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Contraves
Goerz
Corporation
301 Alpha Drive, Pittsburgh, Pa. 15238

The American Subsidiary of Contraves AG,
Oerlikon-Bührle Holding

FINAL REPORT

FOR A

THREE-AXIS FLIGHT SIMULATOR

TR-3547

The American Subsidiary of Contraves AG, Oerlikon-Bührle Holding

FINAL REPORT

FOR A

THREE-AXIS FLIGHT SIMULATOR

(S.O. K00213)

CONTRACT NO. NA58-31018

PROJECT ENGINEER: Michael G. Mason

TR-3547

Prepared for

NASA/MSFC
Huntsville, Alabama

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FINAL REPORT
FOR A
THREE-AXIS FLIGHT SIMULATOR
(S.O. K00213)

1.0 INTRODUCTION

The equipment, Model 158-0070, shown in Figure 1, is a three-axis simulator for testing and evaluating inertial measuring units and flight platforms. Each axis is independently digitally controlled by manual or computer commands in either Position or Rate modes. The inner axis is equipped with a 30-inch diameter cast aluminum table top which is capable of continuous rotation. Electrical access to the test package is by connectors on the table top which provide 100 lines for experimental use. The system was shipped at the end of May 1975 and installation was completed in the second half of July 1975.

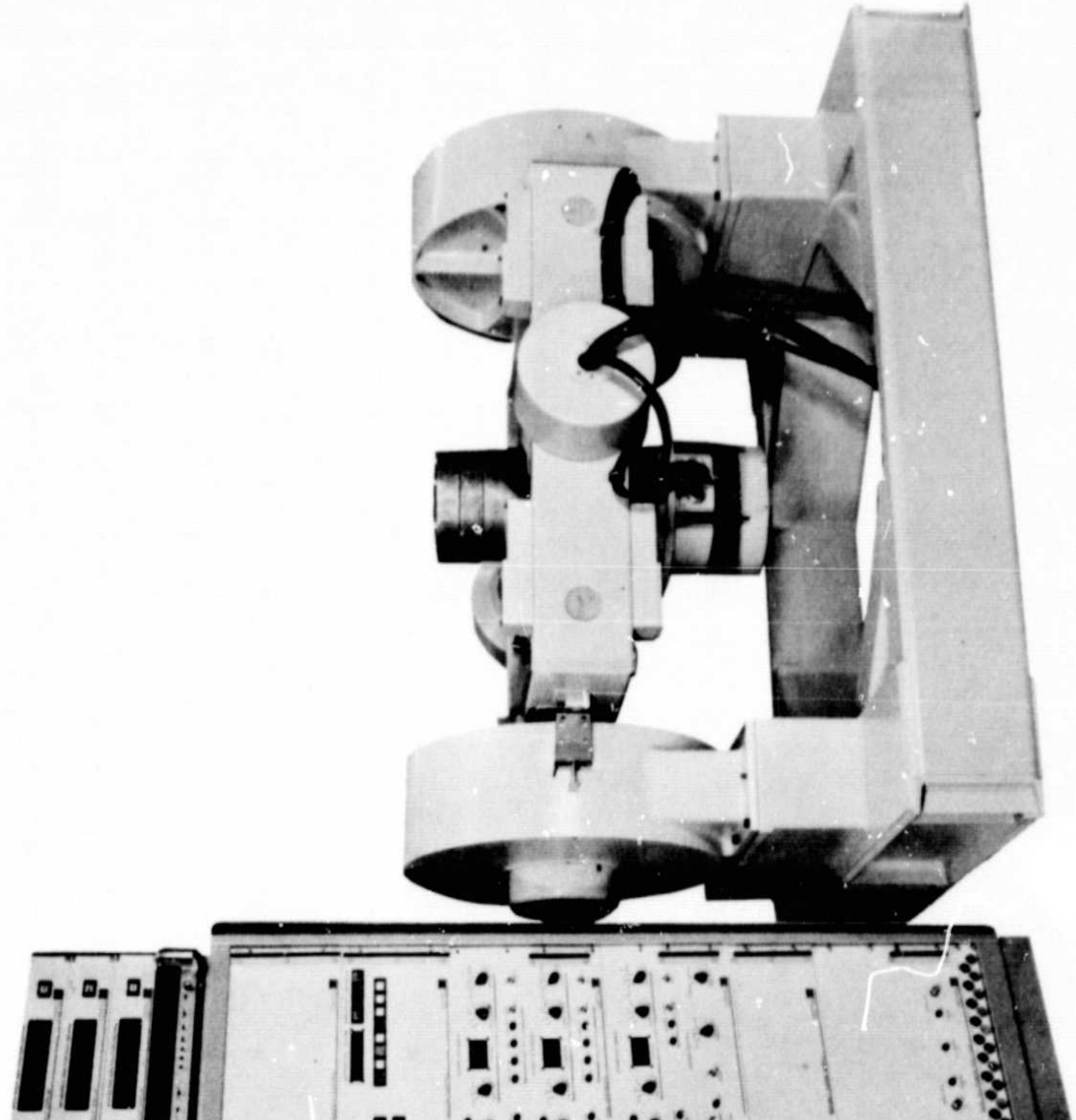

Figure 1. Model 158-0070
Three-Axis Flight Simulator

2.0 SPECIFICATION SUMMARY

2.1 MECHANICAL

2.1.1 OUTER AXIS

Range	±95°
Orthogonality	5 arc seconds
Wobble	5 arc seconds
Bearings	Precision ball
Torque Motor	300 ft-lbs
Position Readout	
Fine	12-inch Inductosyn 720 poles
Coarse	2-pole resolver
Rate Readout	
Transducer	DC Tachometer
Ripple	0.1%
Scale Factor	9.5 ±1 v/rad/sec

2.1.2 MIDDLE AXIS

Range	±170°
Orthogonality	5 arc seconds
Wobble	5 arc seconds
Bearings	Precision ball
Torque Motors	33 ft-lb, total
Position Readout	
Fine	12-inch Inductosyn 720 poles
Coarse	2-pole resolver
Rate Readout	
Transducer	DC Tachometer
Ripple	0.1%
Scale Factor	9.5 ±1 v/rad/sec

2.1.3 INNER AXIS

Range	Infinite
Orthogonality	5 arc seconds
Wobble	5 arc seconds
Bearings	Precision ball
Torque Motor	16 ft-lbs
Position Readout	
Fine	12-inch Inductosyn 720 poles
Coarse	2-pole resolver
Rate Readout	
Transducer	DC Tachometer
Ripple	0.1%
Scale Factor	9.5 ±1 v/rad/sec

2.2 ELECTRICAL

2.2.1 POSITION MODE

Range	
Inner Axis	360 degrees
Middle Axis	340 degrees
Outer Axis	190 degrees
Resolution	0.0001 degree
Accuracy	<5 arc seconds
Repeatability	0.1 arc second
Slew rate, direction	10°/sec, least distance path

2.2.2 RATE MODE

Ranges (CW/CCW)	0 - 99.99 degrees/second 0 - 9.999 degrees/second 0 - 0.9999 degree/second 0 - 0.09999 degree/second
Resolution	0.01% of full scale
Accuracy	±5% of command

2.2.3 DATA READOUT

Position	1) Visual Display 2) Computer addressable, TTL compatible 3) 1° pulse

Rate	Hewlett Packard counter using 1° position pulses displays inverse or direct rate.

3.0 TEST RESULTS

The results of the acceptance test on the Model 158-0070 Three-Axis Test Table (TP-3520) are presented in Appendix A.

