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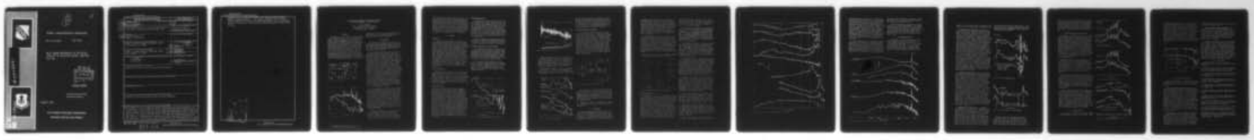

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FRANK J. SEILER RESEARCH LABORATORY

SRL-TR-76-0014 JULY 1976

MULTI-SENSOR MEASUREMENT OF THE MOTION STABILITY OF AN ACTIVE CONTROL ISOLATION TEST PAD

INTERIM REPORT

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frequencies in 6 degrees-of-freedom with inertial-sensor/electromagnetic shaker-activators. The current stability of the Iso-pad and its potential for ultra low noise instruments tests, is discussed as well as its use for controlled low level excitation of test instruments.

MULTI-SENSOR MEASUREMENT OF THE MOTION STABILITY
OF AN ACTIVE CONTROLLED ISOLATION TEST PAD

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Abstract

Performance data of a variety of motion sensors at controlled sub-seismic excitation levels is presented. Sensors compared include representative state-of-the-art seismometers and tilt detectors, as well as newly developed quartz fibre linear and angular motion sensors developed under AFSC/FJSRL sponsorship, and the TGG gyro. The basis for a stable low level motion test pad, and calibrated, controlled excitations is a pneumatically supported, actively controlled Isolation Test Pad (Iso-Pad).. The Iso-pad is motion controlled at high frequency to local level with precision level-sensor/pneumatic-activator servos, and controlled at high high frequencies in 6 degrees-of-freedom with inertial-sensor/electromagnetic shaker-activators. The current stability of the Iso-pad and its potential for ultra low noise instrument tests, is disucssed as well as its use for controlled low level excitation of test instruments.

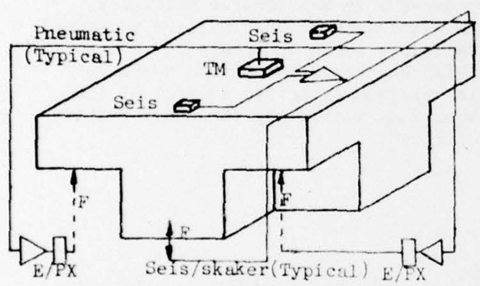

Fig. 1 Iso-pad schematic

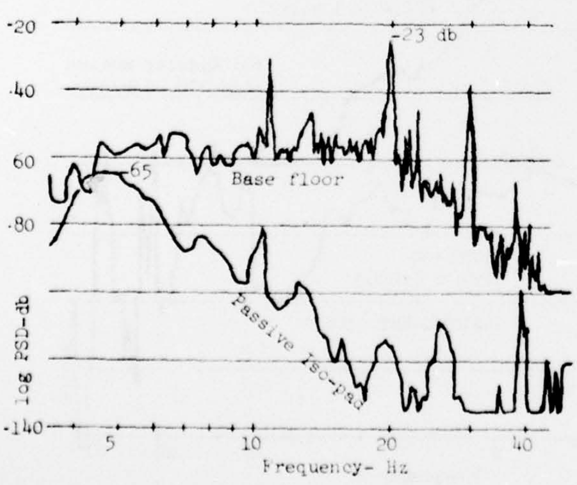

Fig. 2 Passive Isolation

I. Introduction

The purpose of this paper is twofold; (1) to present the pad motion stability status after implementing several seismometer/shaker control channels, and (2) to present some comparative performance data between recently developed and other high quality motion sensors.

The instrument parameters of most interest in developing improved test techniques and motion control are threshold sensitivity, stability, signal/noise (s/n), and frequency response. The need for a more stable test base (or pad) is evident when one considers that sensor specifications for threshold sensitivity are orders of magnitude below the nominal motion of a good test pad of seismic-mass design. The latest generation of inertial guidance components, for example, will generate a significant error at angular rate deviations of 0.001 arc sec per minute in attempts to determine instrument response at 1 Hz, the motion of the test pad must be controlled, or at least known, to about 10^{-5} arc sec.(1) The development and description of the Iso-pad toward its target specifications of 0.001 arc sec, equal to 3/4 microinch linear motions at the Iso-pad edge, will be briefly covered. The current stability of the Iso-pad will be covered in sufficient detail as is necessary to establish an environment for instrument measurements at low level. The TGG gyro was considered as the reference in establishing stability goals, and in turn becomes an instrument for the evaluation of any substandard stability.

It will be shown that the so-called instrument comparisons generally do not provide a good measure of the relative merits of instruments of the same type and purpose. Although this paper was not intended as an instrument survey and evaluation, the relative capability of several types of sensors used for the various linear and angular motions is shown. It will be evident from the size of the equipment to be monitored that no single type of sensor will suffice for all motion determinations. The Iso-pad, a 25 ft. square by eight ft. deep, reinforced concrete structure, supported by 20 "springs", is a highly anisoelastic, non-homogenous, non-rigid system; i.e., it is a big bowl of jelly.

The size and weight of sensors used for Iso-pad measurements is relatively unimportant. Therefore, large, sensitive seismometers, or linear accelerometers could be used to monitor inertial motion of the Iso-pad to the required 3/4 microinch, and yet due to motion internal to the Iso-pad, provide false information of the surface upon which a gyro test table is mounted. Contrarily, sensors of required characteristics and appropriate size and weight to allow mounting several on the gyro test table itself are not presently available. These other considerations have led to the use of instruments in several sizes and response characteristics in both linear and angular types of inertial motion sensors. The instruments and the TGG gyro will be described, and compared in so far as possible on an uncommon basis - the Iso-pad.

