Trans

C

125

VARIABLE DYNAMIC FORCE VECTOR ROCKET TEST APPARATUS

By Melvin H. Lucy, Robert L. Swain,
and John L. Hudson, Jr.

NASA Langley Research Center
Langley Station, Hampton, Va.

Presented at the Second Annual Meeting of the
ICRPC Working Group on Static Testing

Redlands, California
October 21-23, 1964

[redacted]

VARIABLE DYNAMIC FORCE VECTOR ROCKET TEST APPARATUS

By Melvin H. Lucy, Robert L. Swain,
and John L. Hudson, Jr.

NASA Langley Research Center
Langley Station, Hampton, Va.

N66 33424

ABSTRACT

In an effort to systematically study and evaluate the effects of dynamic motor environments on the performance characteristics of solid rockets, the NASA Langley Research Center has installed a special test apparatus capable of imposing variable conditions of roll and/or longitudinal accelerations on solid rockets while firing. This Dynamic Force Vector Rocket Test Apparatus employs the centrifugal principle utilizing a 4-foot-radius rotating arm which will produce up to 30,000g pounds with a 100-pound rocket motor specimen. Within the rotating arm is a separately driven spin shaft capable of simultaneously rolling the test specimen about its longitudinal axis at rates up to 3000 rpm. Individual controls are provided for the rotating arm and the spin shaft which are both electrically driven and separately adjustable and variable over their entire range. Test specimen instrumentation is provided through the use of double slipring assemblies. The test specimen can be counterbalanced through a weight system prior to each test as required but the apparatus is designed to withstand the full unbalance which could result from loss of specimen. This paper presents the design details of this specialized rocket test apparatus and its performance characteristics obtained to date.

Author

INTRODUCTION

There has arisen an area of growing concern to the Rocket Community, involving the effect of flight vehicle dynamics, namely acceleration and roll rate, on solid rocket motor booster performance. The NASA Langley Research Center employs spin stabilization on a large number of its flight vehicles with roll rates ranging from several cycles per minute to rates in excess of 30 cycles per second in some cases. Flight test data on solid rocket booster performance obtained from some of these vehicles exhibit marked differences when compared with static firing data. In an effort to systematically study and evaluate the effects of dynamic motor environments on the performance characteristics of solid-propellant rockets, the NASA Langley Research Center has installed a special test apparatus capable of imposing variable conditions of roll and/or longitudinal accelerations simultaneously on solid rockets while firing. This Dynamic Force Vector Rocket Test Apparatus employs the centrifugal principle as shown in figure 1, utilizing a rotating arm to produce the longitudinal acceleration loading and a separate spin shaft within the rotating arm to simultaneously roll the test specimen about its longitudinal axis. Test programs are planned which will consider the isolated or combined effects on rocket performance of any or all of the following variables:

a. Propellant composition.
b. Motor roll or spin rate.

L-4167

[redacted]

c. Motor longitudinal acceleration.
d. Motor internal configuration.
e. Burning surface - acceleration field orientation.

Data generated by these studies should prove invaluable in the future design of solid-propellant motors which must meet the demands of a high-level dynamic environment imposed by vehicle considerations. This paper presents the design details of this specialized rocket test apparatus and its performance characteristics obtained to date.

DISCUSSION

Test complex.- The Variable Dynamic Force Vector Rocket Test Apparatus is housed within a 24-foot inside-diameter cylindrical test cell which is earth barricaded as shown in figure 2. A blowoff roof with a removable hatch immediately above the machine for maintenance purposes is employed. Housing for the test apparatus drive power and control equipment as well as for test specimen instrumentation is provided in a separate building adjacent to the test cell. This test complex is complete and self-supporting, requiring no additional facilities for control or instrumentation. The test apparatus as shown in figures 3a and 3b employs a rotating arm of a 4-foot radius which revolves in a horizontal plane normal to the vertical machine center line and is capable of producing in excess of 33,000g pounds with a 100-pound rocket motor specimen.

Test machine.- A spin shaft within the rotating arm is separately driven and capable of simultaneously rolling the test specimen mounted to the end of the rotating arm about its longitudinal axis at rates up to 3000 rpm. Individual controls (fig. 4) are provided for the rotating arm and the spin shaft which are both electrically driven and separately adjustable and variable over their entire range. The test specimen can be counterbalanced through a weight system prior to each test, as required.

