MS-1

REPORT NO. ER671.2

CONTRACT NO. NAS 8-11600

CUSTOMER

WORK ORDER 23885

DRAWINGS

N66-14554

(ACCESSION NUMBER)	(THRU)
28	1
(PAGES)	(CODE)
CR 69101	15
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FACILITY FORM 602

GPO PRICE $

CFSTI PRICE(S) $

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65

FORM 120D

A. Heyman 10/1/65
PREPARED BY

H. D. Wintle
APPROVED BY

PROJECT MGR. IS N. Wrigglesworth

FINAL REPORT ON THE COMMUTATORLESS TORQUER

DATE OF ISSUE 9/15/65 REV. A

KOLLMORGEN CORPORATION
NORTHAMPTON, MASSACHUSETTS
AREA CODE 413 TELEPHONE 584-0230

nmp

KOLLMORGEN
CORPORATION
NORTHAMPTON, MASSACHUSETTS

REPORT NO. ER 671.9
A-PAGE

REVISIONS

REV. LET.	CH. NO.	DATE	PAGES AFFECTED	REMARKS	APPROVED
A		9/15/65		Release Order # 4433	

FORM 1228

DISTRIBUTION LIST

Revision A·

(1) E/R File via H. E. T.
(1) H. Wintle
(1) N. Wrigglesworth
(1) G. Ganczarski
(3) A. Heyman
(1) Roger Bross, I.M.C.
(1) Frank Joseph, I.M.C.
(1) John Luneau, I.C.C.

FORM 121C

1.0 SCOPE:

This final report summarizes all performance test data on the brushless torquer model no. 671 built under Kollmorgen Work Order 23885 and NASA Contract # NAS 8-11600 and includes final test data on the two engineering models.

2.0 INTRODUCTION

In the prototype unit the per cent torque ripple which is defined as

$$\frac{T_{max} - T_{min}}{T_{max} + T_{min}}$$

was 27.2% and the power consumption was 56 VDC at 4.00 amps for peak torque. By changing to a new resolver which had much lower distortion the per cent torque ripple in the Engineering Model was reduced to 12%. Increasing the stack length of the motor and changing previous test procedures which demagnitized the motor reduced power consumption to 56 VDC at 230 amp for peak torque. According to NASA Contract NAS8-11600 maximum torque ripple is 5% and maximum power consumption is 56 VDC at 2.00 amps.

3.0 REFERENCED DOCUMENTS

NASA Contract NAS8-11600

FORM 121C

ER671.2, Rev. A	Brushless Torque Motor and Resolver Progress Report
ER671.4, Rev. B	Statement of Work Brushless Pancake Resolver
ER671.5, Rev. A	Performance Tests on the Brushless Torquer
ER671.6, Rev. A	Operating Procedure Brushless Torque Motor
ER671.7, *	Statement of Work for Commutatorless Torquer

Drawings

DX671-3, Rev. B	Test Fixture for Inland Torque Motor
D671-4, Rev. B	Multi-Speed Brushless Resolver
D671-6, Rev. B	Outline & Installation Dwg. Brushless Torque Motor Model 671
D671-7, Rev. B	Outline & Installation Dwg. Commutatorless Torquer Electronics
D671-8, Rev. A	Brushless Torque Motor

* ER revised by addition to purchase order.

FORM 121C

Drawings (Con't.)

D671-17, Rev. A	Interconnection Diagram for the Commutatorless Torquer
F671-5, Rev. A	Schematic Diagram Commutatorless Torquer - Amplifier Section
C671-18, Rev. A	Schematic Diagram Commutatorless Torquer - Power Supply Section

4.0 PHASE I, DEVELOPMENT OF THE PROTOTYPE MODEL

4.1 Chronological Review.

The original brushless torquer and resolver (TR2801-A) was built by Inland Motors.

The engineering data is contained in ER671.2. It was found that the output of the sine and cos winding of the first resolver departed from an ideal sine and cosine by ± 24%. Also the torque motor could not deliver rated torque. A conventional one-speed resolver was geared up by a factor of 6 to match the motor and the torque ripple of the combination was only 5.4%. This determined that the high ripple torque was directly attributed to distortion in the resolver outputs. The prototype motor had only 5.4% torque ripple

FORM 121C

and the final engineering model 12% torque ripple because the flux density in the prototype motor was demagnitized by 50% prior to testing.

The torque motor and resolver were sent back to Inland Motors for remagnization of the torque motor and adjustment of the resolver. The Engineering data of the reworked unit is contained in ER671.5. ER671.6 contains the operating procedures of the prototype unit which was shipped to NASA in January 1965.

4.2 Discussion of Problem Areas.

The high per cent torque ripple was caused by distortion in the resolver outputs. In order to meet NASA Contract NAS8-11600 resolver output distortion had to be reduced by a factor of ten and the torquer's stack length had to be increased to limit power consumption.

4.3 Demagnitization.

If the motor is driven by a power supply without the associated electronics the motor will be demagnitized in torque measurement tests. If armature reaction MMF opposes the MMF of the rotor magnets the magnets will be demagnitized. This condition happens

FORM 121C

when the rotor of the torquer is pulled through a maximum and then accelerates maybe through two or three poles and is an unnatural condition for the torquer. When the resolver and electronics drive the motor, the armature MMF will always be in quadrature with the MMF of the magnets and the only effect will be a distortion of the field in the air gap.

It is interesting to note that this is the way Inland Motor and Kollmorgen personnel tested the motor prior to July 6, 1965 and this analysis would explain why previous DC commutatorless torquers were so easily demagnitized.

FORM 121C

5.0 PHASE II, DEVELOPMENT OF THE TWO ENGINEERING MODELS

5.1 Design Improvements.

5.1.1 Resolver

A new vendor, Clifton Precision Product, have built the resolvers according to the Statement of Work for the Brushless Pancake Resolver ER671.4, Rev. B, for the two engineering models.

5.1.2 Motor

The torquer's stack length has been increased .050 inch to limit

peak power consumption. ER671.7 covers the statement of work for the Commutatorless torquer.

5.1.3 Electronics.

There have been several improvements in the electronics for the engineering model. Using compact circuitry the complete amplifier channel minus the output transistors is packaged on a 2-3/16" by 8-1/2" circuit board. Transistor circuitry prevents both sides of the D-C power bridge from conducting if the minus 65 VDC bias is ever removed. Common mode feedback in the preamplifier stabilizes sensitive bias level adjustments. Because of internal heating which changes the winding resistance current feedback is used to stabilize the ratio of output current to input excitation voltage.

Drawing D671-17, Rev. A, shows the interconnections for the system. Drawing F671-5, Rev. A, is the schematic diagram of the amplifier section of the commutatorless torquer; Drawing C671-18, Rev. A, is the schematic diagram of the power supply section of the commutatorless torquer and Drawing D671-7, Rev. B, provides the installation information for the electronics.

FORM 121C

5.2 Test Method for the Engineering Models.

5.2.1 Test set up and methods

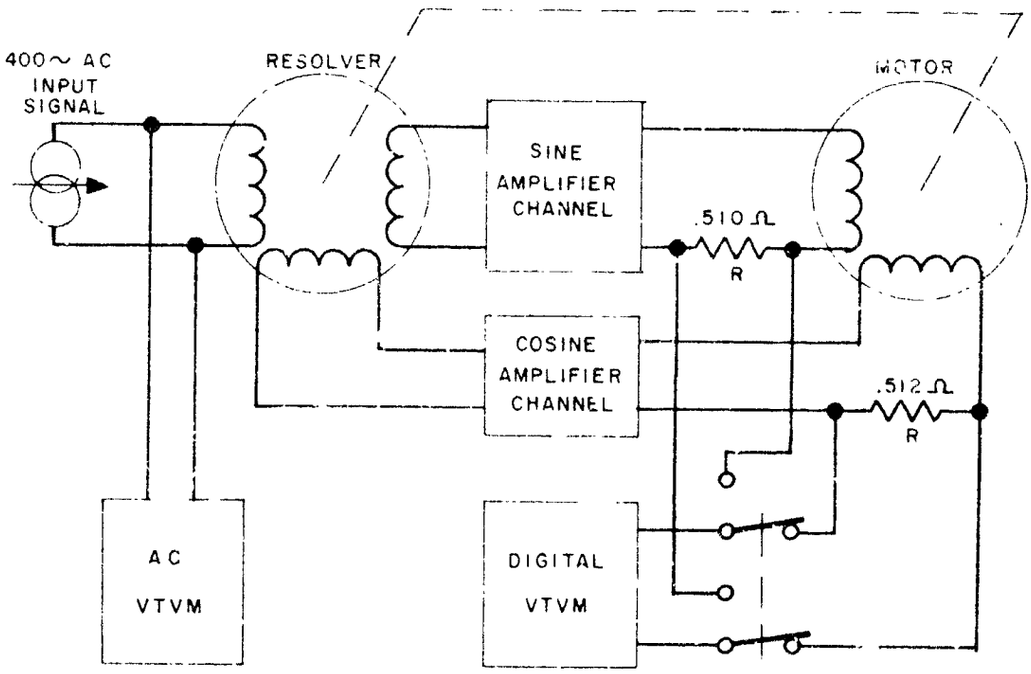


FIGURE 1. BRUSHLESS TORQUER SYSTEM.