II. Iso-pad

Background

The isolation test platform (Iso-pad) at the USAF Academy has been described by several workers in previous papers.[1][2][3] Briefly the Iso-pad, Figure 1, is a 450,000 pound reinforced platform, 25 ft. on a side, supported by 20 pneumatic isolators. The most recent advance in the progression to "active control" was presented by Broderson[4] by configuration, analysis and single axis performance data. Low Frequency Inertial motion is sensed by TM-3 Tiltmeter and signals generated to correct level orientation by pressure changes in the pneumatic actuators. High frequency inertial motion is sensed by 8 HS-10 (1/2 Hz) seismometers and correction signals to apply counter torques to three axes of angular control, and forces to three linear translation controls, with electromagnetic shakers. The six channels of the seismometer/shaker servo have been activated. Typical performance data is shown below.

Passive Performance

The mode of operation where the Iso-pad is supported and maintained at "floor level", has been termed "passive". The pad is not stabilized with respect to the gravitational vector, nor any azimuth reference, however, there is a significant reduction in vibration levels above 3 - 5 Hz. As point of reference, Figure 2 shows one mode of motion, vertical, as it exists on a ground contact system, and the "floated" system.

Input Excitations

The base floor motion (vertical is shown in Figure 2) is but one source of input excitation to the Iso-pad. The time variant input excitations also include the following: acoustic and pressure transient coupling to the Iso-pad, and indirectly via the false floor; false floor resonance vibrations and acoustic coupling to the Iso-pad; air conditioning pressure transients; base floor motion; and mechanical coupling via air lines and electrical conductors. There are strong correlation peaks between base floor and Iso-pad at 4.5, 10.5, 12.7, and 19.2 Hz. Acoustic and false floor vibration PSD's also have peaks observable on the Iso-pad PSD. An example of the large resonant mode, oscillations of the passive Iso-pad resulting from very small input excitations, is the effect of personnel traffic. The laboratory where the Iso-pad is located, has a low (0.2 inch of H_2O) pressure to facilitate the required air flow. The magnitude of the angular oscillation, with "moderate" door openings, is about 0.1 arc sec.

Resonant Excitations

An additional source of large peak vibrations on the Iso-pad are resonant vibration modes of the Iso-pad and of test equipment mounted on the Iso-pad. The more important of the former were identified by Broderson[4]. Iso-pad system vibrations now identified are 48, 59, 65, 67, and 350 Hz. Transmitted input excitations of these frequencies are small, but the effect can be relatively large when compared to the active-control, low frequency, residual. The proximity of three resonances to A.C. line pick-up at 60 Hz has been a servo stabilization problem.

Some test equipment resonant modes have been identified, the most serious frequencies being at 23 and 26 Hz. These are traceable to the structural mount of the gyro test table to the Iso-pad.

Stability Improvement by Active Control

As stated above, the basic active-servo control loop, multi-channel concept, and one-channel performance has been previously covered[4]. Some improvement has been obtained by optimizing servo compensation and seismometer damping. No large change in single-channel performance was observed as a result of activation of multi-channels other than the two horizontal axis angular servos.

The improvement in N-S angular stability, (about an E-W axis) with known simulated personnel motion excitation is shown in Figure 3. A stability of 2-3 milliarc seconds rms of the N-S axis (Figure 4) is obtained by active control of the angular servos, and restricting personnel traffic ("quiet conditions").

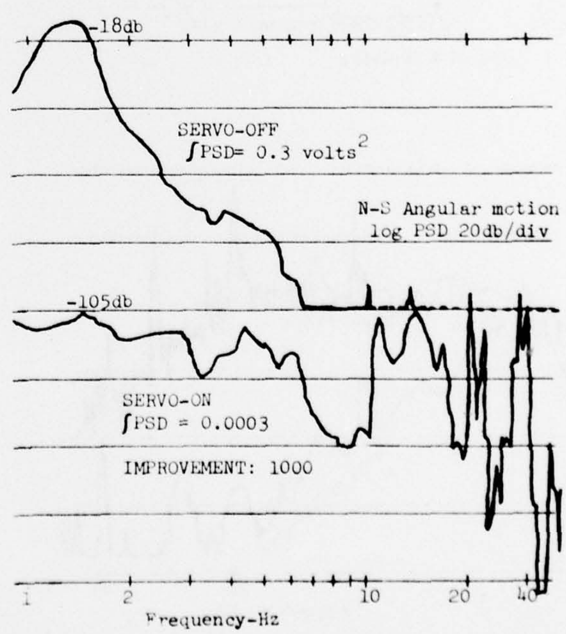

Fig. 3 Stability Improvement by Active Servo

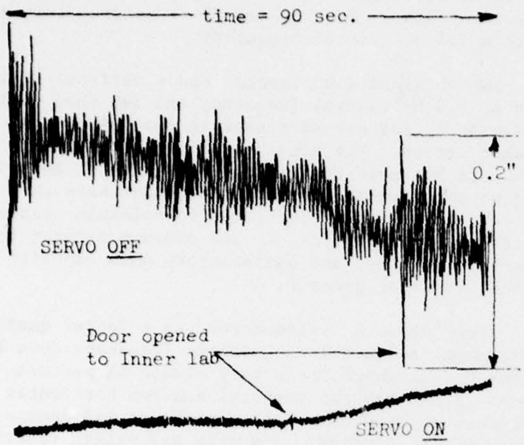

Fig. 4 Real time performance plots

Figure 5 shows PSD's of all 6 channels where the N-S and E-W angular servos are "ON", as well as the channel indicated. Improvement emphasis has been on N-S angular stability, as that which is generally the most important to gyro tests. The horizontal translation, and azimuth channels are subject to improvement with existing sensors.