Rotating arm.- The rotating arm revolves counterclockwise when viewed from above the test machine. The plane of rotation is within ±0.010 inch of the horizontal at the 48-inch radius. The driving force is supplied through a timing belt by a 40-horsepower variable-speed d-c motor whose power source is a motor-generator set located remotely in the instrumentation building. The control system is adjustable and continuously variable within the following tolerances:

a. Sensitivity of manual speed set point is better than ±1 percent as indicated on a digital counter.

b. Indicated speed on the digital counter varies less than 1 percent from the mean average speed reading.

c. The drift rate of the mean average speed as indicated on the digital counter for any setting of the manual set point station does not exceed 1 percent of the mean average speed reading obtained over a period of 2 minutes.

Bearing support; rotating arm.- The bearing support for the rotating arm is accomplished through the use of two (2) sets of tapered roller bearings. These bearings are Timken Type [illegible]ne No. 67787 and Cup No. 67720. The bearings are rated at 16,500-pound radial load and 14,000-pound thrust load. The moment applied to the main shaft supporting the rotating arm amounts to 80,000 inch-lb which causes a radial load of 2500 pounds in each of the tapered bearings. The only thrust load applied to these bearings is due to the weight of the main shaft, the rotating arm, the counterweights, the specimen, and the pre-load applied to the tapered bearings. The actual maximum operating speed of these bearings is only 500 rpm's. Lubrication is accomplished through the use of grease fittings.

Thermocouples.- Thermocouples are provided on the bearings of both the rotating arm and the spin shaft. Minimum bearing design life was for 5000 hours total operation or 2500 hours at 300g's and 1500 rpm with maximum unbalanced load caused by loss of 30 pounds of propellant.

Statically balancing.- As previously mentioned, provisions have been made which allow the rotating arm to be statically balanced before each run and a locking mechanism prevents the balance weights from moving during the firing. The design allows for the capability of withstanding the unbalanced load for 30 minutes resulting from the loss of 30 pounds of propellant. The design also allows for the capability of withstanding the full unbalanced load resulting from loss of the entire 100-pound specimen until deceleration of the machine can be accomplished. A maximum motor thrust load of 1500 pounds in a direction opposing the centrifugal force was a design condition.

Spin shaft.- The spin shaft rotates clockwise when viewed from the specimen toward the center of the machine. The driving force is supplied through a timing belt by a 4-horsepower variable-speed d-c motor. The power source for this motor is a Diode and Thyratron Rectification System located remotely in the instrumentation building. The control system is separately adjustable and continuously variable within the following tolerances:

a. Sensitivity of manual speed set point station allows the operator to make incremental changes of ±2 percent as indicated on a digital counter.

b. Indicated speed on the digital counter varies less than ±2 percent of the mean average speed reading.

c. The drift rate of the mean average speed as indicated on the digital counter for any setting of the manual set point station does not exceed ±1 percent of the mean average speed reading obtained over a period of 2 minutes.

Bearing support; spin shaft.- The spin shaft incorporates three (3) bearing housings. The locations and descriptions are as follows:

a. One (1) ball-type bearing by the test specimen. This bearing is an MRC-220 R rated at a radial load of 6000 pounds (based on a 500-hour running time) and 4800 rpm when using grease as the lubricant. In actual use, this bearing is carrying a radial load component resulting from the dynamic forces involved of only 1500 pounds. This bearing does not have to withstand any thrust load.

b. Two (2) duplex-angular contact bearings mounted at the center of the spin shaft support all the spin shaft thrust loads. These bearings are

NIRC-9316 U rated at 7,350-pound radial load and 7,350 pounds of thrust. The machine is capable of inducing 50,000 pounds of thrust but the counterbalance system allows for the reduction of this force to zero. The changing loads caused by the burning of propellant are easily handled by these bearings. The actual radial loads on these bearings do not exceed 2,300 pounds of force.

c. One (1) roller-type bearing is used at the counterbalance weight flange. This bearing is an MRC No. 7316 designed to only support radial loads as the rollers are capable of sliding with respect to the outer race. This motion allows growth or shrinkage between shaft housings, mounts, and the spin shaft proper. The bearing is capable of withstanding 13,000 pounds of radial load. The actual radial load is only 3,000 pounds.