FORM 121C

5.2.2 Tabulation of Errors in the Equipment Used

Equipment Used	Errors
(1) Spring Scale Chatillon, John & Sons 85 Cliff Street New York 38, New York Model 4200 Range 0 - 240 oz. Used in all torque measurements	Reading Error in scale ± 1/8 oz. Calibration Error in scale ± 1/8 oz. Moment Arm is 1.5 inches Reading Error in torque ± 3/16 in-oz or ± .20 oz-in Calibration Error in torque ± 3/16 oz-in or ± .20 oz-in
(1) Test Stand Kollmorgen Corporation 347 King Street Northampton, Mass. Dwg. DX671-3, Rev. B	Friction in test stand - 0.1 in-oz.
(2) Current Sampling Resistors Omtronics 2406 Leavenworth Omaha 5, Nebraska .500 ohm 1%	± 20 PPM 50 watts ± 1% resistance tolerance know to ± .10%
(1) Digital Voltmeter United System Corp. Dayton 3, Ohio Model 202A Range 0 - 2 volts	Reading error ± 1/2 mv Calibration Error ± 2 mv
(1) AC Voltmeter Hewlett-Packard Co. Palo Alto, California Model 400H Range 0 - 1 mv, 0 - 300V	Reading error ± 1/4% of full scale Calibration error ± 1% of full scale

FORM 12IC

CONT'D ON PAGE 10

5.2.3 Discussion and Definition of Types of Errors

For the purpose of these tests, two types of errors are considered; a reading error and a calibration error. All data has been reduced by calculating machines to eliminate slide rule error.

5.2.4 Uncertainity in Torque Ripple Measurements

Torque ripple is defined as follows:

$$\text{per cent torque ripple} = \frac{T_{max} - T_{min}}{T_{max} + T_{min}} \times 100$$

Since Tmax and Tmin are taken at approximately the same torque level the errors in the calibration of the scale will cancel and only a reading error and friction in the test stand will be left (0.3 oz-in). Since the excitation voltage is not changed, the only errors in the excitation will be a reading error in the AC voltmeter. The gain of the amplifiers are adjusted to deliver 1.5 amperes at 22 VRMS. Therefore, if the AC voltmeter is on the 30 volt range the error in torque because of the reading error in input signal is

$$= 30V \times .0025 \times \frac{1.5}{22} \frac{\text{amps}}{\text{volt}} \times 120 \frac{\text{in - oz}}{\text{amp}}$$

$$= \pm 0.6 \text{ in-oz.}$$

FORM 121C

CONT'D ON PAGE 11

The total uncertainty in the measurement of torque ripple is the sum of errors in measured torque (± 0.3 oz-in) and the errors in torque due to errors in measured input signal (± 0.6 oz-in). The total uncertainity in measured torque is ± 0.9 oz-in.

In the test data at the end of this report torque ripple is measured at .65 IR and is to be less than 5%.

$$\frac{118 \pm 0.9 - 106 \pm 0.9}{124 \pm 0.9 + 100 \pm 0.9} = \frac{12 \pm 1.3}{224} = 5\% \pm 0.8\%$$

This demonstrates that the uncertainity in per cent torque ripple will be less than 0.8% at current of .65 IR.

5.2.5 Uncertainity in Linearity Measurements

Linearity for the complete system is defined as follows:

$$\% \text{ linearity} = \frac{T_{dev} - T_{rated} \times \dfrac{E_{excitation}}{E_{excitation\ max.}}}{T_{rated}}$$

The total error in the measurement of developed torque and Trated in the linearity test is the errors in measured torque (± 0.5 oz-in).

FORM 121C

The total errors in Eexcitation and Eexcitation max. assuming the measurements are on the 30V range is sum of the calibration error (± .3V) and reading error (± .075V). If linearity is measured at 1/2 IR and Tdev = 91.5 in-oz,

$$\% \text{ linearity} = \frac{91.5 \pm 0.5 - 167 \pm 0.5 \dfrac{11.0 \pm .375}{22.0 \pm .375}}{167 + 0.5}$$

$$= \frac{8 \pm 5}{167} = 5\% \pm 3.0\%$$

This demonstrates that the uncertainity in per cent linearity will be less than 3.0% at a current of .50 IR.

5.2.6 Uncertainity in Maximum Torque Measurements

Using the test set up in figure 1 current can be measured to within ± 6 MA. Since torque can come from both phases the error in torque because of a measurement error in current is:

$$\pm 6 \text{ MA } 1.414 \times Kt$$

$$\pm 6 \text{ MA } 1.414 \times 120 \frac{\text{oz-in}}{\text{amp}} = \pm 1 \text{ oz-in.}$$

The total uncertainity in rated torque measured at rated current (1.5 amperes) is the sum of the errors in measured torque (± 0.50 oz-in) and the errors in torque due to errors in measured current (± 1.0 oz-in). The total uncertainity in rated torque measurements is ± 1.5 oz-in.

5.2.7 Discussion of Test Results

The test data at end of this report was taken on brushless torquer assembly outline dwg. (D671-6, Rev. B) which is composed of a brushless pancake resolver(outline Dwg. D671-4, Rev. B)and brushless torque motor(outline Dwg. D671-8, Rev. A) mounted in the test fixture (outline Dwg. DX671-3, Rev. B.)

The torque ripple (Graph 2 and 4) for the complete system is 12%. In the area of the curve where the motor is driven by perfectly sinusoidal currents the torque ripple is about 10%. The worst contribution to torque is caused by a 49 cycle per shaft revolution ripple. This ripple was not seen on previous torque motors.

The gains of the power amplifiers are adjusted to deliver rated current (1.5 amperes) at 22 VRMS input and higher input signals will tend to demagnitize the magnets. The torque sensitivity (per phase) is 120 oz-in/amp.

FORM 121C

Torque and winding current were measured at different excitation voltage levels at a fixed angle (Graph 1 and 3). The zero based linearity for the whole system is

$$T_{dev} = \frac{T_{rated} - \text{Excitation}}{\text{Excitation max.}} \times 100 \text{ and is equal to } 1\%.$$

T_{rated}

6.0 CONCLUSION

The percent torque ripple of the complete system is 12% and well above the specification of 5%. The fact that the 49 cycle per shaft revolution ripple coincides exactly with the number of motor slots leads us to believe that it is slot ripple and could possibly be decreased in a new motor design. The one cycle per shaft revolution ripple could be decreased by reducing the eccentricity in the test stand. The total supply current at peak torque is 2.30 amperes which is greater than the 200 amperes maximum available. The maximum torque and linearity are according to specifications.

FORM 121C

Data Sheets and Graphs included.

Graph 1 Measurement of maximum torque and linearity of brushless torquer motor TR2804A and resolver SPR-46-D-1 D671-4 S/N 3.

Graph 2 Torque ripple measurements of TR2804A with resolver SPR-46-D-1 D671-4 S/N 3.

Graph 3 Measurement of maximum torque and linearity of brushless torquer motor TR2804A S/N 65-692-3 and resolver SPR-46-D-1 D671-4 S/N 2.

Graph 4 Torque ripple measurement of TR2804A S/N 65-692-3 and resolver SPR-46-D-1 D671-4 S/N 2.