The PSD plots of figures 3 and 5 do not extend to "near D.C."; however, previous measurements show that the 1-2 arc secs peak to peak daily level of the passive Iso-pad (10^{-5} Hz) are reduced to the

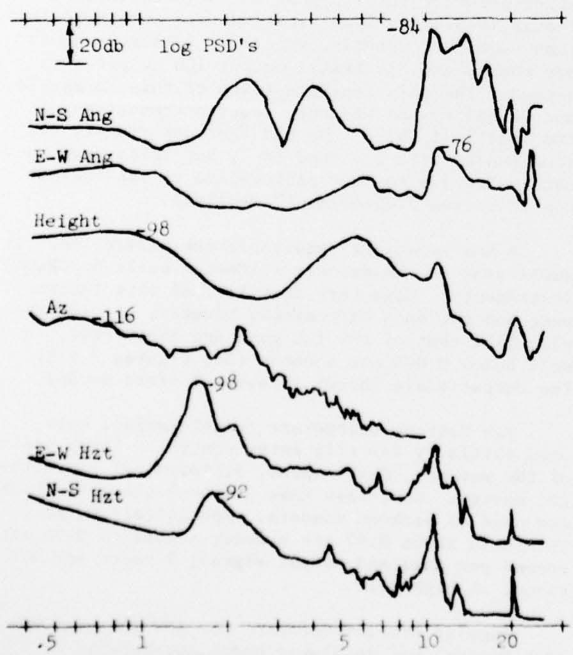

Fig. 5 Active-servo Performance

milliarc second range with the tilt servo controls. Generally, the low frequency band 10^{-5} to 10^{-1} Hz, has not been evaluated to the extent desired; this has been partly due to the sensitivity roll-off of the HS-10's used in the seismometer/shaker servos from 0.5 Hz to D.C. This sensitivity problem is an area where improvements have been initiated.

Method of Controlled Excitation

One of the most important uses of an active-control Iso-pad has been for imposition of known excitations to test specimens. For example, during a gyro test a given frequency of angular vibration could be imposed about an E-W axis and the effect measured on the gyro performance. Or all motion in 6 degrees-of-freedom at one test site could be measured, taped, and used as excitation to the six channels of Iso-pad active control servos. The technique (Figure 6) is straightforward, and has been used in instrument comparisons described in section IV. Excitation signals, from sine wave oscillators, and random noise generators, were imposed on the tilt servo for low frequency excitation as well as on one or more of the seismometer/shaker servo channels.

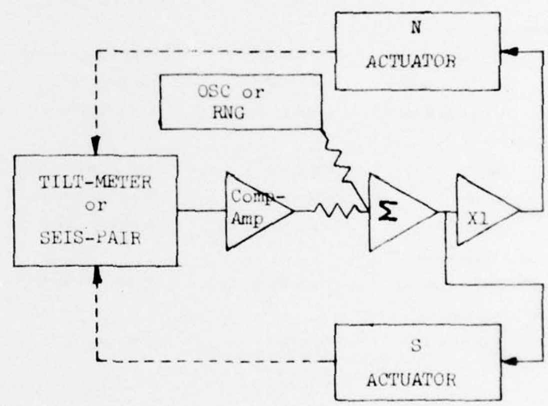

Fig. 6 Excitation Schematic (Typical)

Two other forms of excitation used ocassionally, are step-inputs to vertical shaker channels by means of weight lifts on the pad, and the use of a "floating" shaker, positioned on the Iso-pad without coupling to ground, but loaded with a 2 to 3 pound weight. The latter technique is sufficient to excite resonant modes of vibration in the Iso-pad and some test equipment.

Methods of matching, or calibrating instruments e.g., seismometers, have been covered in previous papers(5)(6).

III. Instruments

The inventory of motion sensors used in Iso-pad development and evaluation vary greatly. Except for test specimens, e.g., the TGG gyro, there was no intent to compare motion sensors other than as required in association with Iso-pad development. The primary goal has been to select sensors with low threshold, usable S/N, long term repeatability, low temperature coefficient, low cross coupling into the sensitive axis, etc., compatible with the Iso-pad stability objectives. Another requirement has been for motion mode measurement in 6 degrees-of-freedom from D.C. to a high frequency to be determined (initially considered to be 100 Hz) and use of sensors in continuous control servos. Small size could be important if it becomes necessary to locate the sensor in close proximity to the test specimen.

Four years ago, sensor compatible with system objectives of 0.001 arc seconds, appeared to exist only for low frequency, level axis, sensors, i.e., tiltmeters or level detectors, and then with new, relatively unproven (in use) instruments. The use of available seismometers at ultra-high gains for 10^{-8}g and lower sensitivity, the stable conversion of electrical error signals to less than 0.001 psi pneumatic control signals, angular sensors better than 0.001 deg/hr gyros, and continuous azimuth sensors of even that accuracy, were apparently non-existant.

As a result of these factors, FJSRL has amassed the motion sensor assortment listed below:

Type	Size	Manufacturer
Seismometer:		
EV - 22 (H & V)	1.3"d x 1.5"l	Electro Tech. Labs
HS - 10 - (H & V)	4.5"d x 8"l	Geo Space Corp.
S - 13 (H & V)*	6.5"d x 15"l	Teledyne/Geotech
Tiltmeters:		
TM - 3	4"d x 7"h	Hughes Research Lab
Hg TM	2"d x 4"h	Okubo Instruments
33520*	8"w x 11"l x 6"h	Teledyne/Geotech
Angular Accelerometer:		
AMS (H & V)	6"w x 6"l x 2"th	Okubo Instruments
Linear Accelerometer:		
DIAX (H & V)	Vertical: 12"w x 18"l x 18"h Horizontal: 18"w x 24"l x 18"h	Diax Inc.
Azimuth Angle Sensor:		
Azimuth Orienter (non-inertial)	16" x 16" x 32"h	Teledyne (Geotech)

* Part of the original Iso-pad installation.