Lubrication of these bearings is critical and is accomplished by filling them to 35 percent of their grease capacity every 500 hours. Cooling of these bearings has been enhanced due to circulation of the air around and through the machine during its operation. No heating up of these bearings has been detected to date under operating conditions.

Tachometer.- A pulse-type tachometer (Hewlett-Parker type 508) is provided for each drive system with the following ranges:

a. 3600 pulses/revolution of rotating shaft.

b. 600 pulses/revolution of spin shaft.

An electronic frequency meter is also provided for each drive system (Hewlett-Packard type 500 B). The meter has four (4) usable ranges and its accuracy is better than ±2 percent of scale, linearity of current at output meter jack is ±0.1 percent of full scale on all usable ranges. An electronic counter (Hewlett-Packard type 521 C) is provided with an accuracy of ±1 count. The output of either the rotating arm or spin shaft can be displayed on the counter.

Sliprings.- Two (2) rotary assemblies, electrical slipring and brush type, are provided for test specimen instrumentation. Each assembly includes twelve (12) instrumentation rings suitable for use in strain-gage circuitry with input voltages up to 12 volts and gage outputs from 2 to 12 millivolts. Two of the rings in each assembly are used for the firing circuit. The instrumentation rings are low noise silver rings with silver graphite brushes. All sliprings and wiring are insulated to withstand 150 volts without breakdown. Insulation between rings is nonmoisture absorbing and maintains a resistance between adjacent rings and rings and ground in excess of 100 megohms. Additional sliprings have been provided for monitoring the test apparatus. All instrumentation leads, wiring, and slipring assemblies have been adequately shielded from adjacent power circuits and from each other to prevent interference with instrumentation signals. At all operating speeds of both shafts, the noise level of the instrumentation ring and brush assemblies is less than 50 microvolts in a 50-milliampere d-c bridge circuit. The slipring assembly on the spinning shaft is located at the center of the machine and on the center line of the shaft to minimize the effects of "g" loading. The sliprings for the spin shaft power system are separated and shielded from the test specimen instrumentation in order to prevent stray current pickup.

Operating conditions.- Operating conditions for this specialized apparatus were established as being normal atmospheric pressure and ambient temperatures.

Safety.- A safety interlocking system is provided which insures that neither shaft can be operated while the test cell door is opened. Closed circuit TV is provided to monitor the test apparatus and the specimen during tests. Fastax cameras are located at several stations around the test cell wall to observe the motor during test.

Instrumentation.- Figure 5 shows in block form the instrumentation associated with this facility. The sensors consist of pressure and strain transducers, thermocouples, and other special instrumentation as required. These strain-type signals are fed through conventional signal conditioning units (Elcor Model BSC-416) and into the recording equipment (CEC Model 114). Signals are also fed from the thermocouple sensors into the thermocouple calibration unit and then into the recorders. As can be noted from figure 5, the conditioned signals can be recorded on magnetic tape and fed directly into an electronic computer for reduction.

SUMMARY

In summary, the NASA Langley Research Center has installed and is presently using a Dynamic Force Vector Rocket Test Apparatus employing the centrifugal principle for simulating in ground tests the dynamic environments experienced by rocket motors in free-flight applications. This test apparatus is capable of imposing on a 100-pound specimen simultaneous conditions of roll rates to 3,000 rpm and "g" loadings to 340g's.

CONCLUSIONS

This test apparatus will provide a useful tool to systematically study and evaluate the effects of dynamic motor environments on the performance characteristics of solid-propellant rockets under carefully controlled conditions. Data acquired from the use of this test apparatus should prove invaluable to the rocket motor industry in the future design of solid-propellant rocket motors which must meet the demands of a high-level dynamic environment imposed by vehicle considerations.