FORM 121C

KOLLMORGEN CORPORATION

Date [illegible] 16

ENGINEERING LABORATORY TEST DATA

Project NASA W.O. # [illegible] Sec. Class. _____

Data by [illegible] Computed by _____ Checked by _____ Approved by _____

Test [illegible]

[illegible] .915 [illegible]

Description [illegible] + [illegible] + [illegible]

[illegible] - 48[illegible] - 980

[illegible] 473

[illegible]	Force	[illegible]	[illegible] I x .510	[illegible] I x .[illegible]	[illegible] I	[illegible]	$Is^2 + Ic^2$	$\sqrt{Is^2 + Ic^2}$	[illegible]	ΔI mA
deg	oz	in-oz	amps	[illegible]	amps	amps				
[illegible]	78.0	117	-.005	+.496	+.0098	+.969	.9310	.969	+4.0	-6
58.5	69.75	104.6	-.163	+.466	+.320	+.910	.9305	.965	-8.4	-10
43.3	81.0	121.5	-.361	+.244	+.708	+.672	.9529	.976	+8.5	+1
45.2	71.0	106.5	[illegible]	+.214	+.884	+.418	.9562	.978	-6.5	+3
50.5	81.75	122.6	-.505	-.002	-.990	-.0039	.9801	.990	+9.6	+15
54.0	71.0	106.5	-.470	-.180	-.922	-.351	.9732	.987	-6.5	+13
57.5	81.5	122.3	-.372	-.244	-.729	-.672	.9900	.995	+9.3	+20
61.0	70.25	105.4	[illegible]	-.456	-.435	-.891	.9831	.992	-7.6	+17
65.0	81.5	122.3	-.028	-.516	-.055	-1.008	1.0180	1.010	+9.3	+35
68.1	71.75	107.6	+.163	-.484	+.320	-.945	.9954	.998	-5.4	+23
[illegible]	[illegible]	123.4	+.[illegible]	-.331	+.641	-.744	.9693	.982	+10.4	+7
76.2	68.75	103.1	+.4[illegible]	-.222	+.853	-.434	.9160	.957	-9.9	-18
79.8	79.5	119.3	+.489	-.040	+.959	-.078	.9258	.962	+6.3	-13
83.3	68.75	103.1	+.465	+.142	+.912	-.277	.9084	.953	-9.9	-22
87.2	79.5	119.3	+.[illegible]	+.318	+.729	+.621	.9170	.958	+6.3	-17
90.9	67.5	101.3	+.224	+.434	.439	+.848	.9118	.955	-11.7	-20
94.8	78.5	117.8	-.039	+.491	.076	+.959	.9255	.962	+4.8	-13
98.0	70.0	105	-.123	+.474	-.241	+.926	.9156	.957	-8.0	-18
102.7	80.75	121.1	-.320	+.375	-.627	+.732	.9289	.944	+8.1	-31
105.2	69.75	104.6	-.422	+.256	-.827	+.500	.9340	.966	-8.4	-9
109.7	81.0	121.5	-.497	.049	-.975	+.096	.9598	.980	+8.5	+5
113.0	70.25	105.4	-.479	-.127	-.939	-.248	.9432	.971	-7.6	-4
117.5	81.25	121.9	-.368	-.330	-.722	-.644	.9360	.967	+8.9	-8
124.9	80.0	120.0	.045	-.502	.088	-.980	.9681	.984	+7.0	+9
131.8	80.25	120.4	+.288	-.397	+.567	-.775	.9221	.960	+7.4	-15
135.0	67.25	100.9	+.392	-.276	+.769	-.539	.8819	.939	-12.1	-36
139.5	76.25	114.3	+.470	-.035	+.922	-.068	.8546	.924	+1.3	-49
150.1	65.50	98.25	+.248	+.403	+.486	+.787	.8556	.925	-14.8	-50

KOLLMORGEN CORPORATION

Date [illegible]

ENGINEERING LABORATORY TEST DATA

Project [illegible] W. O. # [illegible] Sec. Class. [illegible]

Data by [illegible] Computed by [illegible] Checked by [illegible] Approved by [illegible]

Test [illegible]

Description [illegible]

Angle	Force	Torque	[illegible]	[illegible]	[illegible]	[illegible]	$I_s^2 + I_c^2$	$\sqrt{I_s^2+I_c^2}$	ΔT	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
153.5	74.0	111.6	+.089	+.468	+.175	+.914	8660	931	-20	-44
159.9	66.25	99.4	-.078	+.469	-.153	+.916	8625	929	-12.0	-46
[illegible]	[illegible]	115.7	[illegible]	[illegible]	-.535	+.762	8668	931	+2.7	-44
[illegible]	[illegible]	101.2	[illegible]	[illegible]	-.788	+.504	8749	935	-11.7	-40
[illegible]	76.25	114.4	[illegible]	[illegible]	-.924	+.120	8862	941	+1.4	-34
172.0	62.9	100.4	[illegible]	[illegible]	-.924	-.168	8820	939	-12.6	-36
[illegible]	76.8	115.2	[illegible]	[illegible]	-.765	-.535	8114	933	+2.2	-42
[illegible]	[illegible]	101.1	[illegible]	-.419	-.467	.819	8889	943	-.19	-32
[illegible]	[illegible]	111.6	[illegible]	[illegible]	-.120	.937	8924	945	-1.4	-30
[illegible]	[illegible]	100.7	[illegible]	[illegible]	+.078	.942	8935	945	-12.3	-30
186.0	[illegible]	114.0	[illegible]	[illegible]	+.514	.764	8479	921	+1.0	-54
[illegible]	[illegible]	98.9	[illegible]	-.238	+.778	.465	8213	906	-14.1	-69
192.4	72.0	108.0	[illegible]	[illegible]	.871	.223	7983	893	-5.0	-82
202.0	[illegible]	99.0	[illegible]	[illegible]	.882	.148	7998	894	-14.0	-81
[illegible]	[illegible]	108.8	[illegible]	[illegible]	.757	+.477	8005	895	-4.2	-80
[illegible]	[illegible]	96.9	[illegible]	[illegible]	.587	+.684	8125	901	-16.1	-74
212.0	67.4	104.1	[illegible]	[illegible]	.145	+.885	8042	897	-8.9	-78
216.3	[illegible]	98.4	[illegible]	[illegible]	-.098	+.897	8142	902	-14.6	-73
222.5	72.2	108.3	[illegible]	[illegible]	-.971	+.766	8086	897	-4.7	-78
224.0	66.9	100.4	[illegible]	[illegible]	-.724	+.555	8322	912	-12.6	-63
[illegible]	71.6	107.4	[illegible]	[illegible]	-.898	+.168	8346	914	-5.6	-61
230.5	62.5	102.8	[illegible]	[illegible]	-.922	-.010	8502	922	-10.2	-53
234.0	73.1	109.7	-.430	[illegible]	-.843	-.363	8424	918	-3.7	-57
234.2	67.75	101.6	[illegible]	[illegible]	-.541	-.754	8612	928	-11.4	-47
242.7	71.8	107.7	[illegible]	[illegible]	.227	-.905	8705	933	-5.3	-42
244.0	62.9	103.4	[illegible]	-.472	.151	-.922	8729	934	-9.4	-41
244.5	74.0	111.0	+.194	-.434	+.380	.848	8635	929	-2.0	-46
252.5	[illegible]	102.6	+.315	-.302	+.618	-.688	8552	925	-10.4	-50

KOLLMORGEN CORPORATION

Date [illegible]

ENGINEERING LABORATORY TEST DATA

Project [illegible] W.O. # [illegible] Sec. Class. _____

Data by [illegible] Computed by _____ Checked by _____ Approved by _____

Test [illegible]

Description [illegible]