Basic Specifications

Seismometers: To date, all seismometers in use on the Iso-pad are off-the-shelf instruments of the electromagnetic types. Some performance latitude exists in most available seismometers, particularly in natural frequency, and coil resistance. The EV-22 is a small low cost sensor of a size and sensitivity common to several manufacturers, which finds wide use in the geophysical exploration industry. With emphasis at the FJSRL project on high frequency (1-100 Hz), and sensor size compatible with gyro table measurements, very high gain (10^5-10^6) electronics were developed to use it near its threshold. The calibration, matching, and use of the EV-22 as sensor in a portable seismic monitor (PSM) has been covered in previous presentations (5) (6) (7). The generator constant is 0.6 v/ips. We have found the best S/N when low (240 - 640 ohms) coil resistance is specified. The EV-22 can be input directly into an op amp with its coil as input resistor. Most of our EV-22 seismometers have a 7.5 Hz natural frequency.

We obtained 4 horizontal and 4 vertical HS-10-1's at 0.5 Hz nautral frequency and 390 ohms coil resistance, for use as sensor in the seismometer/shaker servos. The generator constant is 2.5 v/ips. It has good performance to 0.1 Hz or lower, and no interfering internal vibrations have been noted. It was found difficult to maintain stable matching of HS-10 pairs at the minimum natural frequency of 0.5 Hz, but satisfactory when adjusted to about 0.8 Hz or greater.

The "Geotech" seismometer, is a larger quality instrument adjustable in natural frequency down to about 0.7 Hz where it is very stable in performance. FJSRL has two vertical and two horizontal Geotechs at 3600 ohms coil resistance and generator constant of 16 v/ips. Its size and weight restrict its use in our applications to Iso-pad or floor locations; its mass would effect, for example, the vibration characteristics of the internal structure of the gyro test table.

Seismometer pairs may be used as angular sensors by differencing them to obtain angle, however, one must beware of the possible pitfalls. A large advantage can be gained by locating the seismometer pair at opposite ends of a long lever, e.g., opposite sides of the 25 ft. Iso-pad. However, there is the danger not only of mismatch resulting in response to a linear motion, but also of bending motions of a non-rigid lever leading to error in angular motion sensed. Indeed, the Iso-pad is an 8 foot thick x 25 foot long x 25 foot wide "lever" bending at resonant frequencies of 48 - 67 Hz.

Tiltmeter: The level sensor in use as servo error detector for the past 2 - 3 years is the 2-axis TM-3. Its specifications are threshold less than 0.001 arc seconds, stability 0.1 arc seconds per month, and electrical output 100 mv per arc second. The only feasible tests of this threshold and stability, at present, require comparison of two identical units. We had that opportunity for some months with a second TM-3, but tests were inconclusive due to poor performance of lab thermal controls (see "improvement" section).

A new sensor of remarkable sensitivity for its small size is the mercury tiltmeter built by Okubo Instruments. Long term stability of this instrument has not been determined; however, the threshold, like that of the TGG gyro and HS-10 pair, is well below 0.005 arc seconds (See Figures 7 & 8). The output scale factor is about 1 v/arc second.

Two Geotech tiltmeters (single-axis), were used initially for tilt servo control. These are of the mercury, dual septum, differential capacitator design. Now, less than state-of-the-art, these are used as back-up sensors. Specifications are: threshold about 0.02 arc second; stability 0.01 arc second per day; and output signal, 2 volts per arc second at high gain.

Angular Accelerometers: The AMS (Angular Motion Sensor) was developed under sponsorship of