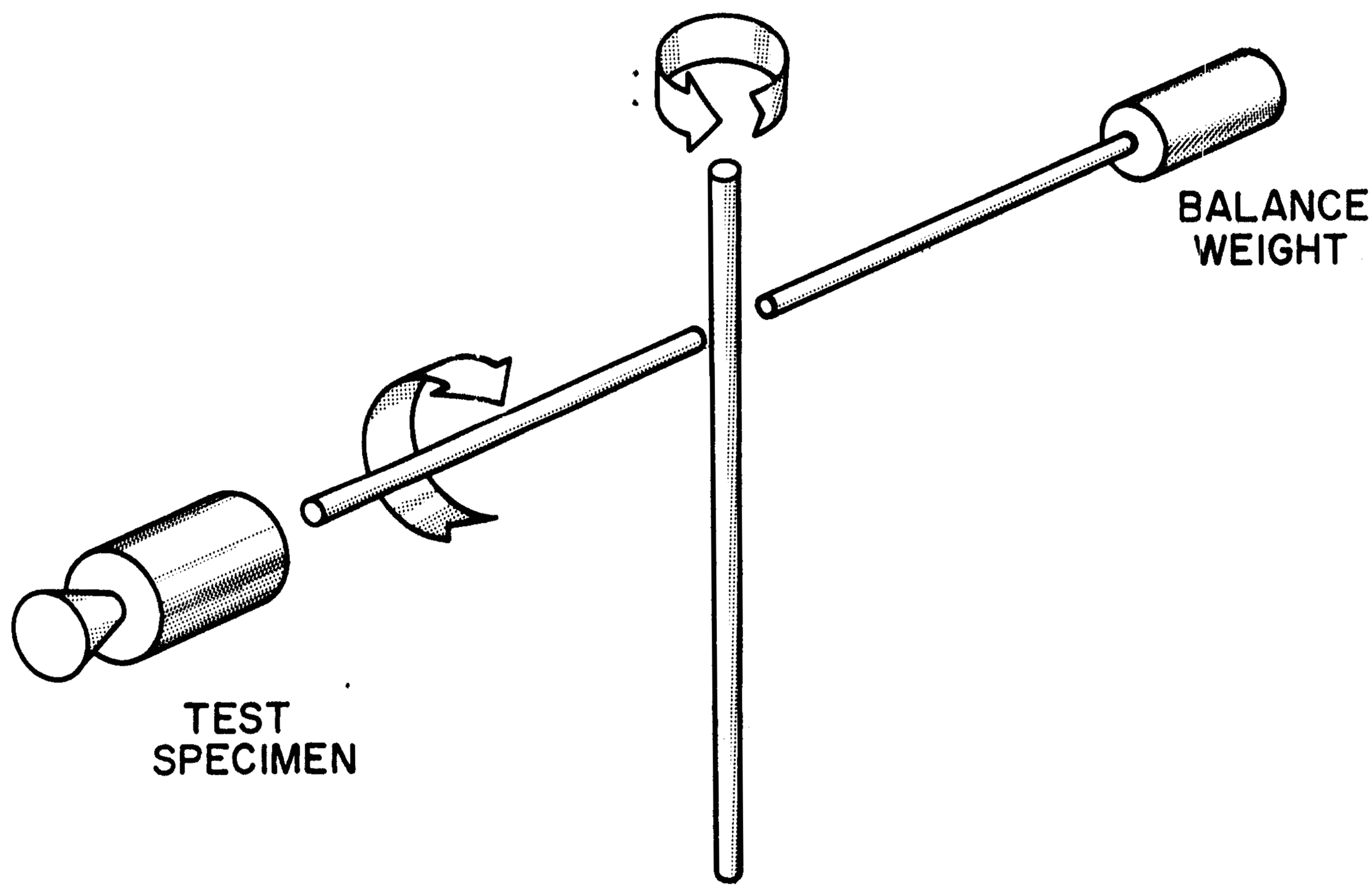

FIGURE 1. APPARATUS SCHEMATIC.

