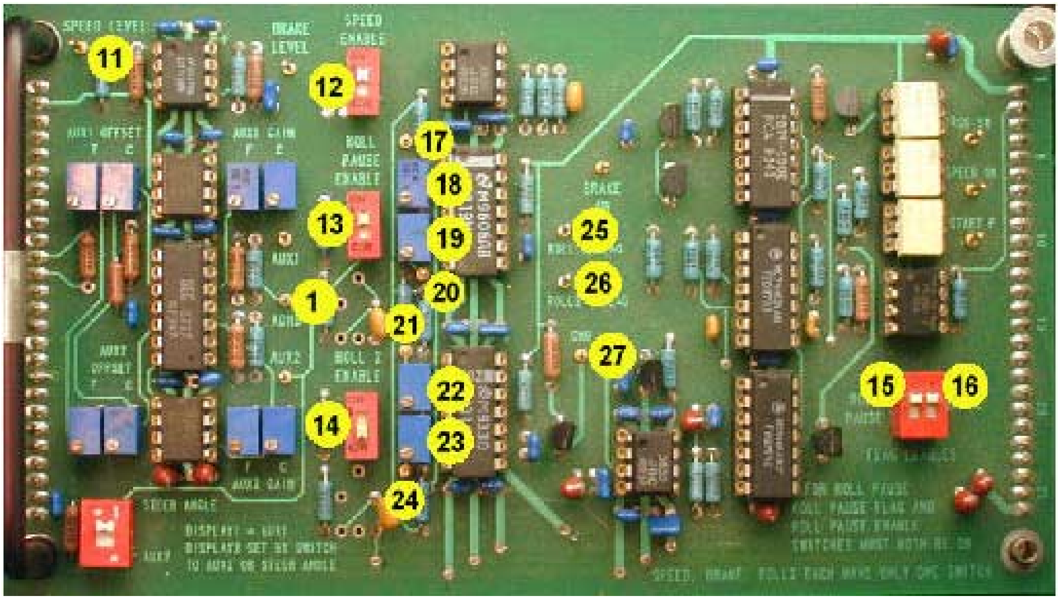

Figure 6B: Test Control Module with Speed and Roll Pause controls identified.

1: Test point for Analog Ground. This is the reference ground for analog signals.

11: Test point for Speed Level. This voltage is set by the Speed pushwheel switch on the Command Module.

12: Speed Enable switch. The Aux1 Speed input is enabled when this switch is ON (↑).

13: Roll Pause Enable switch. The Aux2 Roll rate input is enabled (for roll pause) when this is ON (↑).

14: Roll 2 Enable switch. The Aux 2 roll rate input is applied to the second comparator when this is ON (↑).

15: Roll Pause Flag Enable switch. The Roll Pause Flag is enabled when this switch is ON (↑).

16: Brake Flag switch. The brake flag input is enabled when this switch is ON (↑).

17: Test point for the upper limit of the “roll rate = 0” window for roll pause (roll rate feedback).

18: Potentiometer used to adjust window upper limit voltage at test point (17).

19: Potentiometer used to adjust window lower limit voltage at test point (20).

20: Test point for the lower limit of the “roll rate = 0” window for roll pause (roll rate feedback).

21: Test point for the upper limit of the “roll 2 = 0” window.

22: Potentiometer used to adjust “roll 2” window upper limit voltage at test point (21).

23: Potentiometer used to adjust “roll 2” window lower limit voltage at test point (24).

24: Test point for the lower limit of the “roll 2 rate = 0” window.

25: Test point for the “roll rate = 0” digital signal.

26: Test point for the “roll 2 rate = 0” digital signal.

27: Test point for Digital Ground. This is the reference ground for digital signals.