APPENDIX A

ACCEPTANCE TEST PLAN

FOR

MODEL 158 THREE-AXIS TEST TABLE

TP-3520

RESULTS COPY

ACCEPTANCE TEST PLAN

FOR

MODEL 158 THREE-AXIS TEST TABLE

May, 1975

TP-3520

Prepared for

NASA/MSFC
Huntsville, Alabama

S.O. K00213

The American Subsidiary of Contraves AG, Oerlikon-Bührle Holding

SECTION 1

ELECTRICAL ACCEPTANCE TEST PLAN

(FINAL TESTS)

CONTRAVES-GOERZ CORP.
SUBSIDIARY
CONTRAVES AG, OERLIKON-BÜHRLE HOLDING

CUSTOMER: NASA - MFSC
SALES ORDER: K00213
INSTRUMENT: 3-Axis Mount

TEST PLAN

SPEC PARAGRAPH	ITEM	SPECIFICATION	METHOD OF VERIFICATION	TEST PARAMETER	RESULTS IA	RESULTS MA	RESULTS OA
10	1	POSITION MODE			IA	MA	OA
		Accuracy 5 arc sec	STP-E-1245B		.5	.75	.75
		Resolution 1 arc sec	Visual inspection		.36	.36	.36
12	2	BANDWIDTH $\geq$ 5 Hz	STP-E-2265		30	16	22
12	3	RATE MODE					
		Resolution 0.01%FS	Visual Inspection		.01	.01	.01
		Accuracy, 5% of command	STP-E-2266		≤1.1	≤4.3	≤1.0
		Range, 0.005 to 50°/sec	STP-E-2266		✓	✓	✓
		Acceleration > 1 rad/sec^2	STP-E-270		5.8	1.5	2.9
		Rate Trip	STP-E-2266	°/sec	100.	55.	55.

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DATE	TESTED BY	WITNESSED BY (GOERZ)	WITNESSED BY (CUSTOMER)	PAGE
5.30.75	M. G. Masan	M. G. Masan	James Cook July 22 1975	

SECTION II

STANDARD TEST PROCEDURES
(ELECTRICAL)

In the mechanical alignment of the Inductosyn, sufficient data is obtained to ascertain the alignment errors of the installed Inductosyn (ref. TR-2029A). The eccentricity error is calculated directly in the alignment procedure.

The effective pattern wobble can be deduced from the variation in amplitude of the windings as the unit is rotated by using the formula.

$$W = \text{wobble} = \frac{\text{Voltage Variation}}{\text{Nominal Variation}} \times \frac{.007}{D} \times 2 \times 10^5$$

D = Diameter of the Inductosyn pattern in inches

This formula is based on a minimum spacing of 0.007 inches.

ELECTRONICS ERROR (E_e)

The only significant electronics errors are due to gain unbalance errors between the current drives to the Inductosyn (a factory adjustment). The verification of this accuracy is obtained by measuring the current balance using a special test fixture in conjunction with G/I STP-

The Fine Error contribution as a result of current unbalance is given by the following formula:

$$E_e = \frac{1}{2\pi} \frac{1}{n} \frac{\Delta I}{I} \times 2 \times 10^5$$

n = Electrical speed of the Inductosyn

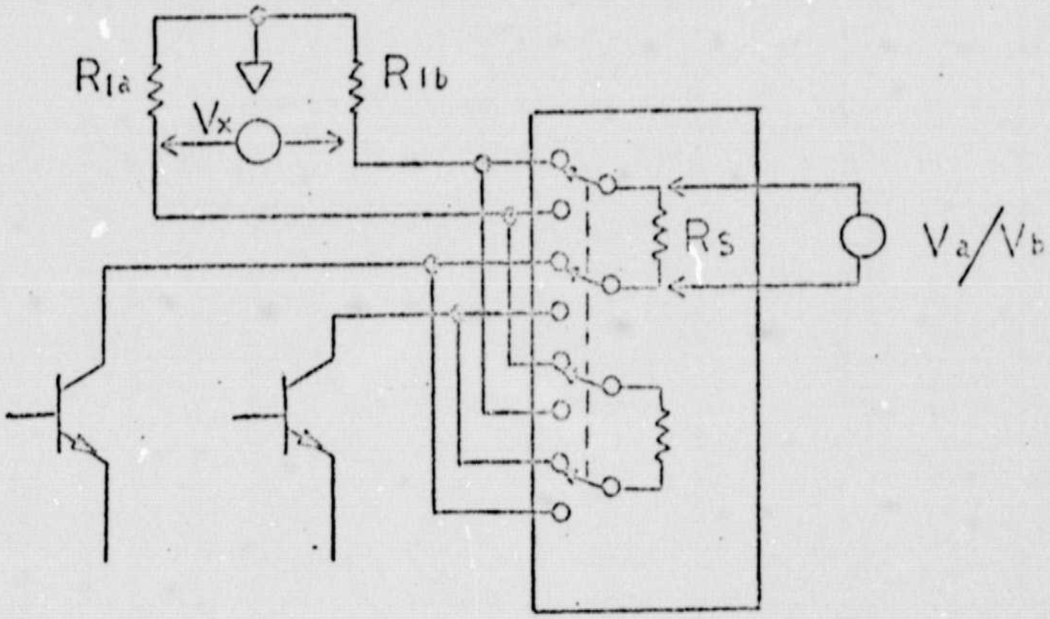
I = Nominal Current Reading

ΔI = Total current difference between current drive channels

Inductosyn drive error is tested using STP

In this test, a measure of the relative magnitude of the sine and cosine drive signals is obtained, as well as a measure of a combination of phase and harmonic distortion error. The former is obtained by direct measurement of voltage across a sampling resistor in RMS form.

The latter is obtained by observing the peak-to-peak voltage across another sampling resistor. To properly combine these values, they must both be scaled into rms current units.



V_x = Peak/peak value of lissajous observed across R_{1a} and R_{1b}

i_x = rms value of difference in current (mostly quadrature error)

$i_x = 0.35\ (V_x/R_1)$ = quadrature imbalance

$i_m = (V_a - V_b)/R_s$ = magnitude unbalance

$I = V_a/R_s$ = nominal current

$$\frac{\Delta i}{I} = \text{Total relative current error} = \frac{1}{I}\sqrt{i_m^{\,2} - i_x^{\,2}}$$

$$= \frac{1}{V_a}\sqrt{(V_a-V_b)^2 - [.35\ V_x(R_s/R_1)]^2}$$

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TOTAL SYSTEM ACCURACY

$$E_T = \sqrt{E_I^2 + E_m^2 + E_e^2}$$

E_I = Peak Inductosyn Error from Manufacturer's data

EQUIPMENT REQUIRED

None - The data required for this test is collected during execution of other tests.

PROCEDURE

Collect data as required from the appropriate test results and fill out Table 1, performing the necessary calculations.

	INNER	MIDDLE	OUTER
① Eccentricity (TIR - inches) from from TR-2029	$.69 \cdot 10^{-4}$	$.69 \cdot 10^{-4}$	$1.45 \cdot 10^{-4}$
② Max Voltage (CD) from TR-2029	31.5	21.0	19.8
③ Min Voltage (CD) from TR-2029	30.0	20.0	19.00
④ Wobble (arc sec) $W = \frac{② - ③}{③} \times \frac{.007}{⑩} \times 2 \times 10^5$	6.30	6.30	5.30
⑤ Peak Mechanical Error (arc sec) $E_m = 10 \cdot ① \cdot ④ \cdot \frac{11}{⑩}$	.004	.004	.004
⑥ Current Reading Channel 1 from STP	1.6477	—	—
⑦ Current Reading Channel 2 from STP	1.6478	—	—
⑧ Quadrature Error (lissajous) V_x = .0005 V from STP $i_x = 0.35\ V_x(R_s/R_1)$	$4.2 \cdot 10^{-3}$	—	—
⑨ Peak Electronic Error (arc sec) $E_e = \frac{1}{2\pi} \frac{1}{⑪} \sqrt{\frac{(⑥ - ⑦)^2 + ⑧^2}{⑦^2}} \times 2 \times 10^5$	.024	—	—
⑩ Inductosyn Pattern Effective Diameter IND TYPE / EFFECTIVE DIAMETER 12" / 11" 8" / 7" 7" / 6" 5" / 4" 3" / 2"	11"	11"	11"
⑪ Inductosyn Electrical Speed (½ number of poles)	360	360	360
⑫ Inductosyn Transducer - E_I Error - Peak From Vendor Test Data (attach copy)	.5	.75	.75
⑬ Total System Error $E_T = \sqrt{⑫^2 + ⑨^2 + ⑤^2}$	.5	.75	.75

