jpl INTEROFFICE MEMO

354:76:761

DATE August 27, 1976

TO R. E. Covey SEC. 365

FROM J. A. Garba EXT. 2566 SEC. 354

SUBJECT NASA 3-Meter IR Telescope - Preliminary Input Parameters for Servo Analysis Model

The attached material defines the input parameters for the Servo analysis to be performed by Section 355.

The values given are best estimates. An attempt has been made to define the important assumptions in the derivation of the input.

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NASA 3 METER INFRARED TELESCOPE
INPUT PARAMETERS FOR SERVO ANALYSIS MODEL

1. Coordinate Systems

The coordinate systems used are defined in Figure 1. All parameters for the Servo analysis model are defined in the yoke coordinates, x_y, y_y, and z_y.

2. Servo Model

A sketch of the proposed Servo-model is shown in Figure 2.

3. Soil Spring Constants

The soil constants have been determined using the information described in IOM 354:76:715. Some of the spring constants shown in this IOM were found to be in error. Table I shows the corrected spring constants defined in Figure 1. All springs are assumed to act at the base of the respective piers.

The proposed modifications of the foundation has not been included in the dimensions of Figure 1 and is not reflected in the spring constant calculations. This effect should be small and is discussed in IOM 354:76:759.

The stiffness matrices for the soil are defined in Table II. The matrices are referenced to the center of the South bearing, Point A in Figure 1 and are defined in the yoke coordinate system. Units are inches, pounds and radians.

The North and South piers have been assumed rigid in the calculation of the matrices. The flexibility of the concrete beams connecting the concrete foundations is included.

The soil spring constants not defined in Table I have been assumed to be very soft, several orders of magnitude below the other springs.

The following deflections have been calculated for a unit torque about the polar axis applied at the South pier, Point A of Figure 1. The angle θ is the rotation of the South pier, Point A, about axis Y_Y.

Method	θ, Radians
Pauw	$.2477 \times 10^{-10}$
AURA	$.6495 \times 10^{-10}$
Parmelee	$.1202 \times 10^{-9}$

4. Foundation Weight Properties

The foundation weight matrix is shown in Table III. The weight matrix has been computed with respect to the center of the South bearing, Point A in Figure 1. The units are lb, in-lb and lb-in^2. The yoke coordinate system is used. The weight of the North and South stand is not included. The foundation weighs 880,000 lbs. The moment of inertia about the polar axis is 8.45×10^{10} lb-in^2 and the cg is 281 inches below the polar axis.

5. Yoke Assembly Properties

The yoke properties will be given two different ways, (1) yoke assembly, including tube by itself and (2) yoke assembly including tube and gear drive stiffness. In either case the torsional springs for the assembly have been calculated from the rigid body inertia and the frequency of the first torsional mode. Since all of the rotational inertia of the assembly is not effective in the first torsional mode this model is probably conservative. It has a larger mass with the proper frequency.

a. Yoke/Tube Assembly

The moment of inertia of the yoke/tube assembly is estimated at 1.8×10^9 lb-in^2 and the first torsional mode with a locked gear drive is estimated at 9.2 Hz thus the spring constant is 1.56×10^{10} in-lb/rad.

b. Yoke/Tube/Drive Gear Assembly

The moment of inertia of the yoke/tube/bull gear assembly is estimated at 1.82×10^9 lb-in^2 and the first torsional mode with the gear drive between the yoke and fixed ground is estimated at 7.2 Hz. Thus the spring constant is 9.65×10^9 in-lb/rad.

6. Bull Gear Properties

a. Stiffness

The bull gear torsional stiffness was estimated by KPNO at 1.2×10^{10} ft-lb/rad.

b. Inertia

The bull gear moment of inertia about the polar axis was estimated by scaling a blueprint. The inertia is 2.46×10^7 in-lb^2.

7. Gear Drive Stiffness

The gear drive stiffness supplied to JPL by KPNO/AURA on June 14, 1976 was 7.8×10^9 in-lb/rad.

A recent reevaluation of the gear drive stiffness was performed by KPNO/AURA. Each of the two gear boxes have a stiffness of 1.38×10^{11} in-lb/rad. The two gear boxes act in parallel and that resultant spring then acts in series with the bull gear.

The gear drive system spring constant obtained from such a combination was analytically derived by KPNO as 11.5×10^9 in-lb/rad.