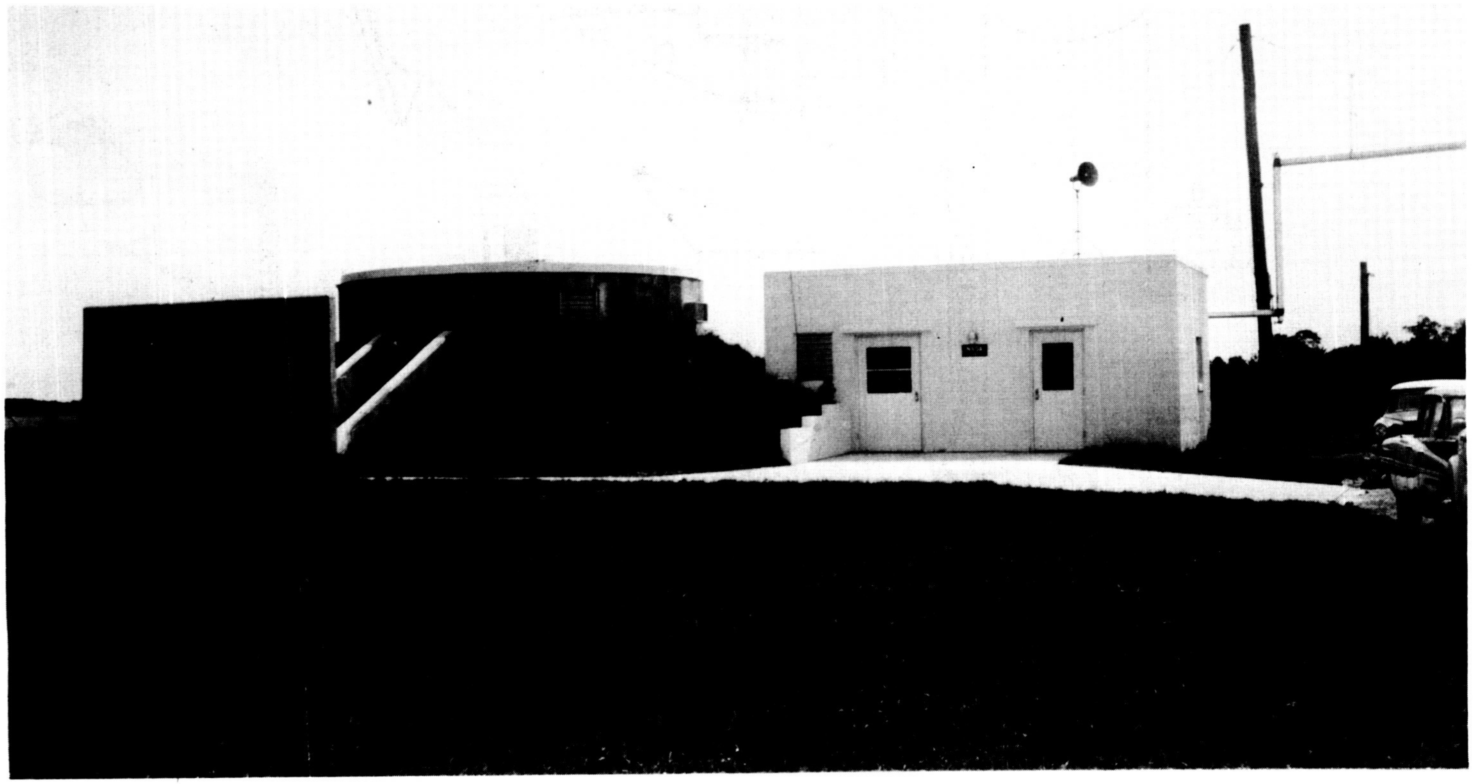

FIGURE 2. TEST COMPLEX.