DATE	TESTED BY	WITNESSED BY (GOERZ)	WITNESSED BY (CUSTOMER)	PAGE
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Instrument: MOTION SIMULATOR

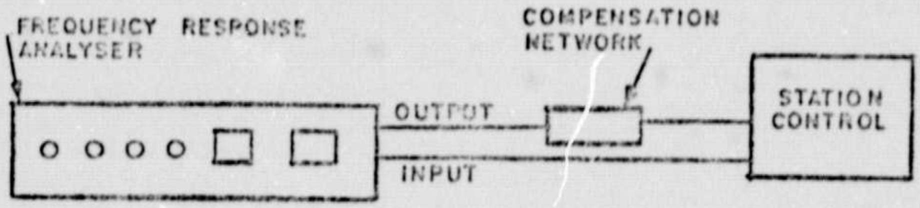
Shop Order: K00213

Customer: NASA MSFC

Axis: ______

Specification: > 5HZ (3dB point)

Test Setup:



Test Equipment:

1. Frequency Response Analyzer

Procedure:

1. Place the axis in POSITION mode with the loop closed and ensure that it is stationary.

2. Connect the output of the analyzer to the summing junction of IC4 on the COARSE/FINE switch card via a compensation network with the same values as R_{26}, C_{12}, and R_{34}. Adjust amplitude for $\pm 0.1°$ (approximately ± 5 V).

3. Connect TP5 on the coarse fine switch to the input of the frequency response analyzer.

4. Measure and record the amplitude and phase of the output signal at suitable frequencies. Record the 3-db point bandwidth.

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Results:

Bandwidth = 30 Hz

Frequency (Hz)	Output Amplitude (db)	Output Phase (degrees)
.2	+.4	-3.
.4	+1.58	-10.
.6	+2.28	-21.
.8	+1.94	-40.
1.	-5.1	-56.
2.	-13.4	-25.
4.	-12.04	-9.
8	-6.0	-5.
10	-2.5	-2.
15	+2.77	-55.
30.	-2.5	-165.
40	-10.37	-237.

5.30.75 | Witnessed by: M. G. Macin C.G.

Results: Bandwidth = 16 Hz

Frequency (Hz)	Output Amplitude (db)	Output Phase (degrees)
.5	0	0
1.	0	-3
2.	0	-3
4.	+3	-10
8	+8	-50
16	-3	-165
32	-16	-265

Results: Bandwidth = 22 Hz

Frequency (Hz)	Output Amplitude (db)	Output Phase (degrees)
.5	0	-2
1.	0	-3
2	+1.6	-3
4.	+4.6	-21
8	+4.6	-80
16	+0.4	-128
22	-3.	-193
32	-5.	-230
64	-20.	-313

5.30.75 | Witnessed by M. G. Mason C.G.

Instrument: MOTION SIMULATOR

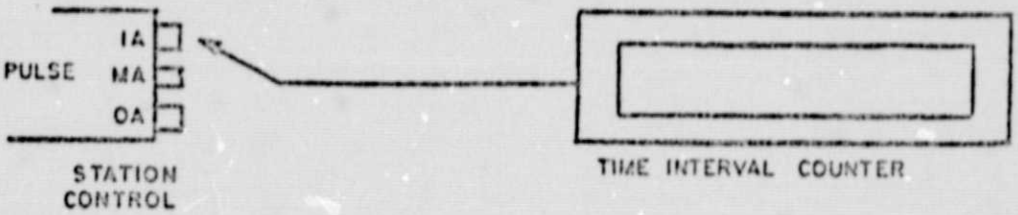
Shop Order: K00213

Customer: NASA MSFC

Axis: ____________

Specification: 5% OF COMMAND

Test Setup:



Test Equipment:

1. Time Interval Counter

Procedure:

1. Servo the axis under test in the RATE mode, command 99.99°/sec and measure the time for 10 pulses.

2. Repeat the test for 9.999, 0.9999, 0.09999°/sec.

3. Verify rate operation below 0.005°/sec by commanding progressively lower rates and observing the position display.

4. Set rate trip for operation at 100°/sec CW/CCW.

5. Measure and record the tach scale factor.

INNER AXIS

Results:

Rate Trip OK ✓ >100°/sec
Tach Scale Factor = 0.166 volts/°/sec

Commanded Rate (°/sec)	Time for 10 pulses sec		Accuracy (%)	
	CW	CCW	CW	CCW
99.99	.09994	.09998	.06	.02
9.999	1.001	.9998	.1	.02
0.9999	10.014	10.016	.14	.16
0.09999	100.102	98.870	.1	1.1

5-23-75 Witnessed by: M. G. Mason C.G.

MIDDLE AXIS

Results:

Rate Trip OK ✓ 55°/sec

Tach Scale Factor = .173 volts/°/sec

Commanded Rate (°/sec)	Time for 10 pulses sec		Accuracy (%)	
	CW	CCW	CW	CCW
~~99.99~~ 50.00	.2001	.1996	.05	.04
9.999	.9957	.9939	.4	.6
0.9999	10.02	9.92	.2	.8
0.09999	104.26	98.089	4.26	1.91

5.28.75 Witnessed by M. G. Mason C.G.

OUTER AXIS

Results:

Rate Trip OK ✓ 55°/sec

Tach Scale Factor = .172 volts/°/sec

Commanded Rate (°/sec)	Time for 10 pulses		Accuracy (%)	
	CW	CCW	CW	CCW
~~99.95~~ 50.00	.1998	.1998	.01	.01
9.999	.9971	.9973	.029	.027
0.9999	10.025	10.008	.25	.08
0.09999	101.007	99.141	1.0	0.86

5·28·75 | Witnessed by M. G. Mason C.G.

PURPOSE

The purpose of this test is to determine the stall acceleration of an axis, and also any other acceleration at any other point in the rate versus time profile when a step rate command is applied. It is useable in testing for specifications which call for:

1) Stall acceleration

2) Average time to accelerate to a velocity

3) Acceleration and deceleration control with accuracy requirements

In addition, since a large step command is applied to the servo, the test is useable for establishing the levels of current limiting the system when features have been incorporated in the power amplifier circuitry as well as dissipation limiting.

TEST ACCURACY CONSIDERATIONS

The acceleration measuring accuracy of this test is limited by the test equipment provided and the accuracy with which the rate output scale factor of the equipment is known. Assuming that a rate calibration test has been performed (STP-E-271) for example, the knowledge of the tach scale factor and the amplitude error of the strip chart recorder in measuring rate would not be an accuracy factor in this test, leaving only the inaccuracy due to the timing of the strip chart recorder. It is recommended that the time calibration of the strip chart recorder should be verified prior to conducting the test, in order to obtain a knowledge of this scale factor.

In general, the specification accuracy of the acceleration mode is in the neighborhood of 1% to 10%, which is within the range of the strip chart recorder accuracy time base; in general, strip chart recorders would not be adequate for 1% amplitude checks. Note that the rate calibrations are generally more accurate than this.

TEST EQUIPMENT REQUIRED

The test equipment requirements for this test are a strip chart recorder and the controller.

If the controller is not equipped with a manual input, an auxiliary means of providing step rate commands is required.

TEST PARAMETER DEFINITION REQUIREMENTS

The call for this standard step procedure in the final test specification should include the rates to be commanded, the specification of acceleration and deceleration parameters (either in time to rate or in peak stall acceleration or average acceleration/deceleration). If the test is used to verify acceleration/deceleration calibration levels, then the test should specify acceleration/deceleration settings for the controller, and the accuracy specifications of the acceleration and deceleration measurement at each of the settings.