Test results at KPNO on the existing hardware established the effective system spring constant at 2.4×10^9 in-lb/rad. This spring constant includes telescope and support stand windup. KPNO suggested that JPL use a gear drive stiffness of 7.8×10^9 in-lb/rad for the analysis as a conservative approximation. The drive stiffness can be taken as high as 11.5×10^9 in-lb/rad if a sensitivity study is desired. A rotational spring constant of 7.8×10^9 in-lb/rad was used to calculate the yoke frequencies including the gear drive.

8. South Pier Properties

a. Stiffness

The influence coefficient and stiffness matrices for the South Pier are given in Table IV. These matrices are derived from a finite element model. The South pier was fixed at the top of the concrete block. The properties are with respect to the center of the South bearing, Point A in Figure 1. The yoke coordinate system is used and the units are lb, in, radians. From Table IV(a) a torsional spring constant for a unit torque about the Polar axis can be determined, assuming an unrestrained bearing, thus

$$K_\theta^S = \frac{1}{.49979 \times 10^{-10}} = 2.00 \times 10^{10} \ \text{IN-LB/RAD}$$

By applying forces to the South stand which simulate the gear train forces an effective spring constant can be determined. This is estimated as

$$K_\theta^S = 7.96 \times 10^{10} \ \text{IN-LB/RAD}$$

The latter spring constant does not account for the bearing ball deflections. The above two values bracket the South pier torsional spring constant.

b. Inertia

The South pier inertia properties have been crudely estimated using the output of the finite element program and by scaling the preliminary blueprints. Detailed blueprints of the South pier were not available. The South stand weighs 8,000 lbs, the c.g. is 31 inches below the Polar axis and the moment of inertia about the Polar axis is estimated at 2.7×10^7 lb-in^2.

9. North Pier Properties

a. Stiffness

The influence coefficient and stiffness matrices for the North pier are given in Table V. These matrices are derived from a finite element model. The North pier was fixed at the top of the concrete block. The properties are with respect to the center of the North bearing, Point B in Figure 1. The yoke coordinate system is used and the units are lb, in, radiants.

From the influence coefficient matrix of Table V(a) a torsional spring constant for unit torque about the Polar axis can be determined as

$$K_\theta^N = \frac{1}{.5337 \times 10^{-9}} = 1.87 \times 10^{9} \text{ IN-LB/RAD}$$

The North bearing is assumed free in the above calculation. By simulating the damper forces on the North stand an effective spring constant can be estimated as

$$K_\theta^N = 8.46 \times 10^{9} \text{ IN-LB/RAD}$$

The latter spring constant does not account for the damper spring, if any, and the ball bearing deflections. The values given above bracket the estimate for the torsional spring constant for the North pier.

b. Inertia

The North pier inertia properties have been crudely estimated using the output of the finite element program and by scaling the blueprints. An allowance for the cable wrapup weight was included. The North stand weighs 27,000 lbs, the c.g. is 97 inches below the Polar axis and the moment of inertia about Point B is estimated at 5.8 X 10^8 lb-in^2.

10. Motor Rotor and Small Gear Inertia

The motor rotor and small gear inertia is estimated at 1.11 X 10^8 lb-in^2.

11. Stator and Gear Case Inertia

For the purposes of this analysis the gear case and Stator inertia is assumed negligible as compared to the South pier inertia.

12. Damper Properties

The equivalent viscous coefficient of the damper is estimated by KPNO as C = 5 X 10^7 to 5.4 X 10^7 ft-lb-sec. The inertia of the KPNO telescope is 3.56 X 10^6 ft-lb-sec^2 and the natural frequency is 1.2 Hz. The system is approximately critically damped.

The damper as installed is A-C coupled and acts as an acceleration device. The coefficient for the acceleration damping, relating torque to angular acceleration is not available.

KPNO suggested the follwoing alternatives to modelling the damper:

a. Use the KPNO telescope properties defined above to relate acceleration to torque for the damper.

b. Obtain acceleration damper characteristics from the hardware by examining the bluebrints.

c. Use, as a first cut, a viscous damper with $C = 5 \times 10^7$ ft-lb-sec or assume a critically damped system. The proposed damper should be capable of providing critical damping for the NASA telescope.

13. Tachometer Properties

The proposed tachometer assembly is <u>Inland Motor Model TG-5714-C</u>. Properties for this assembly can be obtained from a commercially available catalogue.