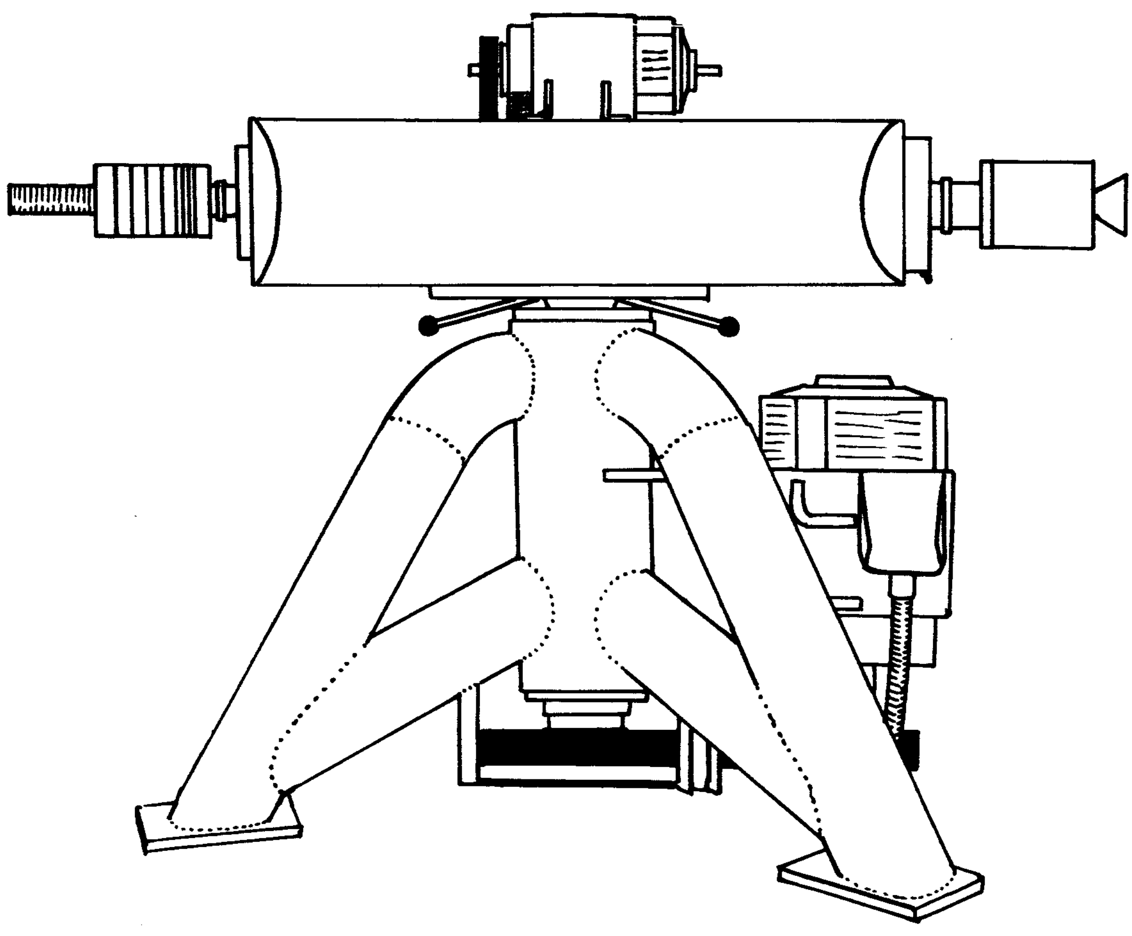

FIGURE 3a. TEST APPARATUS.