Cautions:

1) On systems with limited angular range, such as rate table systems with wires going to a rotating member without slip rings, care should be taken to make sure that the acceleration transient is initiated and run so that the stops will not be reached during the tests.

2) Prior to running this test, it should be verified that the current limit adjustments have been performed on this unit prior to initiating the test. If it has not been performed, this test may be used to set the current limit adjustment keeping in mind the accuracy of the strip chart recorder. If this is done, be sure and start at the low end of the adjustment (see manual).

TEST PROCEDURE

1) Hook up the system under test with the test equipment as shown in the figure.

2) Place the system in the proper operating mode by following the manual.

3) For rate table systems, set up the strip chart recorder, either by calculation or by trial and error, that the traces on the strip chart cover close to the full scale range on the strip chart recorder, and adjust the strip chart recorder speed so that at least five inches of strip chart paper are required to record the acceleration/deceleration transient.

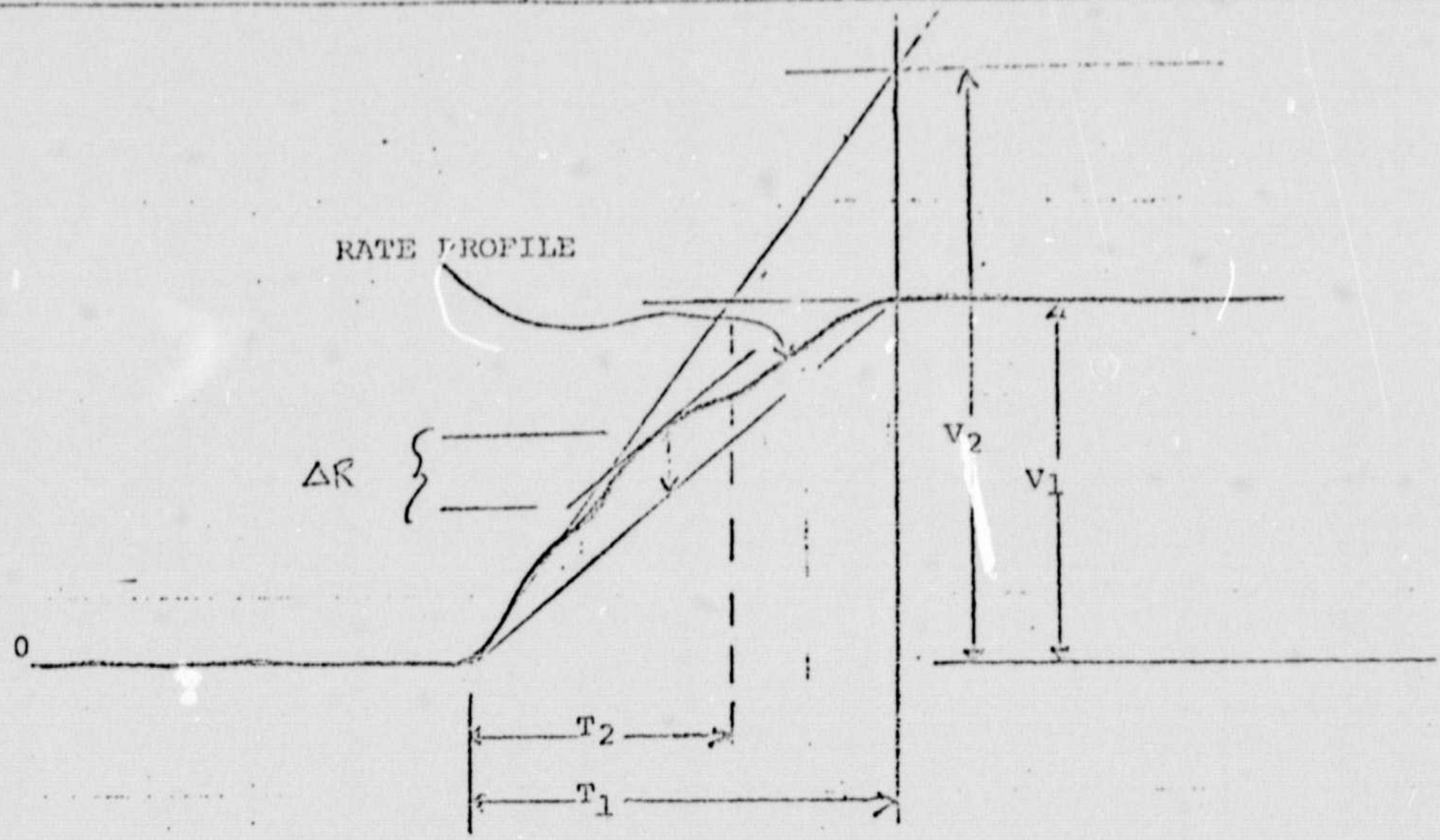
4) Setup the rate table to accelerate to rates and decelerate to rates as indicated in the data sheet. Always turn the strip chart recorder on just prior to initiating the acceleration/deceleration transient, and turn the strip chart recorder off after the transient has subsided prior to setting up for the next step command. Perform all of the tests indicated, and record the values on the data sheet.

5) Measure the rate voltage versus time slope in order to determine the acceleration from the torque or current channel.

6) Measure and record the voltage across the current sampling resistor during the acceleration transient.

7) Determine the magnitude of the current limit by dividing the value of the current sampling voltage obtained by the value of the current sampling resistor, and compare it to the value that is supposed to be set.

8) Calculate the peak acceleration and stall acceleration from the formulas shown in the attached figure, using either the rate over time or (voltage over time) scale factor method for computation (whichever is most convenient).