TABLE I

COMPARISON OF SOIL SPRING CONSTANTS
OBTAINED BY DIFFERENT METHODS

South Pedestal	**AURA**	**Pauw**	**Parmelee**
Vertical Spring, K_Z^S, lb/in	6.2×10^6	1.7×10^6	-
Lateral Springs, K_X^S, K_Y^S lb/in	2.0×10^5	6.7×10^5	1.7×10^6 to 3.5×10^6
Rotational Spring, K_{RX}^S, in-lb/rad	1.5×10^{10}	4.3×10^9	4×10^9 to 1.9×10^{10}
Rotational Spring, K_{RY}^S, in-lb/rad	3.1×10^{10}	2.4×10^{10}	4×10^9 to 1.9×10^{10}
Rotational Spring, K_{RZ}^S, in-lb/rad	-	1.1×10^{10}	-
North Pedestal			
Vertical Spring, K_Z^N, lb/in	7.9×10^6	2.1×10^6	-
Lateral Springs, K_X^N, K_Y^N, lb/in	2.4×10^5	8.2×10^5	2.3×10^6 to 4.0×10^6
Rotational Spring, K_{RX}^N, in-lb/rad	2.0×10^{10}	7.6×10^9	9.0×10^9 to 2.6×10^{10}
Rotational Spring, K_{RY}^N, in-lb/rad	4.0×10^{10}	2.8×10^{10}	9.0×10^9 to 2.6×10^{10}
Rotational Spring, K_{RZ}^N, in-lb/rad	-	1.4×10^{10}	-

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EQUIVALENT SPRING CONSTANT FOR CONTROLS = AURA

             11           12            13            14            15            16

 11     .2104869+06   .0000000      .0000000      .0000000     -.5133022+08   .1261322+08
                      .4808735+08  -.1397179+08   .1064613+11   .0000000      .0000000
                                    .1424436+08  -.2909711+10   .0000000      .0000000
                                                  .2531615+13   .0000000      .0000000
                                                                .2054633+12   .2795180+12
                                                                              .8785532+12
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SYMMETRIC

REFERENCE POINT: CENTER OF SOUTH BEARING

UNITS: LB, IN, RADIANS

YOKE COORDINATE SYSTEM

(b) AURA'S METHOD

TABLE II. EFFECTIVE SOIL STIFFNESS MATRIX

EQUIVALENT SPRING CONSTANT FOR CONTROLS - PARMELEE

	11	12	13	14	15	16
11	.1710487+07	.0000000	.0000000	.0000000	-.4141477+09	.1207264+09
		.4870625+08	-.1642275+08	.1097249+11	.0000000	.0000000
			.8926454+07	-.3119255+10	.0000000	.0000000
				.2614656+13	.0000000	.0000000
					.2693109+12	.2619631+12
						.8832555+12

SYMMETRIC

REFERENCE POINT : CENTER OF SOUTH BEARING

UNITS: LB, IN, RADIANS

YOKE COORDINATE SYSTEM

(c) PARMELEE'S METHOD

TABLE II . EFFECTIVE SOIL STIFFNESS MATRIX

TABLE III. FOUNDATION WEIGHT MATRIX

$$[W] = \begin{bmatrix} 8.80 \times 10^{5} & 0 & 0 & 0 & -2.47 \times 10^{8} & -1.91 \times 10^{8} \\ & 8.80 \times 10^{5} & 0 & 2.47 \times 10^{8} & 0 & 0 \\ & & 8.80 \times 10^{5} & 1.91 \times 10^{8} & 0 & 0 \\ & & & 1.68 \times 10^{11} & 0 & 0 \\ & \underline{\text{Symmetric}} & & & 8.45 \times 10^{10} & 7.10 \times 10^{10} \\ & & & & & 9.95 \times 10^{10} \end{bmatrix}$$

Reference Point: Center of South Bearing

Units: lb, in-lb, lb-in^2

Yoke Coordinate System

TABLE IV. SOUTH PIER STIFFNESS

(a) INFLUENCE COEFFICIENT MATRIX

	01	02	03	04	05	06
01	.1426300-06	-.2040550-23	-.5776200-07	-.3898400-25	.1111500-08	-.1286850-24
02	-.2040550-23	.1236000-06	-.2150500-24	-.6111600-09	-.1170800-26	.7353000-09
03	-.5776200-07	-.2150500-24	.5513900-07	.2455150-25	-.7613100-09	.4188900-25
04	-.3898400-25	-.6111600-09	.2455150-25	.4130300-10	-.3074600-27	.1092100-10
05	.1111500-08	-.1170800-26	-.7613100-09	-.3074600-27	.4997900-10	-.6348600-27
06	-.1286850-24	.7353000-09	.4158900-25	.1092100-10	-.6348600-27	.5383100-10