Angle	[illegible]	Torque	[illegible]	[illegible]	SIN I	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
deg	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
		105.5	[illegible]	[illegible]	+863	-252	8082	.899	-7.5	-76
[illegible]	[illegible]	101.3	[illegible]	[illegible]	+890	-152	9152	.903	-11.7	-72
[illegible]	71.5	107.3	[illegible]	[illegible]	+780	+438	8062	.895	-5.7	[illegible]
[illegible]	[illegible]	102.0	[illegible]	[illegible]	+727	+543	8262	901	-11.0	[illegible]
[illegible]	[illegible]	104.4	[illegible]	[illegible]	+231	+785	8266	915	-8.6	-60
[illegible]	[illegible]	102.0	[illegible]	[illegible]	+265	+875	8252	914	-11.0	-61
[illegible]	[illegible]	109.2	-.120	[illegible]	-333	+856	8436	.918	-3.8	-57
[illegible]	[illegible]	105.0	[illegible]	[illegible]	-443	+809	8507	.922	-8.0	53
[illegible]	[illegible]	103	[illegible]	[illegible]	-878	+352	8942	.946	-2.7	29
[illegible]	[illegible]	105.8	-.492	+.101	-927	+197	8981	948	-7.2	27
[illegible]	[illegible]	112.5	[illegible]	[illegible]	-992	-125	9070	950	-0.5	-25
[illegible]	[illegible]	106.8	[illegible]	[illegible]	-814	-488	9007	949	-6.2	-26
[illegible]	[illegible]	111.9	[illegible]	[illegible]	-502	-819	9228	961	-1.2	-14
[illegible]	[illegible]	107.4	[illegible]	[illegible]	-286	-918	9245	962	-5.6	-13
[illegible]	[illegible]	115.5	[illegible]	[illegible]	+167	-959	9476	972	+3.5	-2
[illegible]	[illegible]	108.0	[illegible]	[illegible]	+553	-787	9252	962	-5.0	-13
[illegible]	[illegible]	112.1	[illegible]	-.318	+720	-621	9040	951	+0.1	-24
[illegible]	[illegible]	103.9	+.468	-.115	+906	-225	8114	933	-9.1	42
[illegible]	[illegible]	112.7	[illegible]	[illegible]	+920	+180	8788	937	-0.3	38
[illegible]	[illegible]	105.6	+.436	[illegible]	+847	+395	8734	935	-7.4	40
[illegible]	[illegible]	112.8	[illegible]	[illegible]	+596	+737	9984	948	-0.2	27
[illegible]	[illegible]	103.9	[illegible]	[illegible]	+259	+910	8952	946	-9.1	29
[illegible]	[illegible]	114.3	[illegible]	[illegible]	-051	+957	9182	958	+1.3	17
[illegible]	[illegible]	105.8	[illegible]	[illegible]	-920	+854	9133	956	-7.2	-19
[illegible]	[illegible]	117.8	[illegible]	[illegible]	-737	+627	9362	968	+4.8	-7
[illegible]	[illegible]	108.0	[illegible]	[illegible]	-924	+301	9444	972	-5.0	-3
[illegible]	[illegible]	119.0	[illegible]	[illegible]	-988	+027	9768	988	+6.0	+13

KOLLMORGEN CORPORATION

Date [illegible]

ENGINEERING LABORATORY TEST DATA

Project [illegible] W. O. # [illegible] Sec. Class. _____

Data by [illegible] Computed by _____ Checked by _____ Approved by _____

Test [illegible] RIPPLE CHECK of [illegible] WITH [illegible] SPR-46 [illegible]

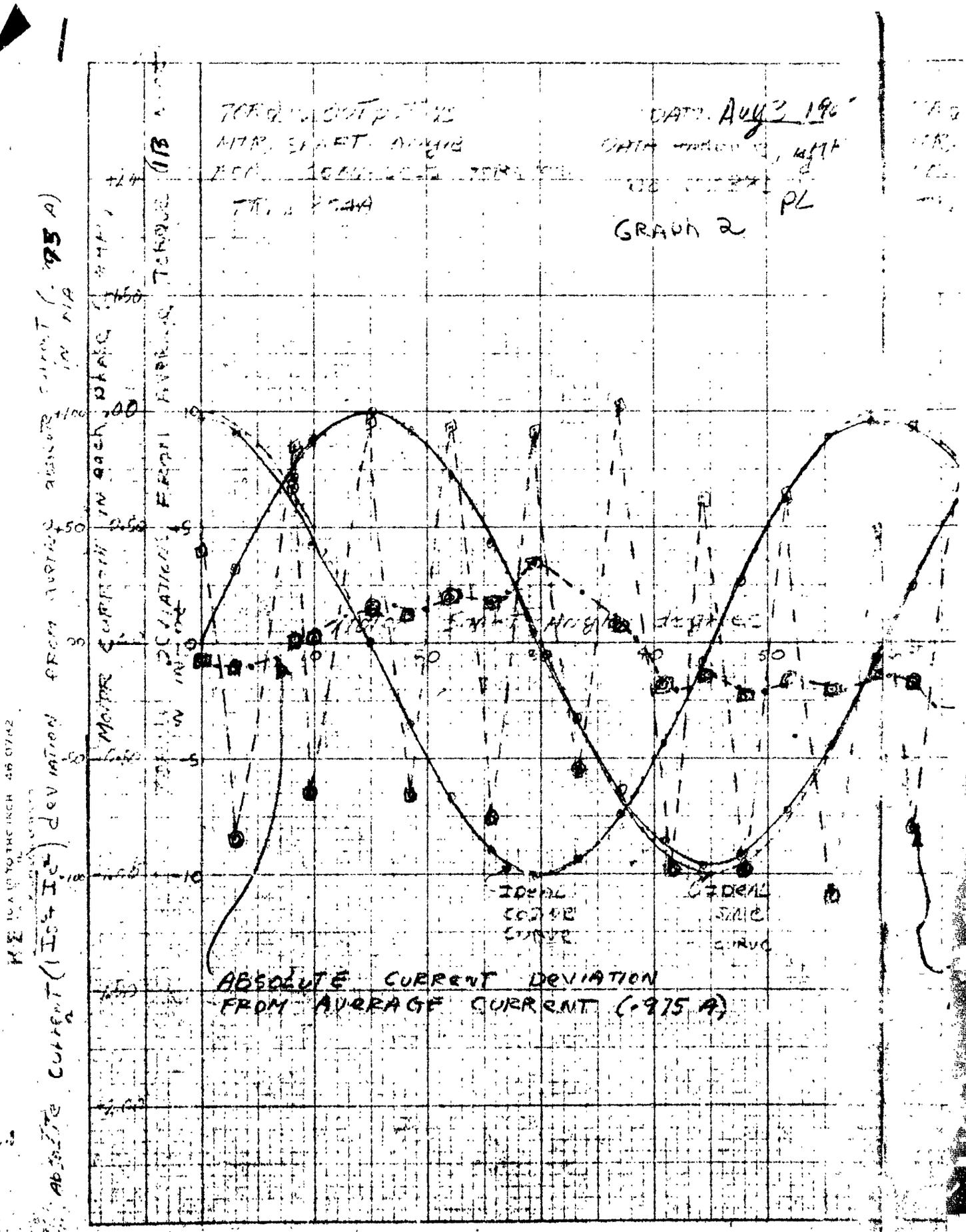
Description [illegible]

Angle	Force	Torque	[illegible] x 10	[illegible] x 512	[illegible] I	[illegible] I	[illegible]	[illegible]	[illegible]	
[illegible]	oz	in oz	[illegible]	[illegible]	[illegible]	[illegible]				
355	71.2	107.7	[illegible]	[illegible]	-867	-451	9551	.977	-5.5	+20
358.8	79.15	119.6	[illegible]	[illegible]	-608	-776	9719	986	+6.6	+90
[illegible]	[illegible]	107.4	[illegible]	[illegible]	-294	-944	9775	989	-5.6	+12
[illegible]	[illegible]	120.8	[illegible]	[illegible]	-000	-1.004	1.008	[illegible]	+7.8	+29
[illegible]	[illegible]	108.0	[illegible]	[illegible]	-384	-908	9720	986	-5.0	+11
013.3	80.1	120.2	[illegible]	[illegible]	-698	-680	9496	914	+6.8	-1
[illegible]	[illegible]	104.4	[illegible]	[illegible]	-898	-328	[illegible]	956	-8.6	-19
[illegible]	[illegible]	117.6	[illegible]	[illegible]	-959	-025	[illegible]	959	+4.6	-16
[illegible]	[illegible]	104.4	[illegible]	[illegible]	+876	+383	9141	956	-8.6	-19
[illegible]	[illegible]	117.9	[illegible]	[illegible]	+682	+676	9221	960	+4.9	-15
[illegible]	[illegible]	102.9	[illegible]	[illegible]	+329	+903	9236	961	-10.1	-14
035.5	70.2	117.3	[illegible]	[illegible]	+004	+967	9351	.967	+4.3	-8
	FORGOTTEN		PTS	(MIN)						
850 1205	6875	103.1	-.237	-.438	-465	856	9489	974	-9.9	-01
915 1270	700	105.0	+.078	-.493	+.153	963	9508	975	-8.0	00
142	665	100	.462	.096	[illegible]					
146.5	755	115	.378	.268	111					

TORQUE RIPPLE $\frac{T_{MAX} - T_{MIN}}{T_{MAX} + T_{MIN}} = \frac{1234 - 969}{1234 + 969} = 12\%$