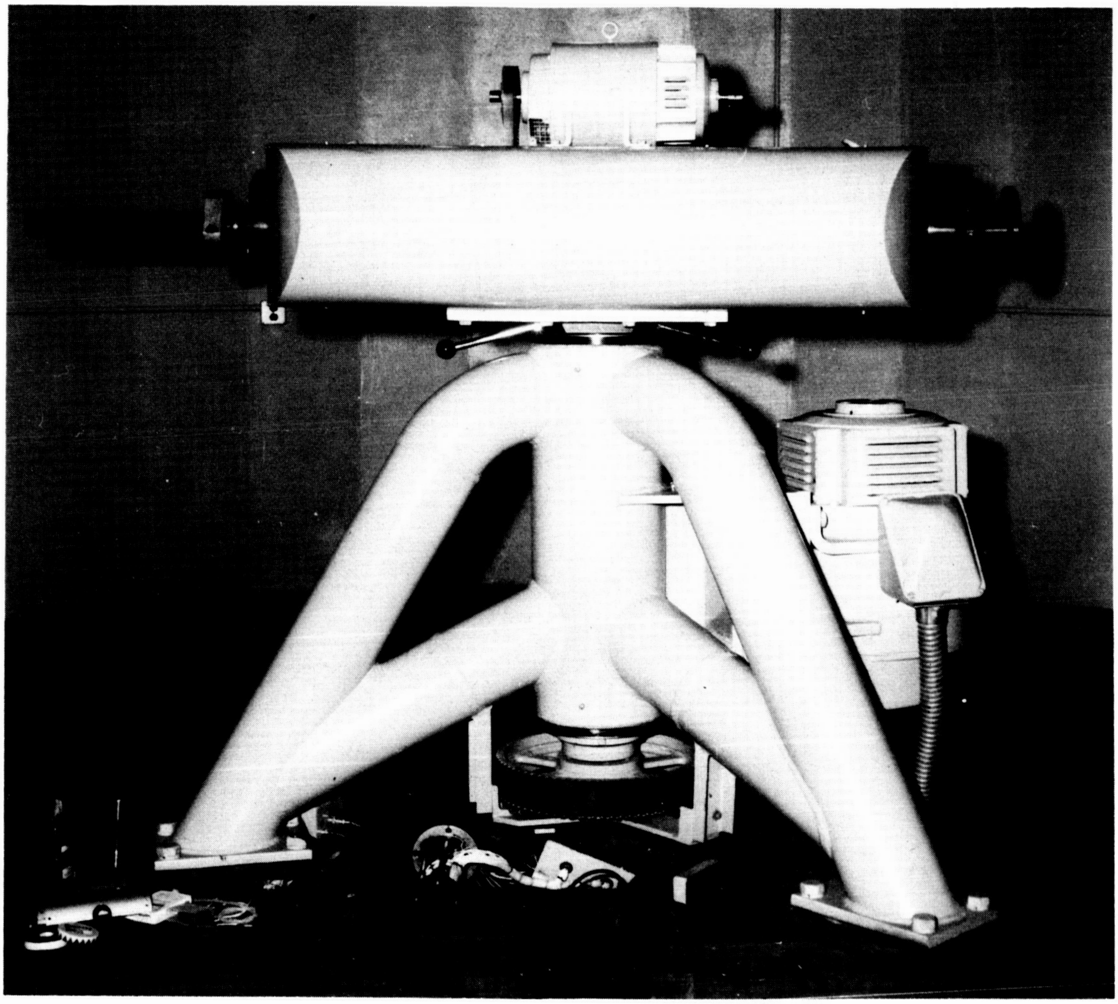

FIGURE 3b. TEST APPARATUS.

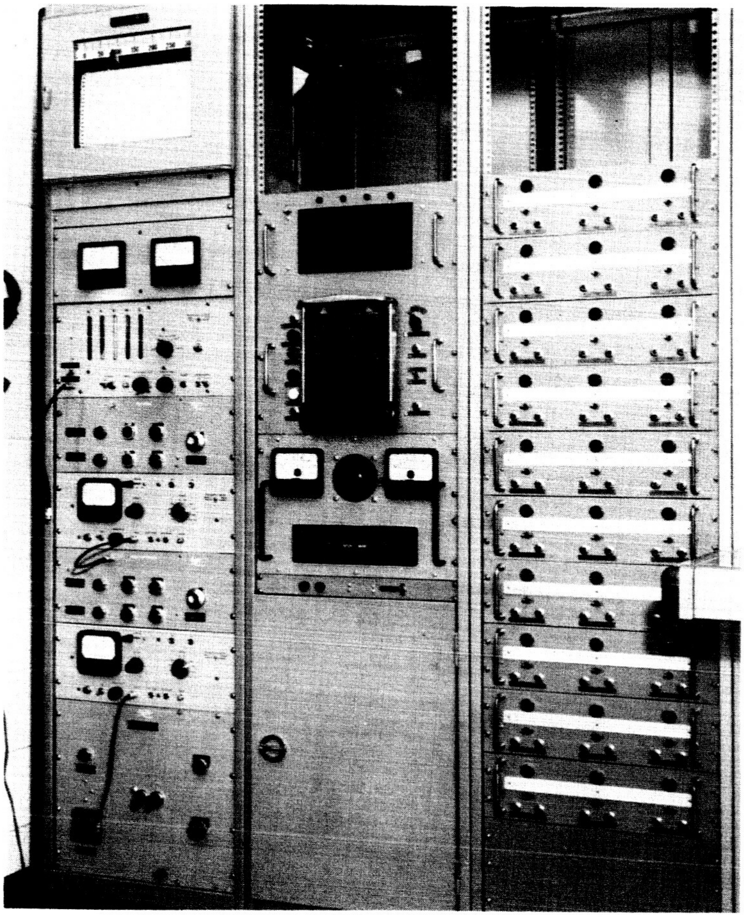

FIGURE 4. APPARATUS CONTROLS.