REFERENCE POINT : CENTER OF SOUTH BEARING

UNITS : LB, IN, RADIANS

YOKE COORDINATE SYSTEM

TABLE IV. SOUTH PIER STIFFNESS

(b) STIFFNESS MATRIX

	01	02	03	04	05	06
01	.1013800+08	-.1273700-09	-.2168500-09	-.3616100-09	-.1975700+09	.1799000+09
02	-.1273700-09	.1255900+08	.1177700+08	.9991200+08	.1284500-08	.1781300-07
03	-.2168500-09	.1177700+08	.3401000+08	-.2561400+09	-.4704700-08	.2722200-08
04	-.3616100-09	.9991200+08	-.2561400+09	.2613200+11	.2545100-07	.1207700-06
05	-.1975700+09	.1284500-08	-.4704700-08	.2545100-07	.2944500+11	-.8737400+10
06	.1799000+09	.1781300-07	.2722200-08	.1207700-06	-.8737400+10	.2297700+11

REFERENCE POINT: CENTER OF SOUTH BEARING

UNITS: LB, IN, RADIANS

YOKE COORDINATE SYSTEM

TABLE V. NORTH PIER STIFFNESS

(a) INFLUENCE COEFFICIENT MATRIX

	01	02	03	04	05	06
01	.5741300-05	-.1800750-09	-.2147200-05	.2634300-12	.5178300-07	-.2448900-12
02	-.1800750-09	.2353300-05	.4316500-10	-.5133300-08	-.1047600-11	.3014400-08
03	-.2147200-05	.4316500-10	.1209300-05	-.5748850-13	-.1073900-07	.1751400-12
04	.2634300-12	-.5133300-08	-.5748850-13	.9605900-10	.1313800-14	.3541400-10
05	.5178300-07	-.1047600-11	-.1073900-07	.1313800-14	.5537000-09	-.3158200-14
06	-.2448900-12	.3014400-08	.1751400-12	.3541400-10	-.3158200-14	.3037500-09