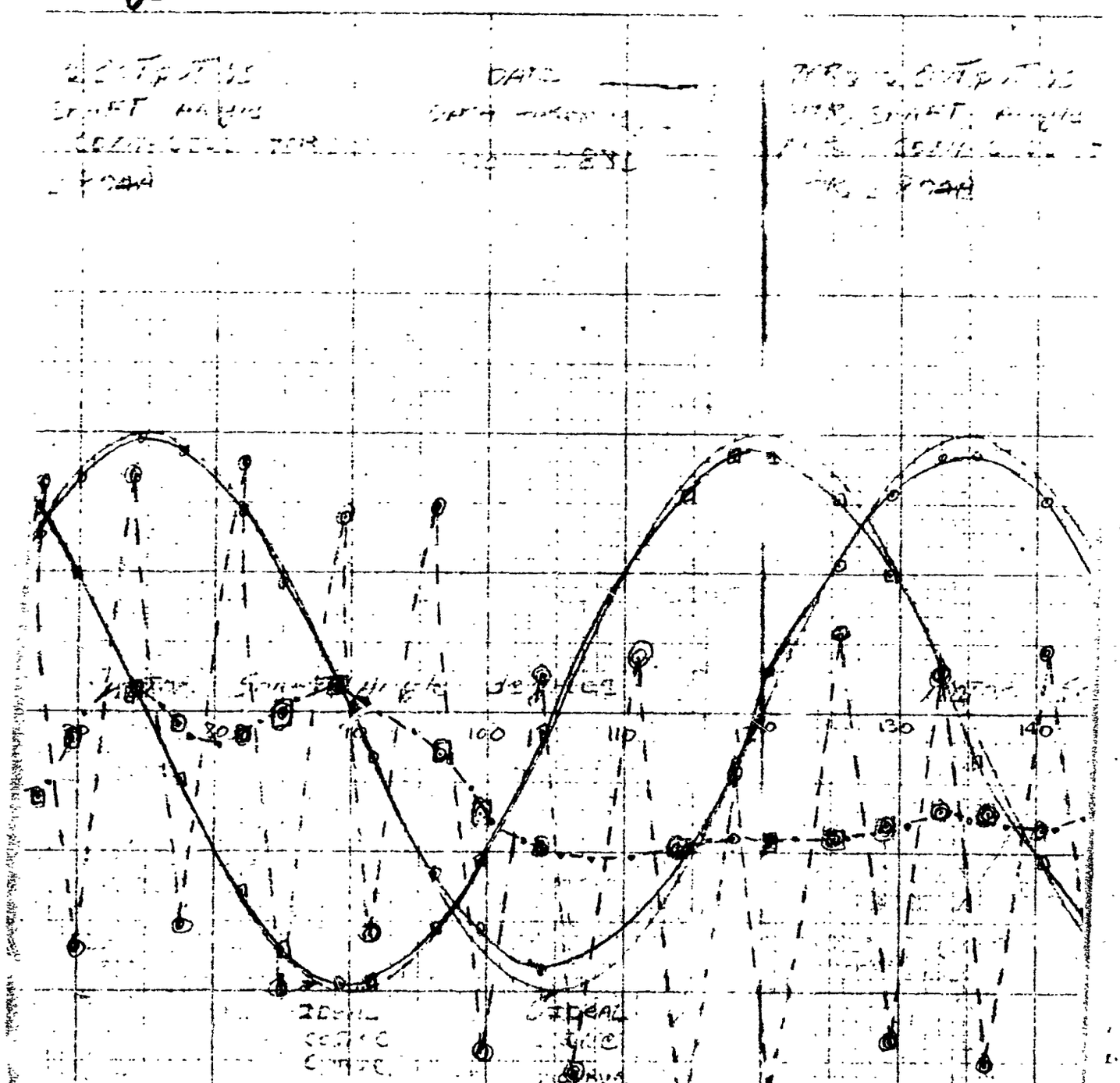
MAX I = 1.010

MIN I = .899



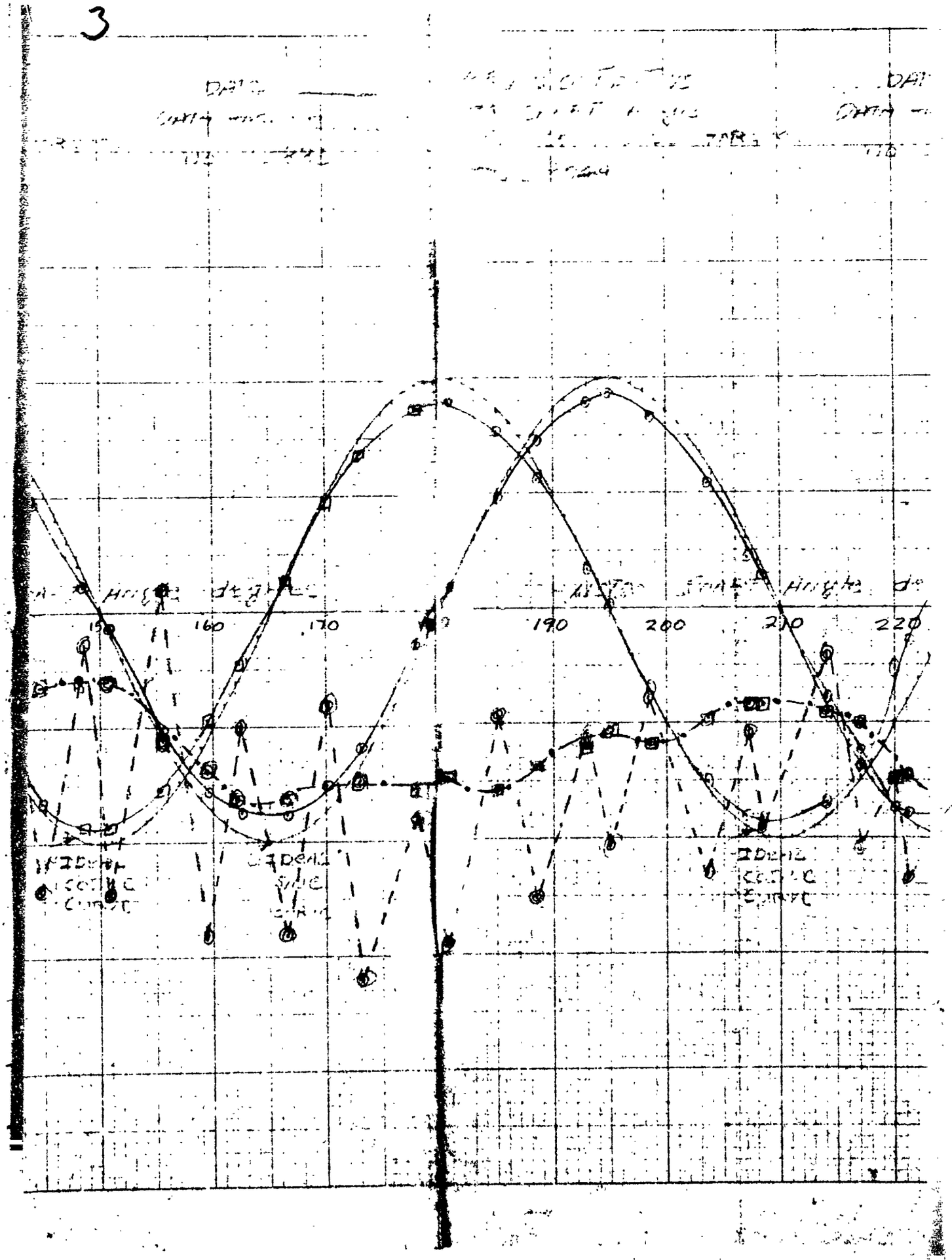
DATE Aug 3 196
PL
GRAPH 2
ABSOLUTE CURRENT DEVIATION
FROM AVERAGE CURRENT (.975 A)
IDEAL COSINE CURVE
IDEAL SINE CURVE