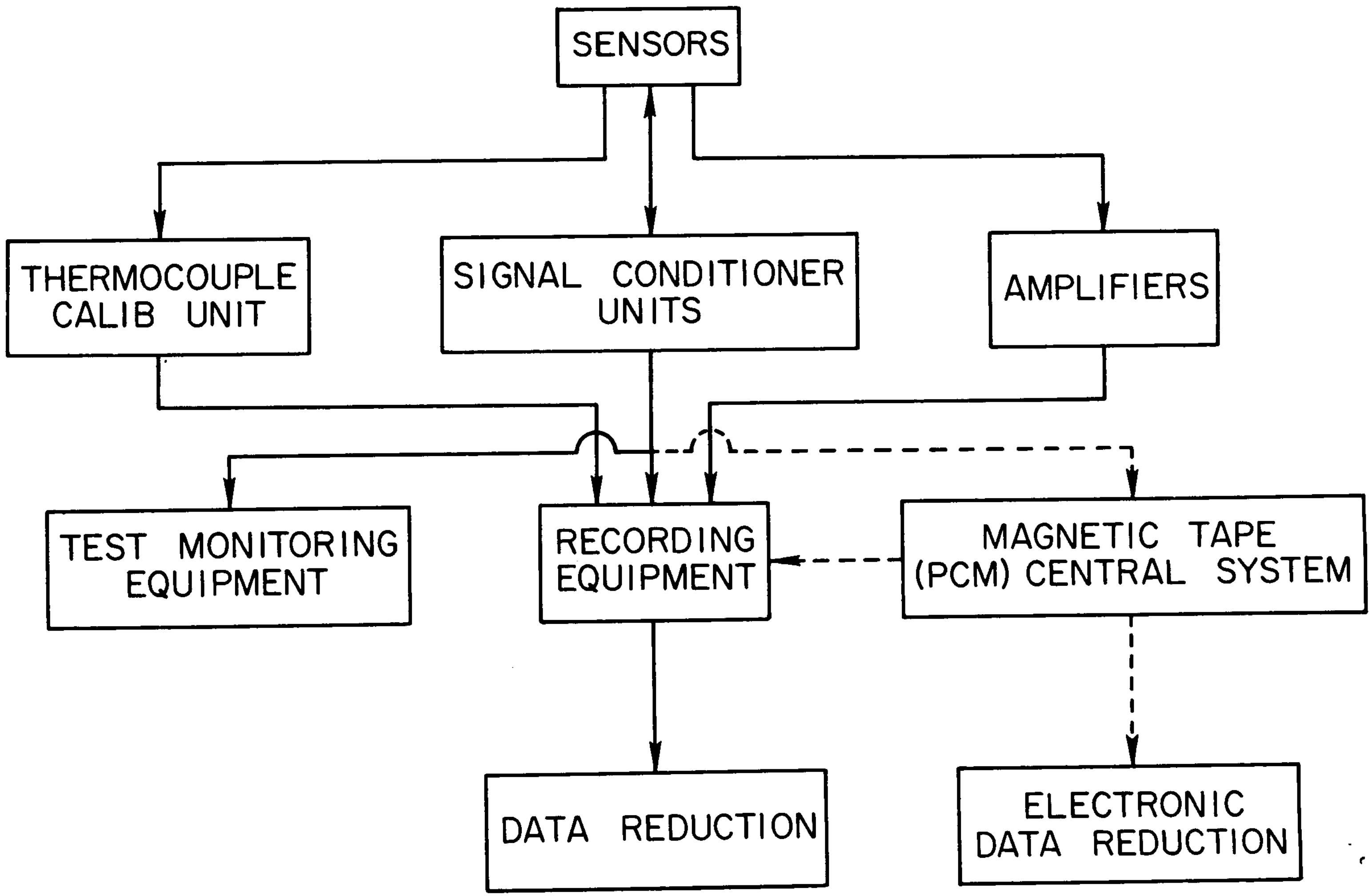

FIGURE 5. INSTRUMENTATION BLOCK DIAGRAM FOR VARIABLE DYNAMIC FORCE VECTOR APPARATUS.