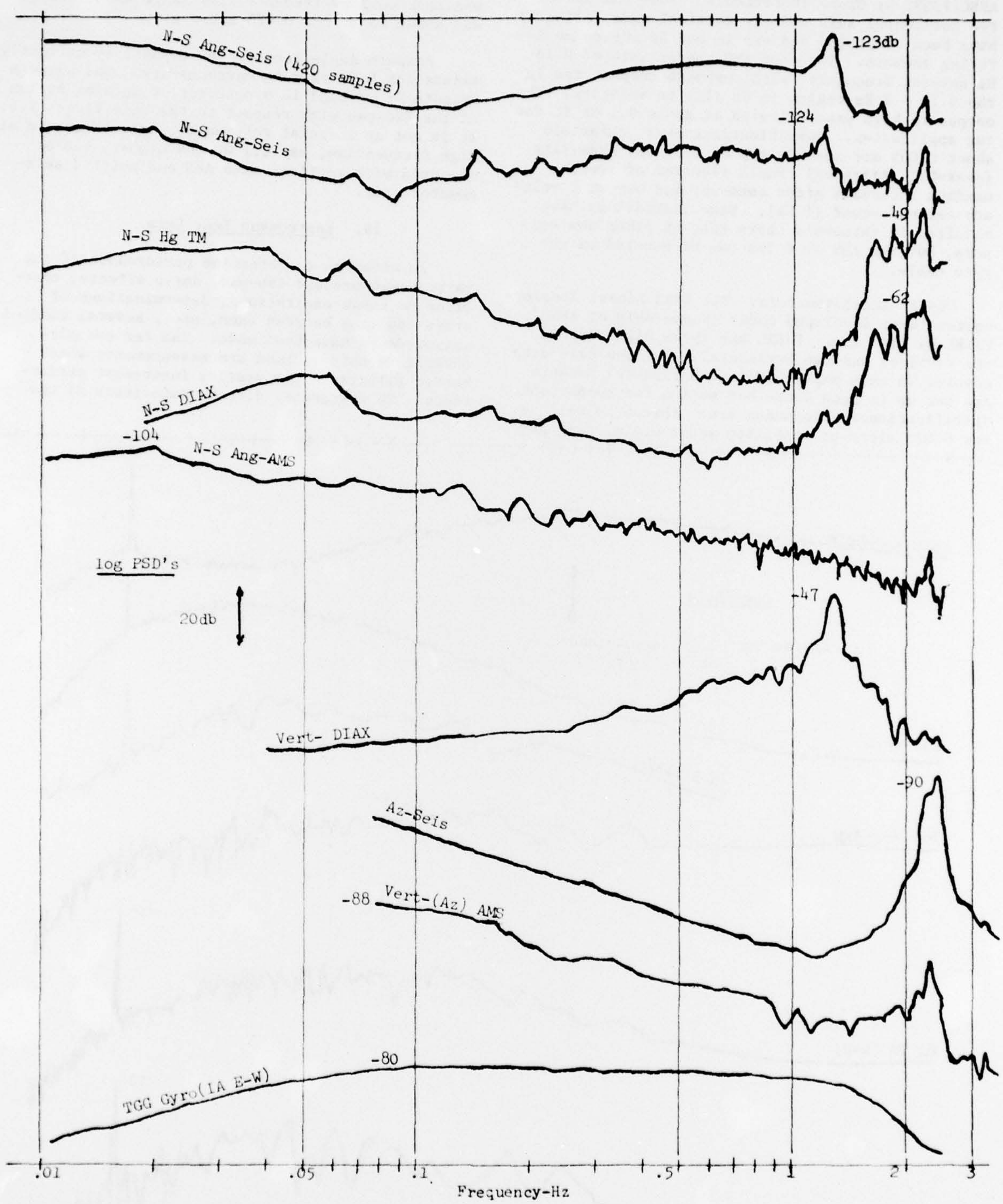

Fig. 7 Various sensors and gyro on quiescent Iso-pad

AFSC/FJSRL by Okubo Instruments. Four AMS units, two horizontal axis and two vertical axis (azimuth) have been completed and are in use as motion monitoring sensors. The four AMS sensors are of 0.16 Hz natural frequency, with response compensated in the 0.16 - 2 Hz region to be flat to velocity. The output is high pass filtered at about 0.1 Hz fc for our application. Specifications are: threshold about 0.005 arc seconds p-p at 0.15 Hz; stability (near-D.C. filtered) renull required of 1/week maximum intervals after warm-up; and output 1 volt/ arc second/second (1 Hz). Size limitations have resulted in threshold above that of other new sensors, but the AMS at 6 lbs can be mounted on the gyro table.

Linear Accelerometers: The DIAX Linear Accelerometers were developed under sponsorship of AFSC/ FJSRL by DIAX Inc. FJSRL has three DIAX sensors, one vertical and two horizontal. For the test data covered in this paper, the two horizontal sensors are set up to both sense N-S motion for comparison. Specifications/performance are: threshold well below 0.025 micro-g; stability about 0.5 micro-g per day; output, multi-range, the threshold measurement was made on 2 mv (sensitivity) range where output was about 25 mv per 0.025 micro-g.

Azimuth Angle Sensor: No capability currently exists for D.C. azimuth measurements. The azimuth orientator on hand is a detector of angular motion of the Iso-pad with respect to the base floor; i.e. it is not an inertial reference. Azimuth motion at high frequencies, say 0.1 Hz and higher, can be measured with vertical axis AMS and matched seismometer pair.

IV. Instrument Test Data

In attempts to determine performance of the various sensors and Iso-pad, servo effects, reactions to known excitations, determinations of cross-coupling between axes, etc., several hundred measurements have been made. The few examples covered in this section are measurements which better illustrate comparative instrument performance. To reiterate, direct comparisons of the