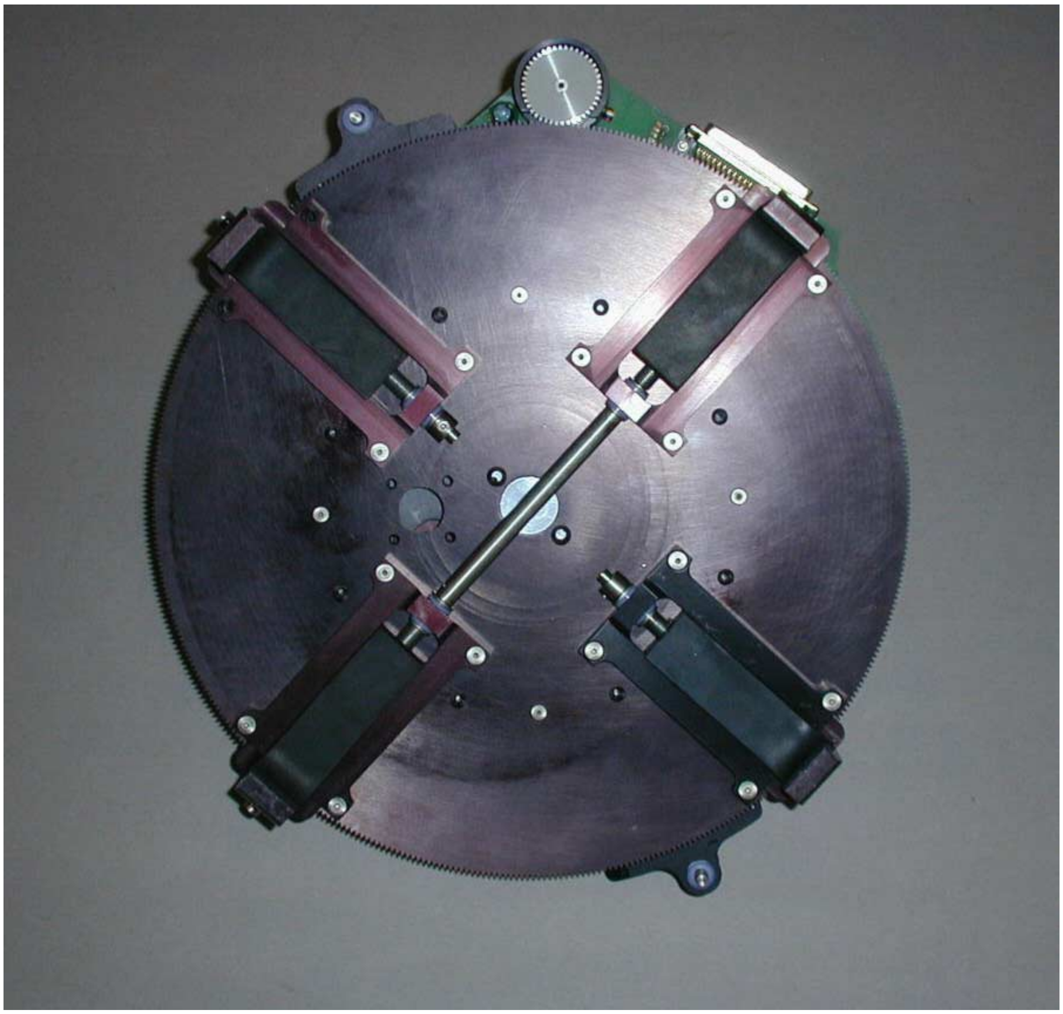

Figure 7: Driven Plate with Skate Key

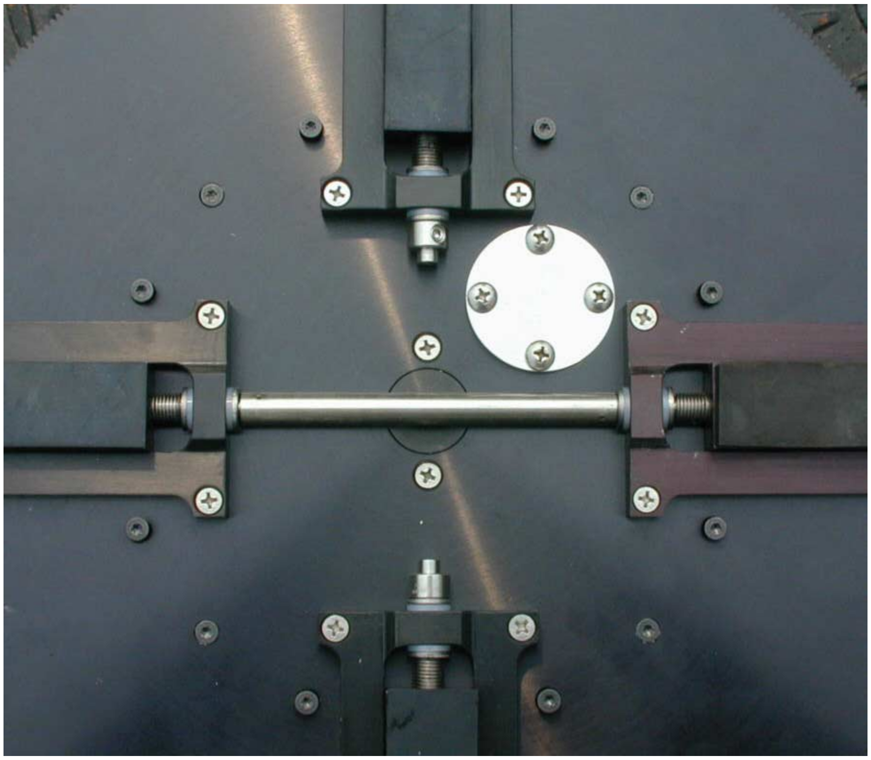