T_1 = Time to achieve set rate

$Rc/T_2 = (K_T)V_1'/T_2 = \alpha_p$ Peak Stall Acceleration = $(K_T)V_2/T_1$

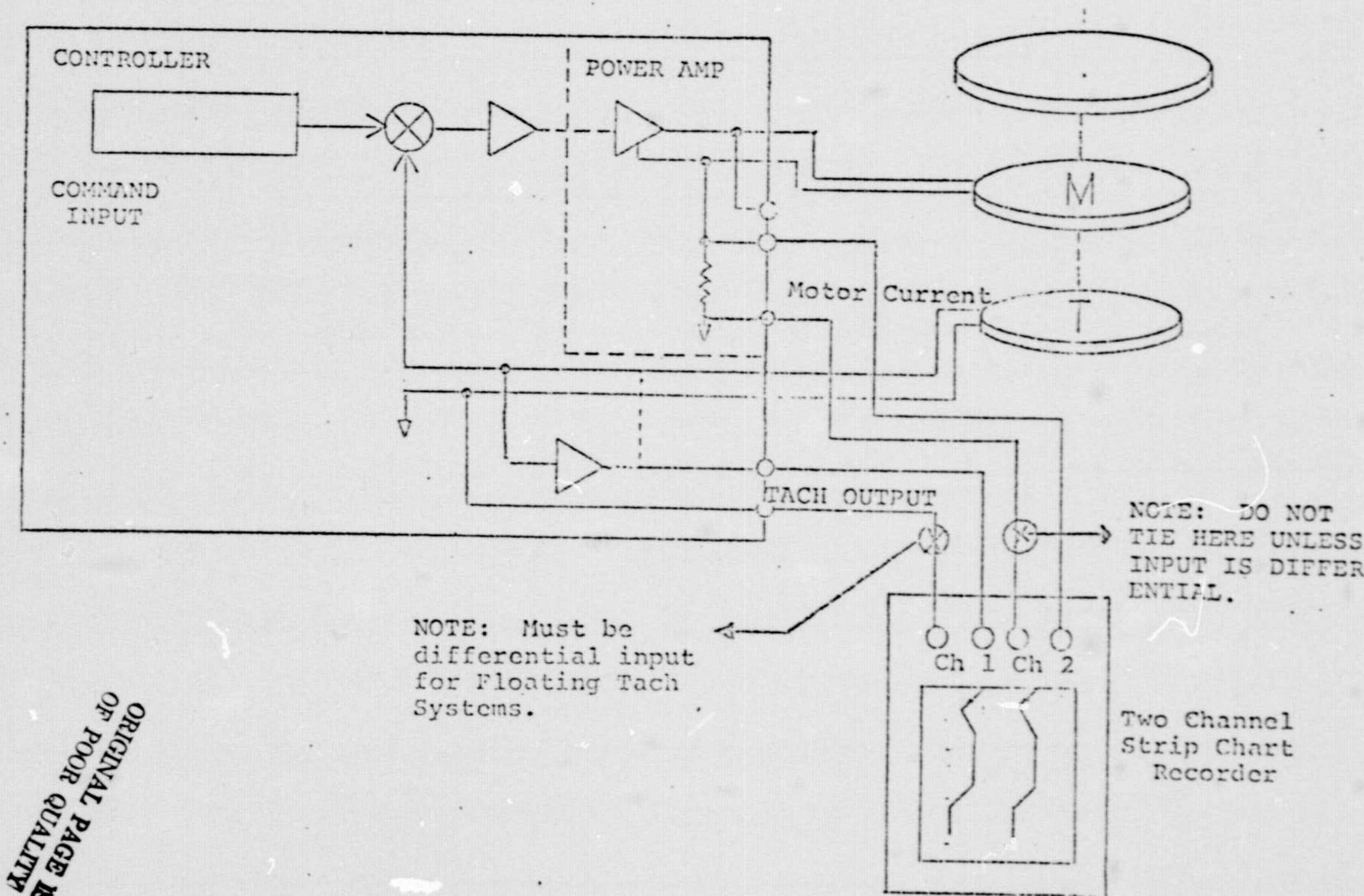
$Rc/T_1 = (K_T)V_1/T_1 = \alpha_a$ Average Acceleration to Set Rate

K_T = Tach Scale Factor, °/sec-volt

Rc = Command Rate

ΔR = Peak Rate Error During Acceleration

FIGURE: DETERMINATION OF ACCELERATION/DECELERATION VALUES



TEST SET-UP

STEP ACCELERATION/DECELERATION TESTS AND CURRENT LIMIT TEST

INNER AXIS

TACH SCALE FACTOR = .166 V/°/sec

IcL = —

R_S = 0.25Ω

RATE °/sec	T_1 spec	T_1 meas sec	T_2 spec sec	T_2 meas sec	V_1	V_2	V_p	I_p	α_p spec rad/sec²	α_p meas rad/sec²	α_a spec	α_a meas
50	—	.15	.87	.15	8.3	8.3	4.8	19.2	1.0	5.8	—	5.8

DATE | TESTED BY | WITNESSED BY (GOERZ) | WITNESSED BY (CUSTOMER)

MIDDLE AXIS

TACH SCALE FACTOR = .173 V/°/sec

IcL = —

R_s = .075 Ω

RATE °/sec	T_1 spec	T_1 meas	T_2 spec	T_2 meas	V_1	V_2	V_p	I_p	α_p spec rad/sec²	α_p meas rad/sec²	α_a spec	α_a meas
50	—	.6	.87	.6	8.7	8.7	1.6	21.3	1.0	1.5	—	1.5

DATE 5.28.75

TESTED BY

WITNESSED BY (GOERZ)

WITNESSED BY (CUSTOMER)

OUTER AXIS

TACH SCALE FACTOR = ·172 v/°/sec

IcL = /　　　R_S = ·0375 Ω

RATE °/sec	T_1 spec	T_1 meas sec	T_2 spec sec	T_2 meas sec	V_1	V_2	V_p	I_p	α_p spec rad/sec²	α_p meas rad/sec²	α_a spec	α_a meas
50	/	·3	·87	·3	8·6	8·6	1.15	30·7	1.0	2.9	/	2·9

DATE 5·29·75 | TESTED BY [signature] | WITNESSED BY (GOERZ) [signature] | WITNESSED BY (CUSTOMER)

SECTION III

MECHANICAL ACCEPTANCE TEST PLAN

(IN PROCESS TESTS)

CONTRAVES-GOERZ, CORP.
SUBSIDIARY
CONTRAVES AG. OERLIKON-BÜHRLE HOLDING

CUSTOMER:
SALES ORDER:
INSTRUMENT:

TEST PLAN

SPEC PARAGRAPH	ITEM	SPECIFICATION	METHOD OF VERIFICATION	TEST PARAMETER	RESULTS IA	RESULTS MA	RESULTS OA
3	1	Unbalance, 5 ft-lb	STP-M-2261		.25	.51	4.[illegible]
5	2	Wobble, 5 arc sec	STP-M-201A		1.2	2.6	2.5
5	3	Orthogonality, 5 arc sec (inner to middle)	STP-M-213			2.9	
5	4	Orthogonality, 5 arc sec (inner to outer)	STP-M-213			2.25	

DATE	TESTED BY	WITNESSED BY (CORP)	WITNESSED BY (CUSTOMER)	PAGE ___ OF ___
4/22/75	U. Grossfelder	RW Mitchell		

SECTION IV

STANDARD TEST PROCEDURES

(MECHANICAL)

TEST EQUIPMENT:

1 Tooling Mirror
1 Automatic Autocollimator, Kollmorgen K-342
1 X-Y Plotter - HP No. 7000AM or equivalent

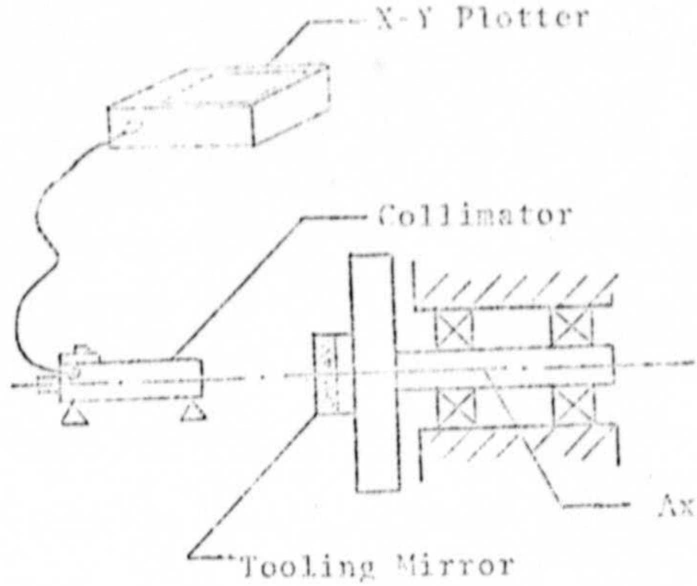


FIGURE 1

PROCEDURE:

1. Make test setup as shown in Figure 1.
2. Establish autocollimation through 360 degrees of shaft rotation.
3. On the graph from the X-Y plotter, draw the smallest circle inscribing the wobble graph. Draw the largest circle possible circumscribing the wobble graph.
4. The radial difference is the total range of the random wobble.