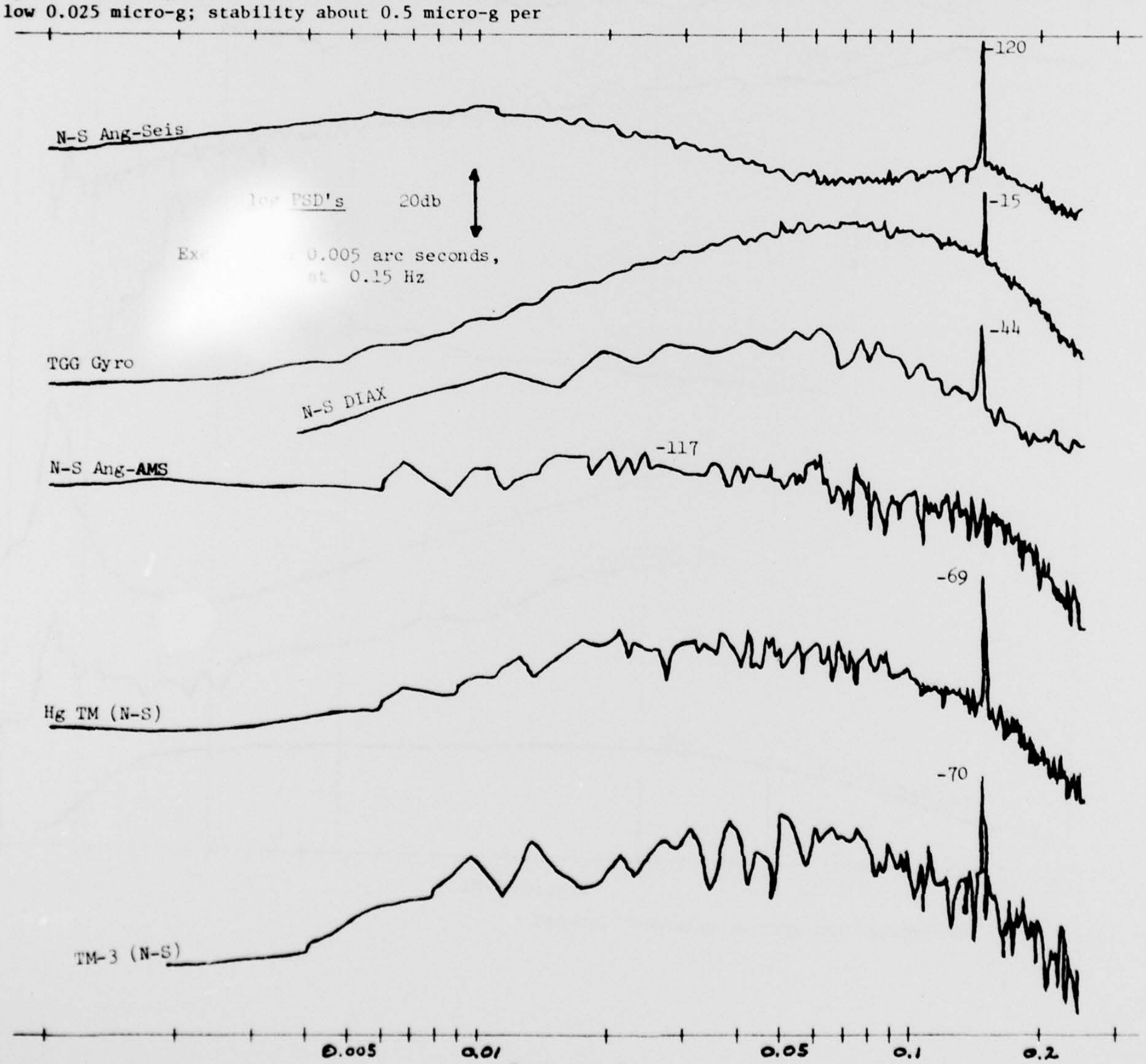

Fig. 8 Sensors output to 0.005 arc second excitation

sensors are only possible within the context of the application (as in any apples vs oranges situation).

Quiescent Data: Measurements with most sensors, the HS-10 pair "Angular seismometers," N-S DIAX, Vertical Diax, horizontal AMS, vertical AMS, HS-10 pair "Azimuth seismometers," Hg TM, and the TGG gyro, have been made of the active Iso-pad under quiescent conditions. Figure 7 shows these measurements as PSD's in the frequency band of D.C- 2.5 Hz. Of note are frequency points at 1.23, 1.65, 1.83, 1.9 and 2.25 Hz. The 1.23 Hz indicated by N-S angular seismometers should have been (and is) well squelched by the angular servos; therefore, the small signal sensed may be an indication of HS-10 mismatch. Perusal of the N-S DIAX shows perhaps a small angular plus translation motion; horizontal AMS and Hg TM (both sensing N-S angular motion) show no angular motion at 1.23 Hz. Then, the Vertical Diax provides the confirming evidence - a large 1.23 Hz signal indicating the vertical motion at this frequency. Finally the TGG gyro, input axis alined E-W, shows no 1.23 Hz, as it should if it were angular. The nature of the 1.63 and 1.83 Hz vibrations is in doubt; they are sensed by the Hg TM and N-S DIAX, marginally by the Angular seismometer, and are apparently below the AMS threshold. The 1.9 Hz is a vertical motion (see vertical DIAX) which due to HS-10 mismatch results in a small apparent angular signal. And the 2.25 Hz is a N-S angular motion (see angular seismometer, Hg TM, AMS, and N-S DIAX); the 2.25 Hz does not appear on the vertical DIAX.

Threshold Determinations: The technique most often used for threshold measurement, incremental reductions in an easily measured variable, was used for all such determinations. The variable might be, for example, the voltage to an exciter, or feedback gain resistor in the exciter amplifier, rather than a direct measurement of the sensible motions. Generally, this technique, which assumes linear behavior in the method of excitation, is satisfactory. However, wherever possible, the excitation was also measured by means of another instrument, more sensitive by inherent characteristic, or by the nature of the set-up. Such is the case in the example shown in Figure 9. Here a large excitation using a sine wave generator at 15 Hz to North and South (at 180° phase difference) Iso-pad exciters (shakers), imparts a N-S angular motion to the Iso-pad. The angular motion is sensed by the seismometer-pair and the N-S DIAX (Figure 9a). (The linear excitation to the DIAX is proportional to the vertical distance of DIAX from axis of rotation). The excitation is then reduced to a value which is not discernable by the sensor under test. (Figure 9c).

Examples of Iso-pad Bending: A redundancy of sensor types has provided a good illustration of this subject (discussed earlier). Figure 10 shows PSD's of two vertical measurements of the Iso-pad; (a) the Vertical DIAX, located near the Iso-pad center, and (b) the "vertical seismometer", a measurement obtained by summing the signals from the vertical HS-10's located at the four cardinal points of the Iso-pad. Bending at resonant frequencies imparts some vertical motions to the near center of the Iso-pad, as seen by the DIAX outputs at 48, 50, 59, and 64 Hz. However, the bending shown pictorially by Brodersen (4) at four modes, 48, 59, 65, and 67 Hz effects edge motion to a much larger extent. As a result, the sum of four seismometers ("vertical seismometer") sees large total deflections at 60 and 66 Hz.