2

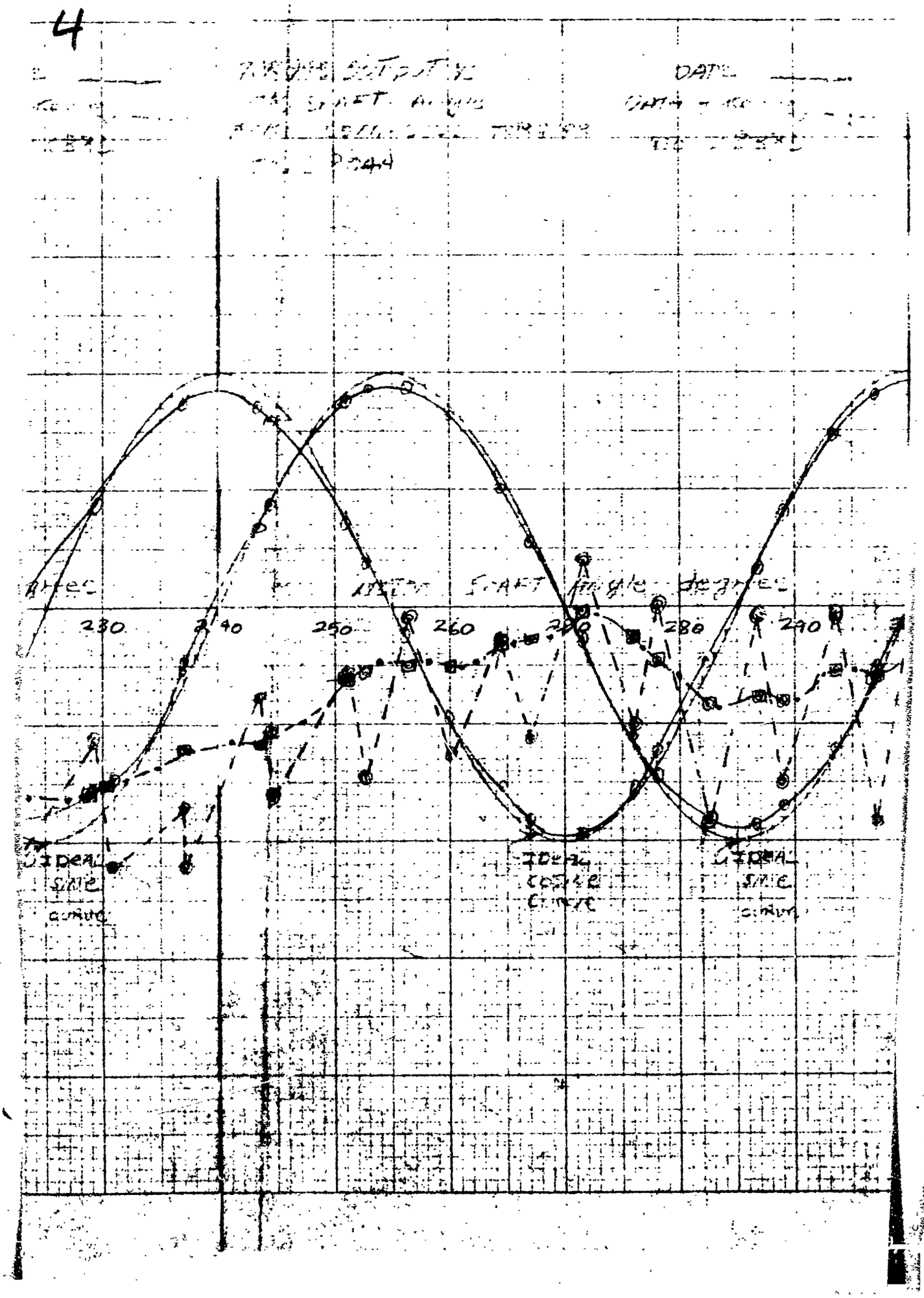


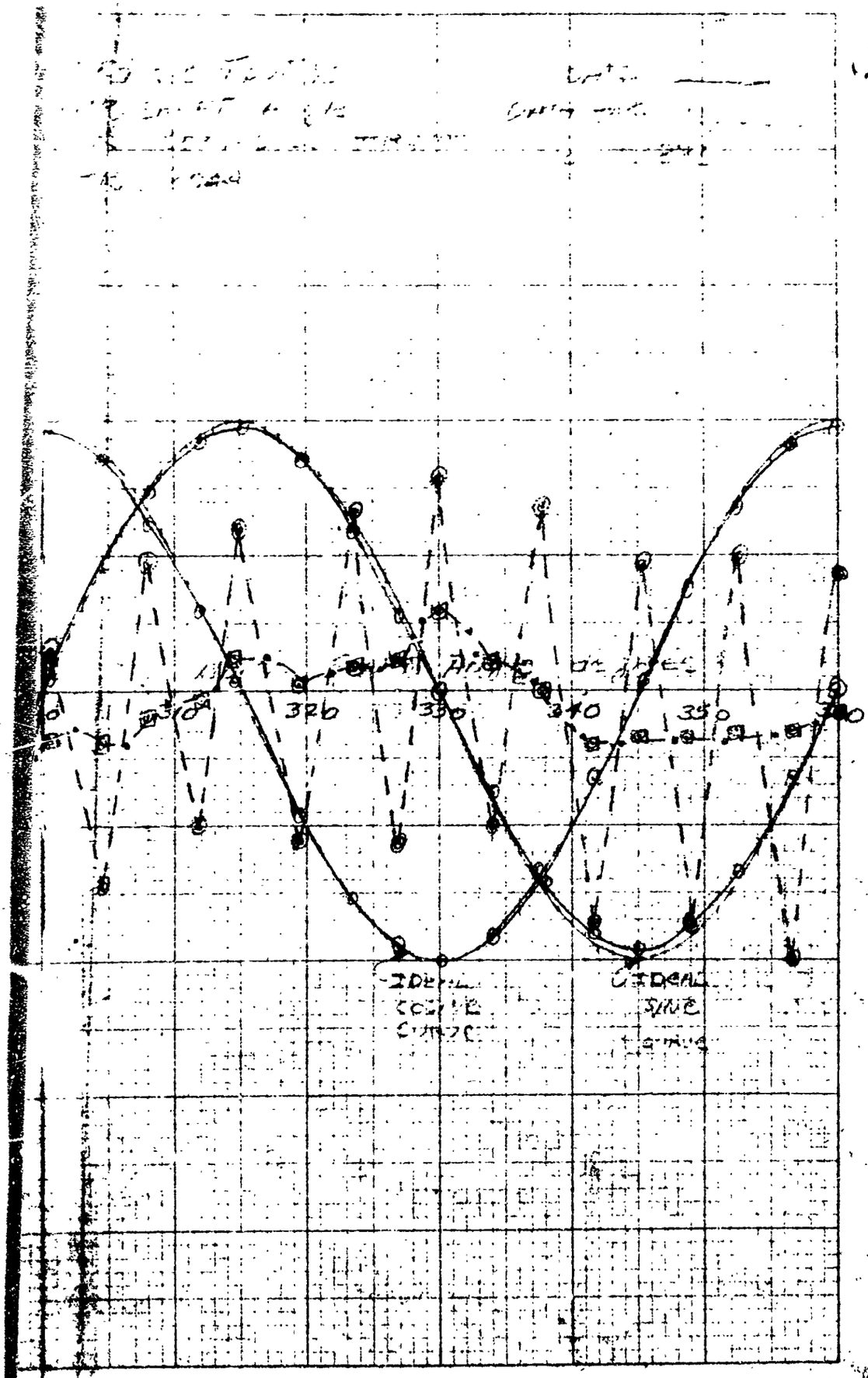
TORQUE DEVIATION FROM
AVERAGE TORQUE 113 IN-OZ