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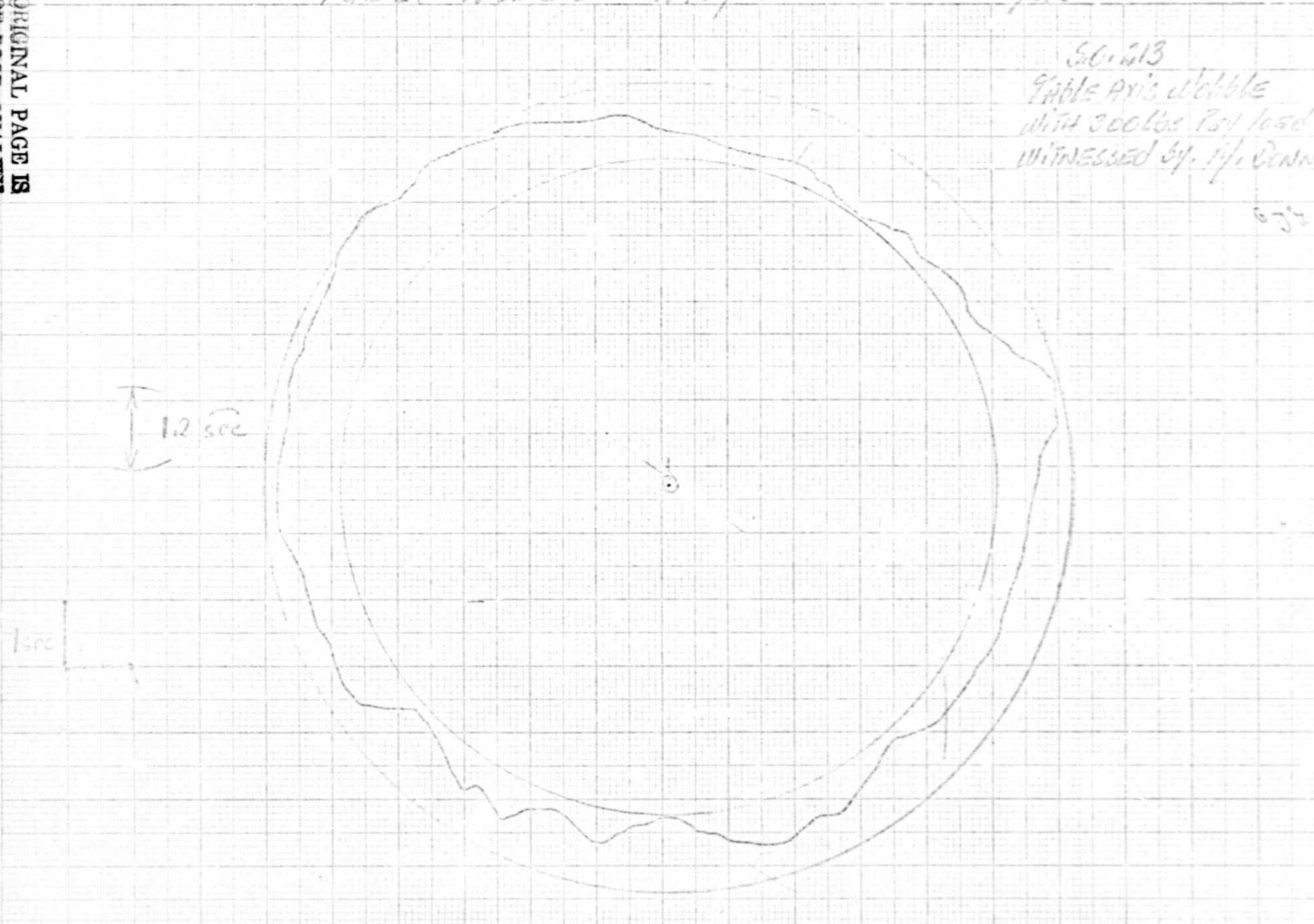
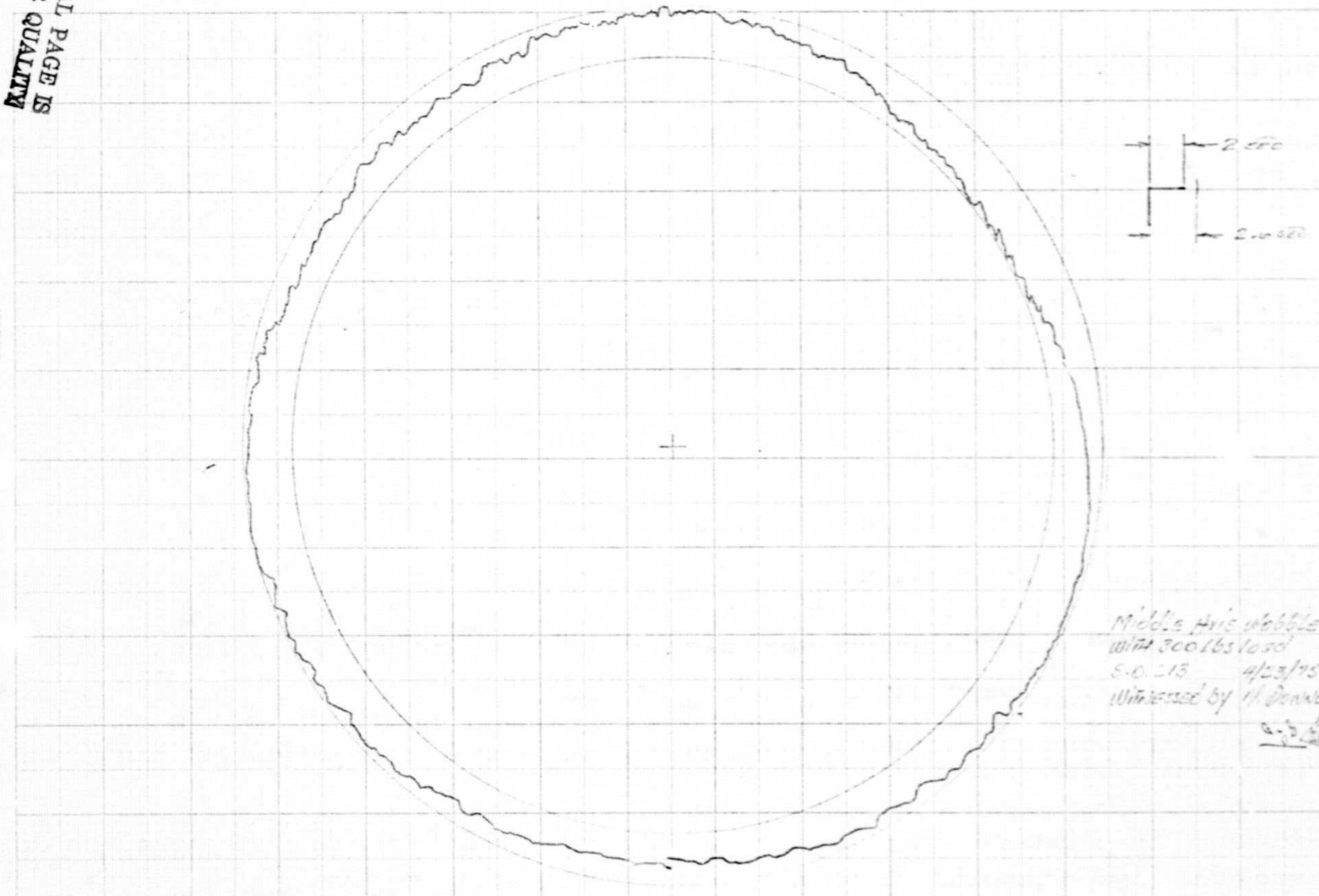
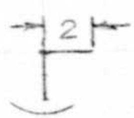
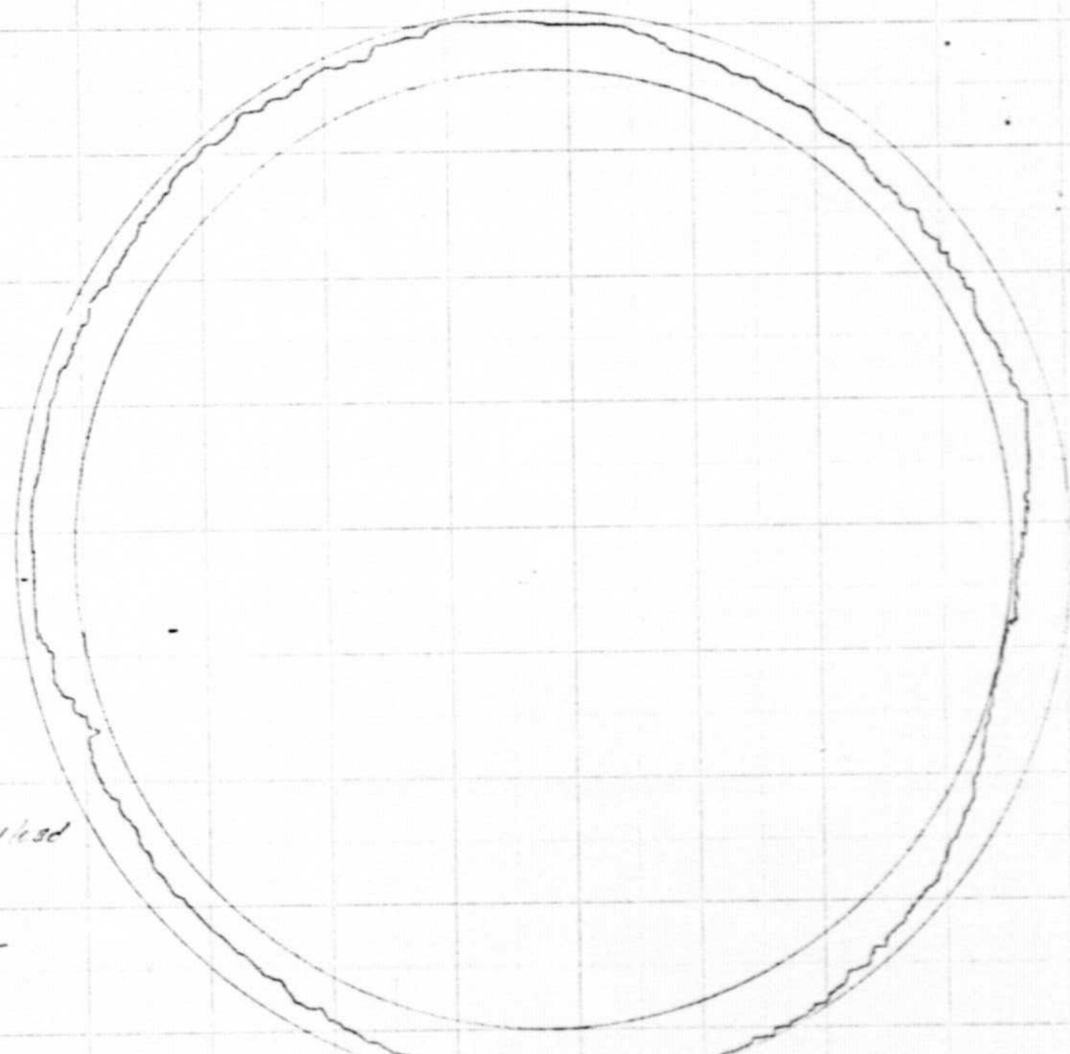
Table wobble with 350 LBS. 4/22