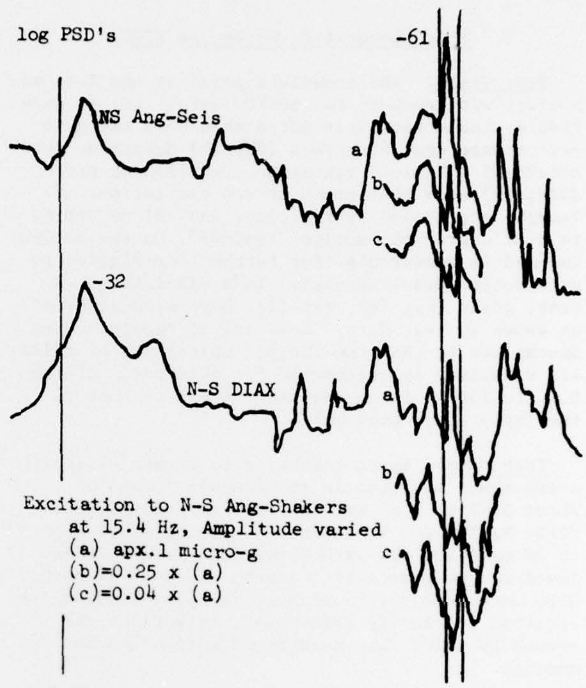

Fig. 9 Threshold determination

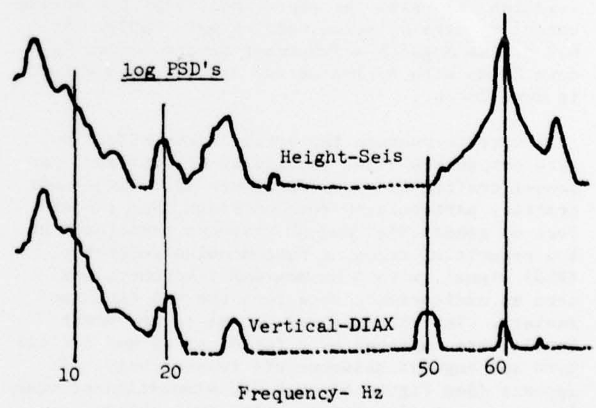

Fig. 10 Illustration of Iso-pad bending

Quiescent Level plus Calibrated Excitations: The PSD plots, Figure 8, incorporate data on most of the Iso-pad sensor set and the TGG under a N-S angular motion excitation and identical test conditions. Basic test conditions are: the Iso-pad N-S and E-W angular servo channels are active; sine wave excitation signal is imposed in the pneumatic controls to effect a N-S angular motion of 0.005 arc seconds at 0.15 Hz; and the lab is maintained at "quiet" operational status. All sensors detected the calibration signal, and for some sensors, including the TGG, it is evident that motion of 1 or 2 orders of magnitude smaller would be measurable.

V. Third Generation Gyroscope (TGG)

Test Goals: The immediate goals of the Iso-pad project with respect to the TGG were: (a) to provide a stable test base compatible with the gyro performance specifications (8); (b) determine the effect of a "quiet" vibration condition on gyro data; (c) show that known motion excitations of Iso-pad are sensed by the gyro; and (d) determine to what degree the motion "residue", on the active Iso-pad is measurable (for further correlation to gyro output measurements). To a significant extent, goals (b), (c), and (d), have been attained as shown in test data. Goal (a) is recognized as incomplete in that the Iso-pad objectives of milli-arc stability is approached for only parts of the D.C. to 100 Hz frequency band; (more on that in the Improvement section).

Test Data: Again referring to Figure 8, it is noted that, at least in the frequency band of about 0.02 to 0.15 Hz, the angular seismometer, DIAX, Hg TM, and TM-3 sensors have thresholds of 5 to 20 db below the gyro background level. This level may be gyro noise, Iso-pad motion, or both. More long term tests, with correlation studies are required to clarify this point, as well as the extent to which this background motion can be modeled.

For further demonstration of the correlation between Iso-pad motion and gyro output, Figure 11 shows PDS's of gyro and angular seismometers under conditions of sine wave N-S angular excitation in steps of 0.1 Hz from 0.4 Hz to 0.9 Hz. Note correlation, and also the improvement that the active conrol effects on servo, and on gyro PSD's. At 0.9 Hz the Angular seismometer sensed motion is down 28 db with active servos and the gyro output is down 26 db.

A test to measure the active servo effect on gyro output PSD under conditions of simulated personnel traffic is shown in Figure 12. Since most traffic, particularly door openings, has the effect of generating "pulse" pressure transients at low repetition rates, a random noise generator (RNG) signal, with 5 Hz maximum frequency, was used as excitation source into the N-S (Angular) shakers. The PSD integral, equal to rms power levels, are improved by a factor of 25 and 121 for gyro and angular seismometers respectively. It appears (See Figure 5) that RNG simulation of traffic is not as disturbing as the real thing.

VI. Gyro Test Table

The test table at FJSRL is a Fecker Co. table with gas hydrostatic primary axis bearing, journal