3



4


DATE
230
240
250
260
270
280
290
IDEAL
SINE
CURVE
IDEAL
COSINE
CURVE
IDEAL
SINE
CURVE


310
320
330
340
350
360
IDEAL
COSINE
CURVE
IDEAL
SINE
CURVE

KOLLMORGEN CORPORATION

Date Aug 2 65

ENGINEERING LABORATORY TEST DATA

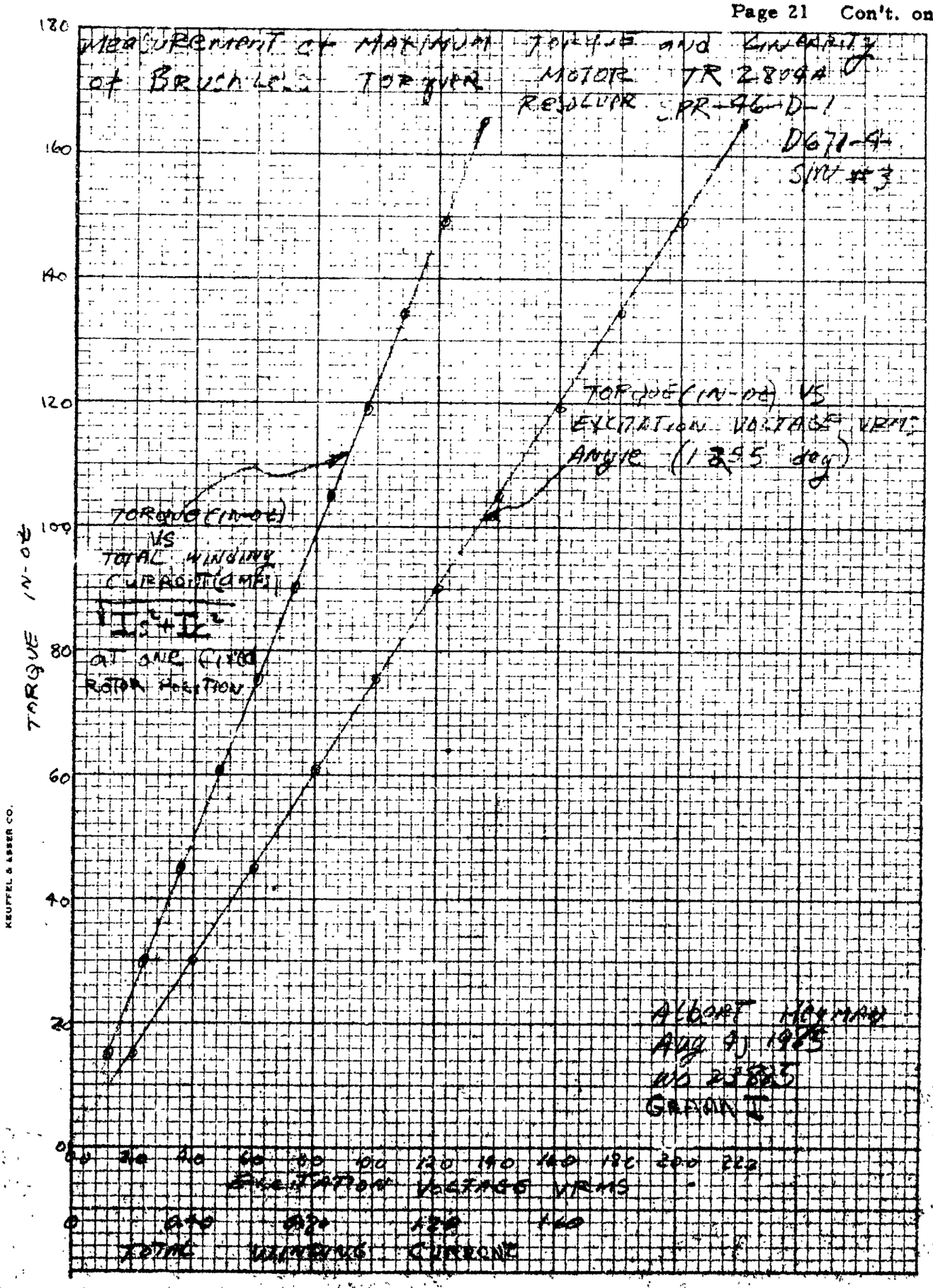
Project NASA W.O. # 22885 Sec. Class. _____

Data by AMH Computed by _____ Checked by _____ Approved by _____

Test Measurement of linearity and maximum torque of Brushless Torquer Motor 7R2804A

Description Res SPR-46-1 D671-4 S/N #3
MAXIMUM Power Supply Current 2.30 amps

Angle degrees	Force oz	Torque in oz	Sin I × 510 amps	Cos I × 510 amps	Sin I amps	Cos I amps	$I_s^2+I_c^2$ amps²	$\sqrt{I_s^2+I_c^2}$ amps	Exciting V RMS	
161	109.75	164.6	-373	.582	.733	1137	1.830	1.353	22	
161	99.5	149.3	-346	521	680	1018	1.498	1.224	20 .18%	144.6
161	89.5	134.3	-310	464	609	.906	1192	1.092	18 .34%	104.7
161	79.5	119.3	-274	414	538	809	944	.972	16 .24%	119.7
161	70.0	105	-236	364	464	.711	.721	.849	14 [illegible]	104.7
161	60	90	-209	309	410	604	533	730	12 .12%	89.8
161	50.5	75.8	-178	254	350	496	369	607	10 .6%	74.8
161	40.5	60.8	145	201	285	393	236	486	8 .54%	59.9
161	30.0	45.0	109	149	214	291	130	361	6 .04%	44.9
161	20.0	30.0	072	098	141	191	0564	237	4 .06%	29.9
161	10.0	15.0	037	048	.073	094	0143	120	2 .0%	15.0
161.0										
35.5										
105.5										



K+E 10 X 10 TO THE INCH 46 0782
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

KOLLMORGEN CORPORATION

Date Sept 9 65

ENGINEERING LABORATORY TEST DATA

Project NASA W.O. # 23885 Sec. Class.

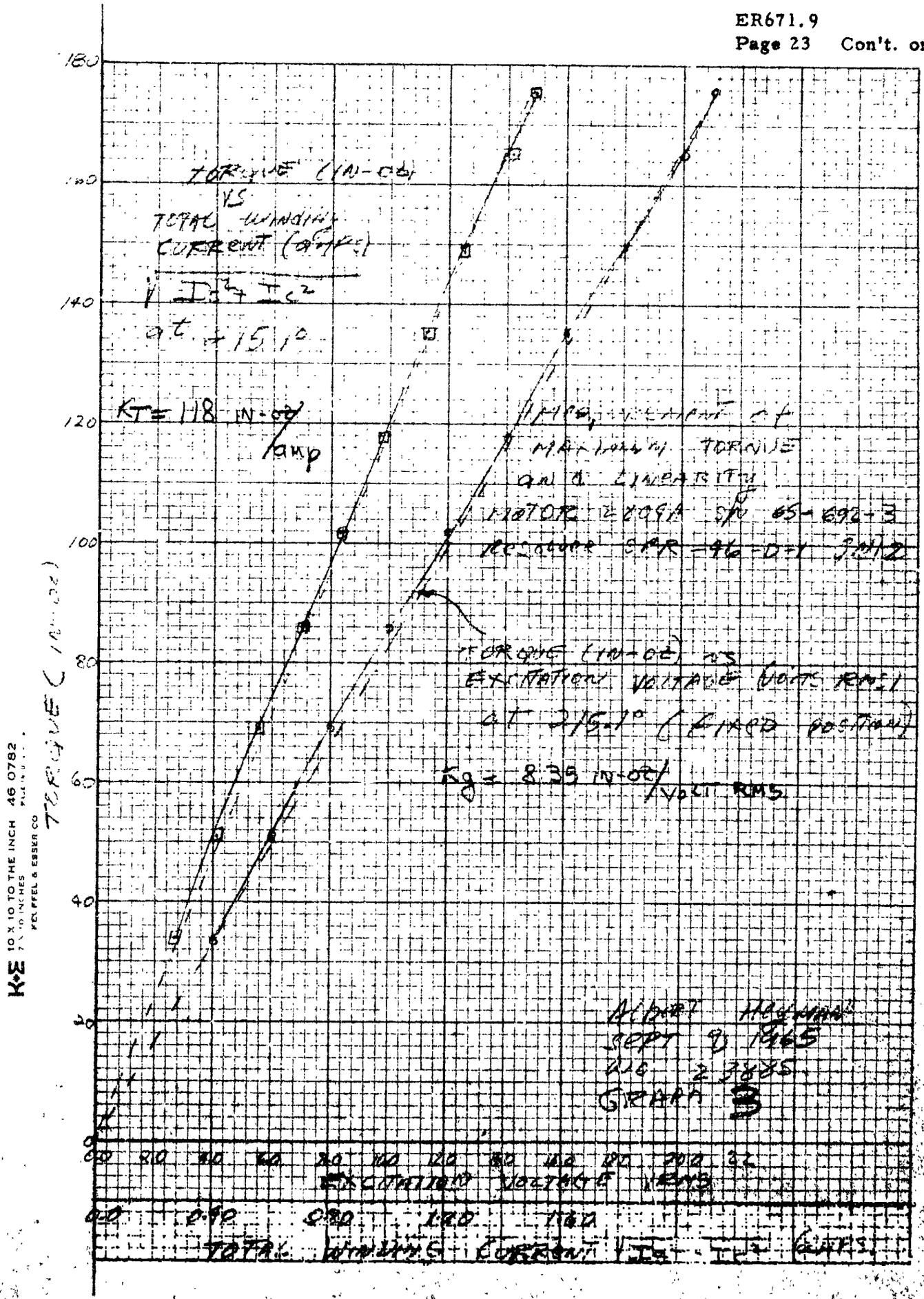
Data by AMH Computed by Checked by Approved by

Test MAX TORQUE & LINEARITY check of TR 2804 A S/N 65-692-3 with resolver SPR-46-D-1 SN/2