Figure 8: Driven Plate with mechanical stop pin installed.

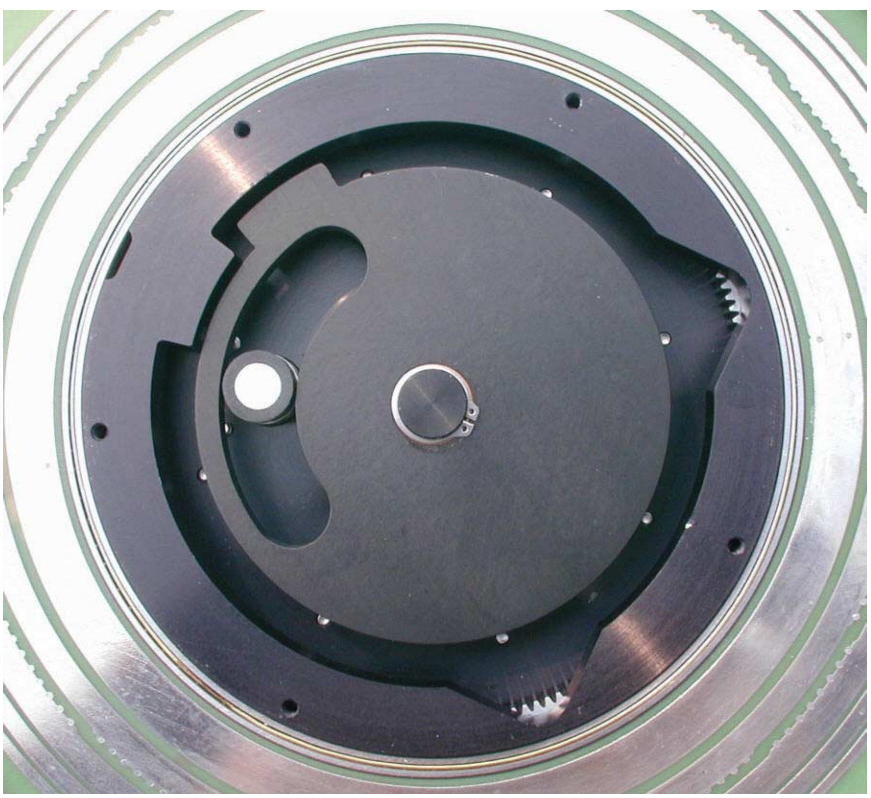

Figure 9: Slotted disk with pin.