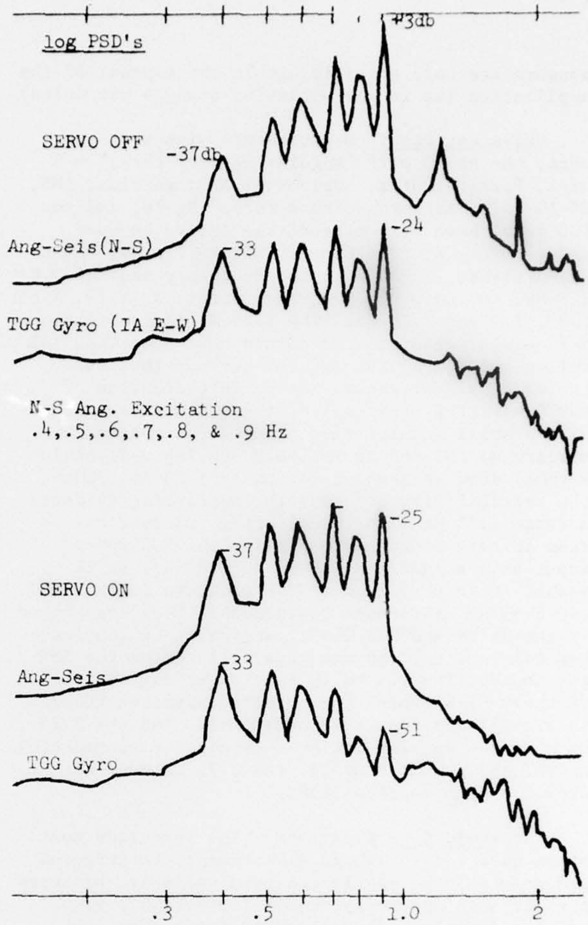

Fig. 11 Gyro/Iso-pad Correlation

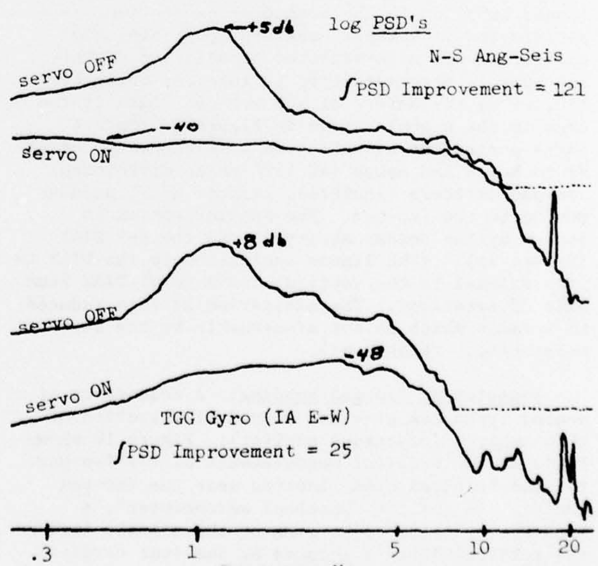

Fig. 12 Active-servo improvement to Gyro test

secondary axis bearing, optical encoder read-outs, and computer compatible controls for automatic setting of orientation and rates (9). A vibration sensitivity within the test table, hopefully amenable to correction, illustrates a problem area which may be unexpected to the unwary, and certainly shows the value of an instrument set capable of a variety of vibration measurements. Using the PSM/EV-22's resonant vibration modes were determined to be associated with the table mounting-base. Figure 13 shows horizontal and vertical "transfer functions" between base and gimbal, under quiet conditions. The resonant frequencies are 23 and 26 Hz.

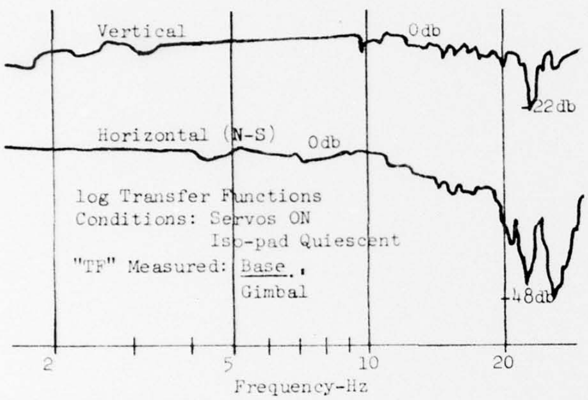

Fig. 13 Gyro Test Table Resonances

VII. Test Systems Improvement

Several possibilities for improvement have been mentioned in the foregoing. Efforts are underway toward improvement of deficiencies in Iso-pad performance.

Acoustic Coupling and Air Conditioning: The two problem areas of acoustic or pressure transient coupling of personnel traffic into Iso-pad excitations, and inadequate control of inner lab temperature, with consequent effect on sensor stability, have in common a need for better isolation from external environmental effects. Two facility improvements are now being added. First, physical isolation of the Iso-pad area is being enhanced by addition of a solid wall, of acoustic material and design, and an air tight, air lock type entry. Second, more precise temperature control of the laboratory is being added. The thermal specification of ± 1°F will apply to the Iso-pad 33.5 x 41 ft. area. The adjacent area, where control electronics are located, will also have improved thermal characteristics.

Instruments: Adequate instrument performance for monitoring motion in the frequency band from near D.C. to 0.1 Hz is in some doubt; certainly the extension of higher servo control gain into lower frequencies requires sensors of broader band coverage than the HS-10 seismometers. We are now in process of obtaining vertical and horizontal, long period (30 seconds or greater) seismometers to better cover this frequency region. Such Instruments will extend azimuth inertial measurements to perhaps 0.0003 Hz or lower.

Improved Analyses (Data Processing): The present equipment for sensor signal processing has not been discussed, suffice to say, there are limitations such as correlation of more than two real time signals, capacity for increased computational accuracy, and tests of digital control concepts (discussed below). Therefore, near future plans do include replacement of the present 8K computer/spectrum analyzer.

Active Servo Controls: Aside from improvement in the servo sensors, covered above, two improvement areas are in work. First is simply an extension of present control configuration to improve low frequency performance by improved compensation and long-period sensors. Second are efforts underway towards digital servo control of the Iso-pad. Preliminary concept, single channel performance and simulation studies of digital controls for the Iso-pad have been covered by Lamont (10). Application of digital servo controls to the Iso-pad is now mainly a matter of enhancing the real time computational capacity of the Iso-pad facility.

VIII. References

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