2 sec
Middle Axis wobble
with 300 lbs load
S.O. 213 4/23/75
Witnessed by





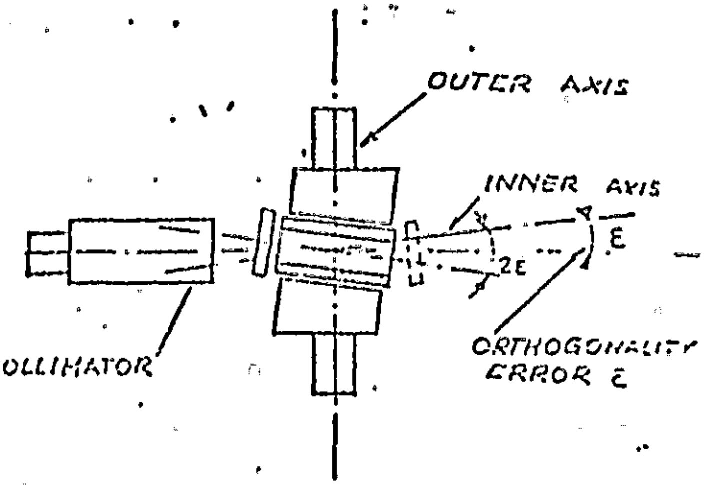
Outer Axis Wobble with 500 lbs payload
S.C. 213 4/22/75
TOTAL Wobble = 2.5 $\widehat{SEC}$
4/22/75

Witnessed by: [illegible]
Q.A.

Instrument: 700-0080 (152-0070)
Unit: ______ Shop Order: K215
Customer: NASA-MARSHALL

Specification Requirement:
5 sec

INNER/MIDDLE



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Task
Determine the perpendicularity error between two intersecting gimbal axes.

Test Setup
Set up an autocollimator or theodolite with an autocollimating eyepiece with a resolution of 0.2 arc seconds minimum, such that autocollimation can be established with the mirror placed on the center of the inner axis. Mount an adjustable double surface mirror on the inner axis and align it perpendicular to the axis of rotation. Two tooling mirrors are to be used if the shaft does not have a central perforation.

Test Procedure
Establish autocollimation and measure and record the shaft direction in the coordinate parallel to the outer axis. Rotate the inner axis about itself 180°. Measure and record the shaft direction. Rotate the inner axis about the outer axis 180° and measure and record the shaft direction as above. Rotate the inner axis about itself 180° and measure the shaft direction. Repeat each measurement 3 times.

Data Reduction
Average the readings of the first two sets of measurements. Average the readings of the second two sets of measurements. The angular difference between the two averages equals 2 times the orthogonality error ε.

OUTER AXIS 0°

ANGULAR POSITION OF THE INNER AXIS ~~Outer~~ MID Axis at 0°		~~Outer~~ MID Axis at 180°	
Inner Axis At Start Pos.	29.1 29.1 29.0	Inner Axis At Start Pos.	56.2 56.0 56.2
Inner Axis 180° From Start Pos.	27.6 27.8 27.8	Inner Axis 180° From Start Pos.	53.8 54.1 53.8
Avg 1. Set	28.4	Avg 2. Set	55.0
Diff. Between Averages = 2ε = 26.6			

OUTER AXIS 180°

ANGULAR POSITION OF THE INNER AXIS ~~Outer~~ MID Axis at 0°		~~Outer~~ MID Axis at 180°	
Inner Axis At Start Pos.	56.1 55.9 56.0	Inner Axis At Start Pos.	17.9 18.2 18.1
Inner Axis 180° From Start Pos.	58.1 57.8 58.0	Inner Axis 180° From Start Pos.	19.3 17.5 19.3
Avg 1. Set	57.0	Avg 2. Set	18.7
Diff. Between Averages = 2ε = 38.3			

OUTER AXIS 2ε ⇒ 15.3 19.1

O.A. Δ2ε = 5.8

Average Orthogonality Error ε = 2.9 Arc Sec

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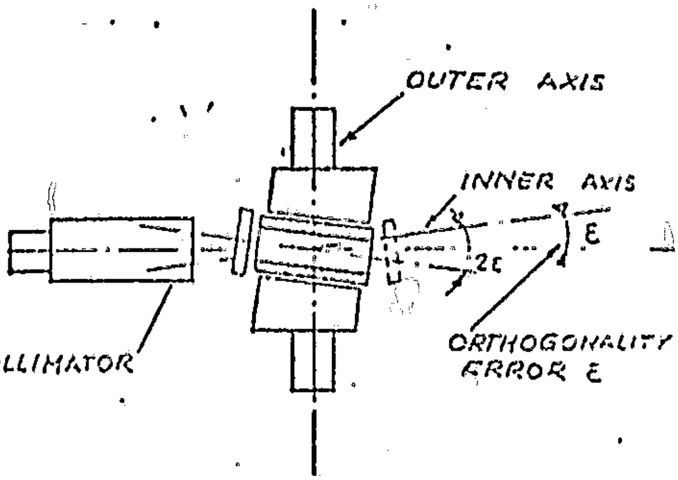
ORTHOGONALITY TEST

Instrument: 700-60RO (158-6570)
Unit: Shop Order: K213
Customer: NASA- MARSHALL

Specification Requirement:
5 sec

OUTER/INNER

ORIGINAL PAGE IS OF POOR QUALITY



Task
Determine the perpendicularity error between two intersecting gimbal axes.