REFERENCE POINT : CENTER OF NORTH BEARING

UNITS: LB, IN, RADIANS

YOKE COORDINATE SYSTEM

TABLE I. NORTH PIER STIFFNESS

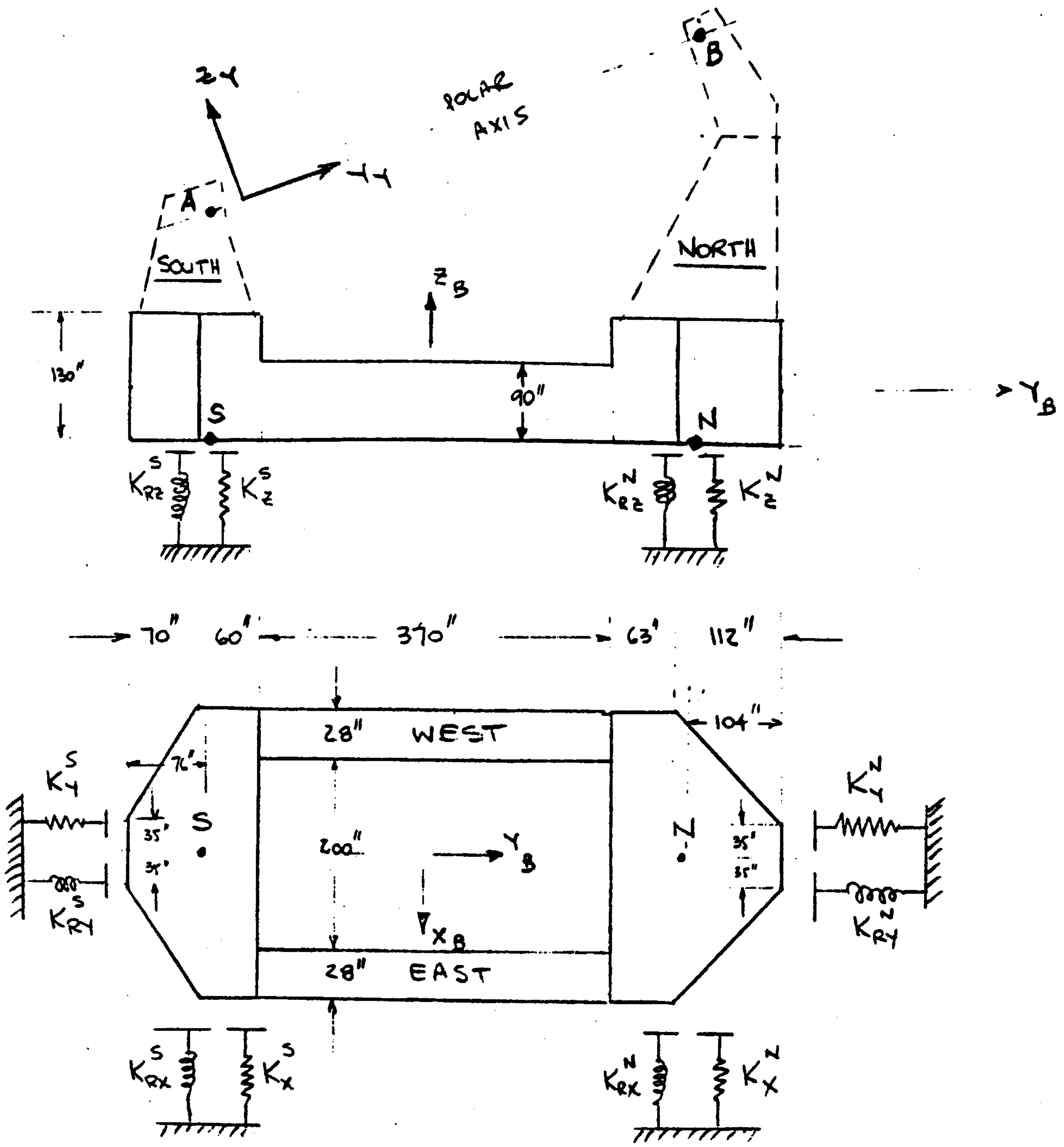
(b) STIFFNESS MATRIX

	01	02	03	04	05	06
01	.6875700+06	-.1311500+02	-.3231600+01	-.1226200+03	-.7120500+08	.1512500+08
02	-.1311500+02	.4021400+06	.4476300+06	.3001100+08	.9668300+03	-.4887900+03
03	-.3231600+01	.4476300+06	.1505400+07	.1314000+08	.4406800+03	-.7271900+03
04	-.1226200+03	.3001100+08	.1314000+08	.4521100+10	.1106000+05	-.3289600+05
05	-.7120500+08	.9668300+03	.4406800+03	.1106000+05	.1958000+11	-.2989400+10
06	.1512500+08	-.4887900+03	-.7271900+03	-.3289600+05	-.2989400+10	.3790800+10