Description MAX [illegible] 2.42 amperes EXCITATION CHAN #1 amp #2 #2 amp #3

Angle	Force	Torque	SIN I × .510	COS I × .512	SIN I	COS I	$I_S^2+I_C^2$	$\sqrt{I_S^2+I_C^2}$	$E_{EXCIT.}$	Error in LIN
215.1	117	175.5	.762	038	1.49	.074	222	149	210	0
215.1	110	165.0	[illegible]	026	1.42	051		142	200	-0.4
215.1	99.5	149.5	643	028	126	054		126	180	-0.8
215.1	90.25	135.4	577	024	1.13	047		113	16	+1.1
215.1	78.5	117.8	.500	024	.980	047		981	14	+0.5
215.1	68.0	102.0	426	026	835	051		.836	12	+1.1
215.1	57.25	85.9	.355	022	696	043		.697	10	+1.5
215.1	46.0	69.0	.283	024	.555	047		.557	8	+1.4
215.1	34.0	51.0	.210	016	.412	031		413	6	+0.6
215.1	22.5	33.8	.139	014	.273	027		275	4	+0.2

% LINEARITY $\frac{1.5}{175.5} = 0.85\%$



K+E 10 X 10 TO THE INCH 46 0782
7 X 10 INCHES
KEUFFEL & ESSER CO.

KOLLMORGEN CORPORATION

Date Sept 9, 1964

ENGINEERING LABORATORY TEST DATA

Project NASA W. O. # 23885 Sec. Class.

Data by AMH Computed by Checked by Approved by

Test TORQUE RIPPLE check of TR 2804A S/N 65-692-3 with resolver SPR-46-D-1 SN 2

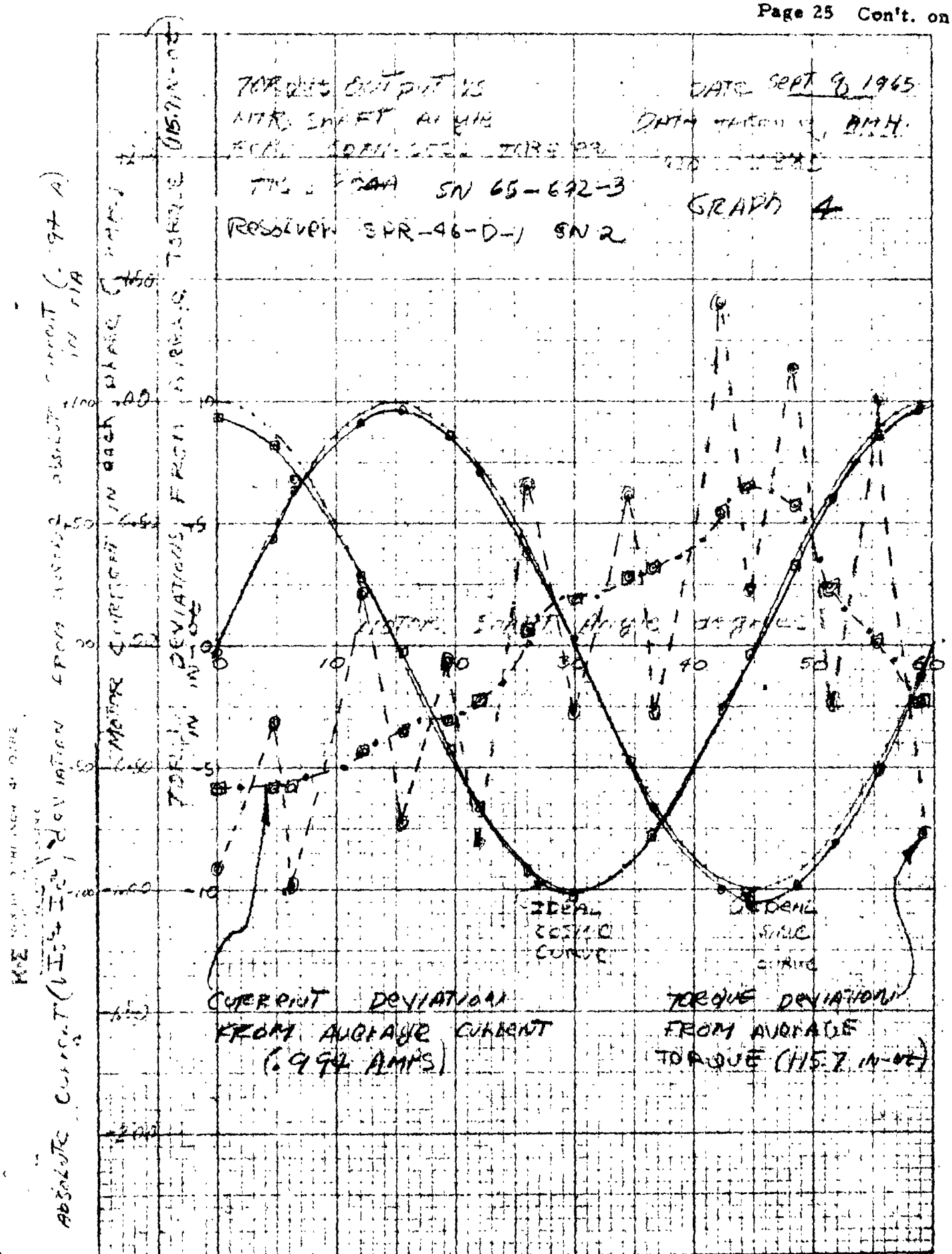
Description

EXCITATION - 14.9 VRMS chan #1 AMP #2

@V TORQUE 115.7 IN-OZ @V I = .994 A chan #2 AMP #3

	Angle deg	FORCE OZ	TORQUE IN-OZ	SIN I × .510 amps	COS I × .512 amps	SIN I amps	COS I amps	$I_S^2+I_C^2$ amp²	$\sqrt{I_S^2+I_C^2}$ amp	ΔT IN-OZ	ΔI MA
0.0	79.5	71.0	106.5	+.013	-.479	-.025	+.936	8267	.936	-7.2	-58
4.8	84.3	75.0	112.5	-.224	-.423	+.439	+.826	8749	.935	-3.2	-59
6.2	85.7	70.5	105.8	-.325	-.352	+.637	+.687	8778	.937	-9.9	-57
12.1	91.6	78.5	117.8	-.462	-.147	+.906	+.287	9032	.950	+2.1	-44
15.5	95.0	72.25	108.4	-.489	+.014	+.959	-.027	9204	.959	-7.3	-35
19.4	98.9	76.75	115.1	-.440	+.219	+.863	-.428	9280	.963	-0.6	-31
22.	101.5	71.75	107.6	-.364	+.337	+.714	-.658	9428	.971	-8.1	-23
26.0	105.5	81.5	122.3	-.195	.413	+.382	-.924	9997	1.000	+6.6	+06
29.8	109.3	75.5	113	-.005	.518	+.010	-1.012	10.42	1.012	-2.7	+18
34.7	114.2	81.25	121.9	+.250	.460	-.490	-.898	10465	1.023	+6.2	+29
36.6	116.1	75.25	112.9	+.337	+.402	-.661	-.785	10532	1.026	-2.8	+32
42.2	121.7	76.50	129.8	.310	+.161	-1.000	-.314	10986	1.048	+14.1	+54
44.7	124.2	78.75	118.0	+.539	+.019	-.057	-.037	1.118	1.058	+2.3	+64
48.5	128.0	84.75	127.1	+.509	-.169	-.998	+.328	1.1036	1.051	+11.4	+57
51.7	131.2	75.50	113.3	.416	-.312	-.816	+.609	10368	1.018	-2.4	+24
55.4	134.9	83.75	125.6	+.259	-.438	-.508	+.855	9891	.995	+9.9	+01
59.0	138.5	72.0	108.0	+.044	-.493	-.125	+.963	9430	.971	-7.7	-23
63.0	142.5	78.0	117.0	+.198	.475	-.290	+.928	9453	.972	+1.3	-32

Ripple = $\frac{129.8 - 105.8}{129.8 + 105.8} = \frac{24}{235.6}$ = 10.2%


DATE SEPT 9, 1965
GRAPH 4
SN 65-672-3
RESOLVER SPR-46-D-1 SN 2
IDEAL COSINE CURVE
IDEAL SINE CURVE
CURRENT DEVIATION FROM AVERAGE CURRENT (.994 AMPS)
TORQUE DEVIATION FROM AVERAGE TORQUE (115.7 IN-OZ)