Test Setup
Set up an autocollimator or theodolite with an autocollimating eyepiece with a resolution of 0.2 arc seconds minimum, such that autocollimation can be established with the mirror placed on the center of the inner axis. Mount an adjustable double surface mirror on the inner axis and align it perpendicular to the axis of rotation. Two tooling mirrors are to be used if the shaft does not have a central perforation.

Test Procedure
Establish autocollimation and measure and record the shaft direction in the coordinate parallel to the outer axis. Rotate the inner axis about itself 180°. Measure and record the shaft direction. Rotate the inner axis about the outer axis 180° and measure and record the shaft direction as above. Rotate the inner axis about itself 180° and measure the shaft direction. Repeat each measurement 3 times.

Data Reduction
Average the readings of the first two sets of measurements. Average the readings of the second two sets of measurements. The angular difference between the two averages equals 2 times the orthogonality error ε.

ANGULAR POSITION OF THE INNER AXIS			
Outer Axis at 0°		Outer Axis at 180°	
Inner Axis At Start Pos.	10.7 10.7 10.6	Inner Axis At Start Pos.	14.4 14.5 14.4
Inner Axis 180° From Start Pos.	11.4 11.4 11.4	Inner Axis 180° From Start Pos.	16.8 16.6 16.6
Avg 1. Set	11.05	Avg 2. Set	15.5
Diff. Between Averages = 2ε = 4.5			

ANGULAR POSITION OF THE INNER AXIS			
Outer Axis at 0°		Outer Axis at 180°	
Inner Axis At Start Pos.		Inner Axis At Start Pos.	
Inner Axis 180° From Start Pos.		Inner Axis 180° From Start Pos.	
Avg 1. Set		Avg 2. Set	
Diff. Between Averages = 2ε =			

Average Orthogonality Error ε = 2.25 Arc Sec

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INSTRUMENT: MOTION SIMULATOR

UNIT: —

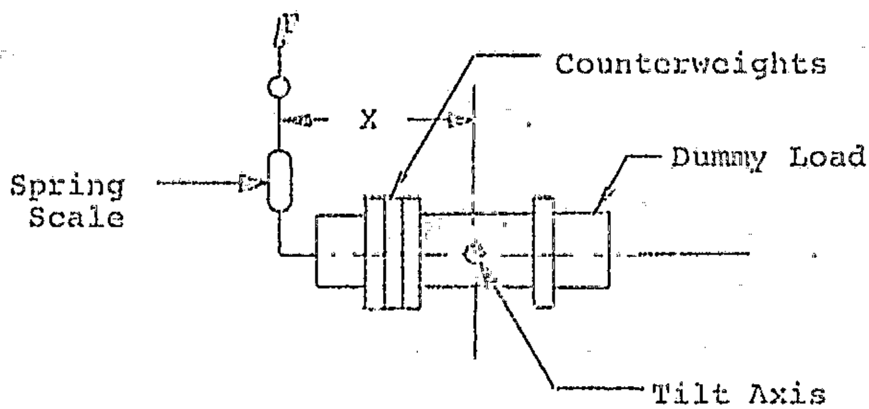
SHOP ORDER: K00 213

CUSTOMER: NASA MSFC.

NOTES:

SPECIFICATION: WITHIN 5 ft-lb.

TEST SET-UP



EQUIPMENT:

Spring Scale

PROCEDURE:

Adjust, add, or subtract counterweights as required to counter-balance the axis within the specified value. F x X must be less than specified value.

RESULTS:

DUMMY LOAD:		F:	3.5 oz
WEIGHT:	300 lb	X:	.14
DIMENSIONS:		UNBALANCE = F · X =	.49 in oz = .255 ft-lb

INSTRUMENT: MOTION SIMULATOR

UNIT: ____________

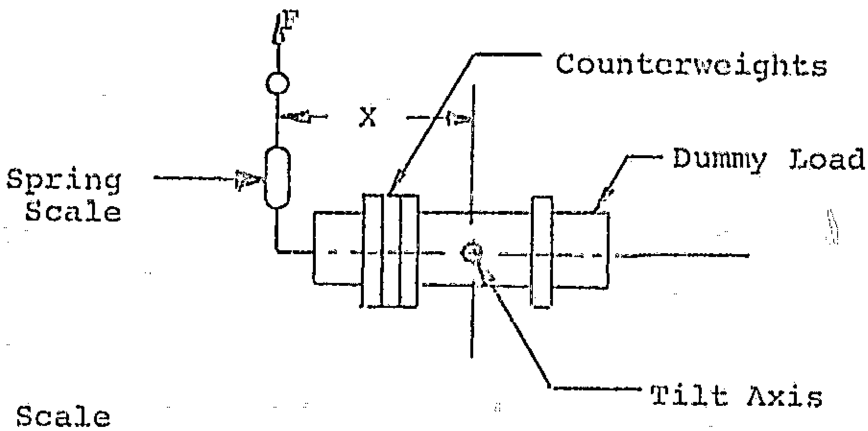
SHOP ORDER: K00213

CUSTOMER: NASA MSFC

NOTES: MIDDLE AXIS

SPECIFICATION: WITHIN 5 ft-lb.

TEST SET-UP



EQUIPMENT:

Spring Scale

PROCEDURE:

Adjust, add, or subtract counterweights as required to counterbalance the axis within the specified value. F x X must be less than specified value.

RESULTS:

DUMMY LOAD: F: 5.5 oz

WEIGHT: ____________ X: 18 in.

DIMENSIONS: ____________ UNBALANCE = F · X = 99 in oz = .51 ft-lb.

INSTRUMENT: MOTION SIMULATOR

UNIT: ____________

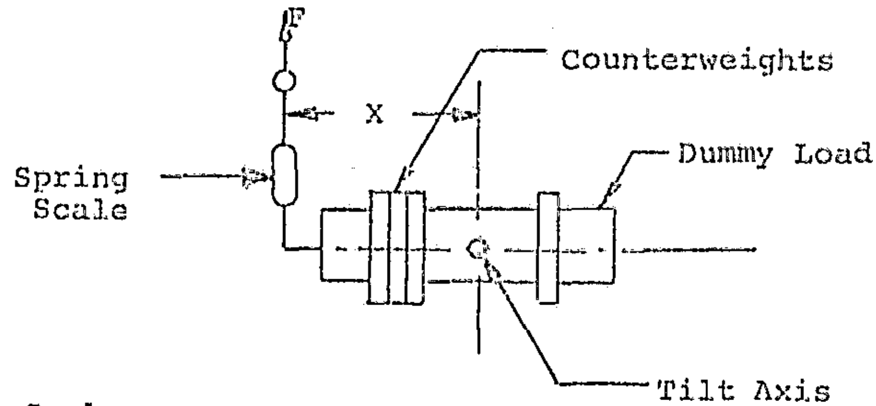
SHOP ORDER: K10213

CUSTOMER: NASA MSFC

NOTES: ____________

SPECIFICATION: WITHIN 5 ft-lb.

TEST SET-UP



EQUIPMENT:

Spring Scale

PROCEDURE:

Adjust, add, or subtract counterweights as required to counterbalance the axis within the specified value. F x X must be less than specified value.

RESULTS:

DUMMY LOAD:

WEIGHT: ____________

DIMENSIONS: ____________

F: 35 oz

X: 22 in

UNBALANCE = F · X = 770 in-oz = 4.0 ft-lb