REFERENCE POINT: CENTER OF NORTH BEARING

UNITS: LB, IN, RADIANS

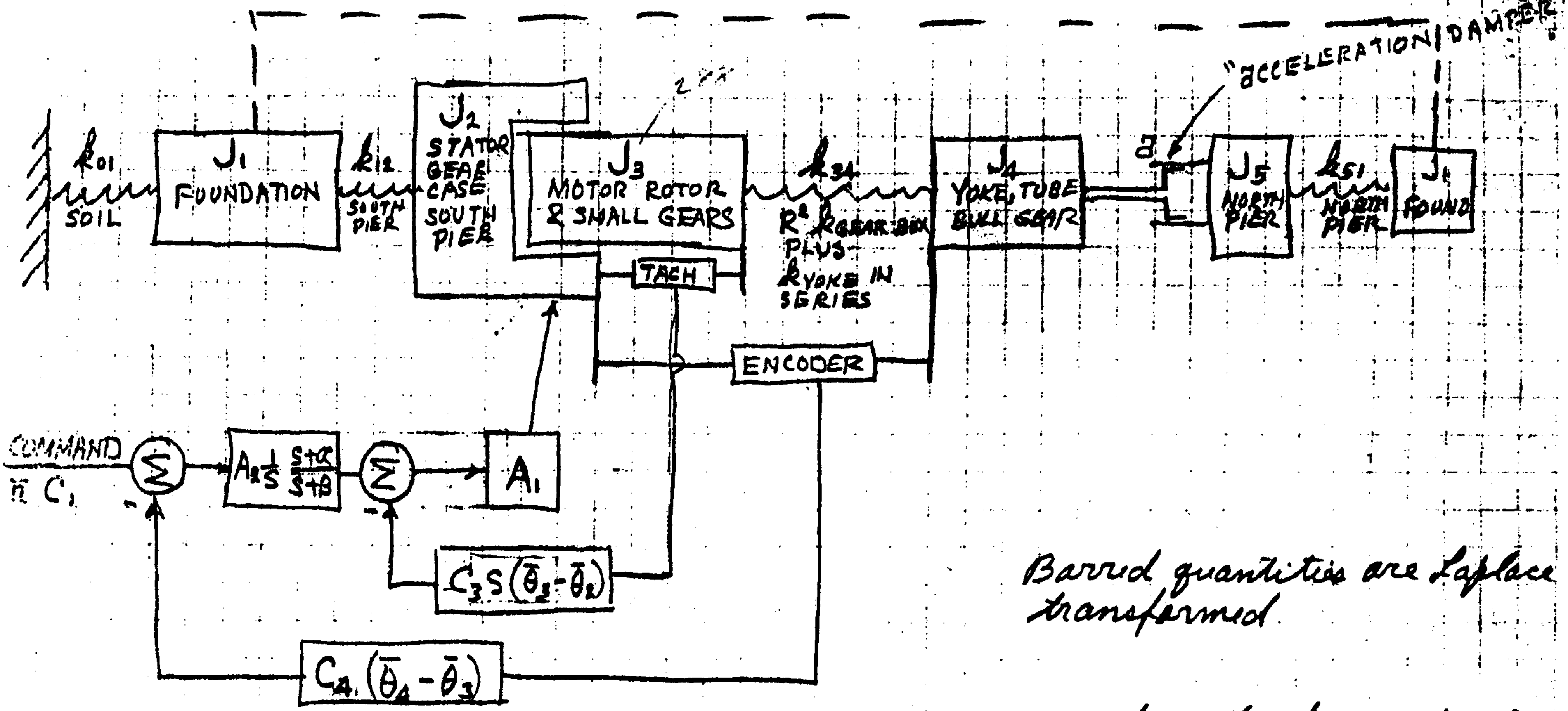
YOKE COORDINATE SYSTEM



- BASE COORDINATES X_B, Y_B, Z_B ; YOKE COORDINATES X_Y, Y_Y, Z_Y
- K_X, K_Y, K_Z LINEAR SPRINGS lb/in
- K_{RX}, K_{RY}, K_{RZ} ROTATIONAL SPRINGS in-lb/rad
- POINTS S AND N ARE LOCATED AT THE CENTROID OF THE SOUTH AND NORTH PEDESTAL HORIZONTAL AREA, RESPECTIVELY
- ALL SPRINGS ACT AT POINTS S AND N, BOTTOM OF THE CONCRE

FIGURE 1. DEFINITION OF SOIL SPRING CONSTANTS AND COORDINATES

FIVE INERTIA MODEL OF 3 M MAUNA KEA TELESCOPE



Barred quantities are Laplace transformed

The equations of motion are:

(1) $J_1\ddot\theta_1 = -k_{01}\theta_1 - k_{12}(\theta_1-\theta_2) - b_1\dot\theta_1 - \underline{k_{51}(\theta_1-\theta_5)}$

(2) $J_2\ddot\theta_2 = -k_{12}(\theta_2-\theta_1) - b_2\dot\theta_2 - L$

(3) $J_3\ddot\theta_3 = -k_{34}(\theta_3-\theta_4) - b_3\dot\theta_3 + L$

(4) $J_4\ddot\theta_4 = -k_{34}(\theta_4-\theta_3) - b_4\dot\theta_4 + a\ddot\theta_4$

(5) $J_5\ddot\theta_5 = -k_{51}(\theta_5-\theta_1) - b_5\dot\theta_5 - a\ddot\theta_5$

The motor torque, L, is

(6) $L = k_1 e_{in} - m(\dot\theta_3-\dot\theta_2)$

where k_1 and m are motor consts.

The Laplace transform of e_{in} is:

(7) $\bar e_{in} = \left\{\left[C_1\bar\pi - C_4(\bar\theta_4-\bar\theta_3)\right] A_2\frac{1}{s}\frac{(s+\alpha)}{(s+\beta)} - C_3 s(\bar\theta_3-\bar\theta_2)\right\}A_1$

FIGURE 2.