NASA TECHNICAL NOTE

NASA TN D-6387

c. 1

NASA TN D-6387

THE MARK VI TORQUEMETER, AN INSTRUMENT FOR MEASURING MAGNETIC TORQUES ON SPACECRAFT

by J. C. Boyle

Goddard Space Flight Center
Greenbelt, Md. 20771

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1971

1. Report No. NASA TN D-6387	2. Government Accession No.
3. Recipient's Catalog No.	
4. Title and Subtitle The Mark VI Torquemeter, an Instrument for Measuring Magnetic Torques on Spacecraft	5. Report Date August 1971
	6. Performing Organization Code
7. Author(s) J. C. Boyle	8. Performing Organization Report No. G-1020
9. Performing Organization Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771	10. Work Unit No.
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	13. Type of Report and Period Covered Technical Note
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Mark VI Torquemeter is a lightweight, high-capacity instrument for measuring magnetic torques on spacecraft that weigh up to 3500 N (800 lb). Characteristics, construction, and circuitry of the torquemeter are described. Calibration of the instrument is performed either with precision weights or by means of a known torque that is generated by energizing an air-core coil in the controlled facility field. The instrument has also been used for measuring nonmagnetic torques. Techniques used in calibration and in data acquisition are described in detail. Under favorable circumstances, torques as small as 5 dyne-cm have been measured.

17. Key Words Suggested by Author	18. Distribution Statement
Torquemeter Magnetic Torques	Unclassified–Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	16	3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

FOREWORD

It is the policy of the National Aeronautics and Space Administration to employ, in all formal publications, the international metric units known collectively as the Système Internationale d'Unités and designated SI in all languages. In certain cases, however, utility requires that other systems of units be retained in addition to the SI units.

This document contains data so expressed because the use of the SI equivalents alone would impair communication. The non-SI units, given in parentheses following their computed SI equivalents, are the basis of the measurements and calculations reported here.

CONTENTS

THE MARK VI TORQUEMETER, AN INSTRUMENT FOR MEASURING MAGNETIC TORQUES ON SPACECRAFT

by
J. C. Boyle
Goddard Space Flight Center

INTRODUCTION

A number of highly sensitive torquemeters have been built in recent years. A feature common to these instruments is the combination of high load capacity and high sensitivity, because their principal use is in the measurement of disturbance torques applied to scientific satellites. Typically, such satellites weigh from 500 to 5000 N (100 to 1000 lb), whereas the disturbance torques are of the order of 10^{-6} to 10^{-4} N-m (10 to 1000 dyne-cm).

Earlier designs met this requirement by means of a liquid flotation system (References 1 and 2) or by a wire suspension system (Reference 3). The resulting instruments have been characterized by very slow dynamic response and, in the case of the floated systems, by large bulk and high noise levels. Table 1 lists the torquemeters that have been developed at GSFC.

The principal purpose of the design described herein was to improve these characteristics significantly.

Table 1—Specifications of torquemeters.

Designation	Size		Weight (N)	Weight Capacity (N)	Torque Capacity (N-m)	Purpose	Status
	Diameter (cm)	Height (cm)					
Mark I	188	81	1600	45	10^{-4}	Experimental	Scrapped
Mark II	203	38	2700	2700	6.6×10^{-3}	Spacecraft testing	Scrapped
Mark III	274	152	7561	22,240	0.2	Spacecraft testing	Available
Mark IV	91	56	450	4450	3×10^{-4}	Experimental	Available
Mark V	15	23	90	450	3×10^{-4}	Component testing	Available
Mark VI	38	25.4	249	3558	0.35	Spacecraft testing	Available

DESCRIPTION OF THE MARK VI TORQUEMETER

Characteristics and Capabilities

The Mark VI (Figure 1) has the following characteristics:

Dimensions – 38 cm (15 in.) diameter X 25 cm (10 in.) high.

Weight – 250 N (56 lb) (portable).

Moment of inertia of rotatable elements – 0.226 N-m-sec^2 (2 lb-in.-sec^2), not including damping fluid.

Damping – adjustable.

Weight capacity – 3550 N (800 lb).

Suspension principle – cross flexures.

Flexure stiffness – 97.4 N-m/rad (862 lb-in./rad).

Maximum torque capacity – 0.35 N-m (3.5 X 10^6 dyne-cm).

Minimum torque capacity – approximately 5 X 10^{-7} N-m (5 dyne-cm).

Transducer – differential capacitor in conjunction with ac bridge circuit.

Torque axis – vertical.

Applicable GSFC drawings –

GD 1190483 – 6 sheets,
GD 1190493 – 1 sheet, and
GD 1190508 – 2 sheets.

Mechanical Construction

The mechanical features of the torquemeter are shown in Figure 1. Compliance to applied torques is furnished by a pair of Bendix flexure pivots, the lower one of which supports the weight of the test specimens. The small rotation (generally a few seconds of arc) is sensed by a differential capacitor: the motion causes one capacitance to increase and the other to decrease.

Squeeze film damping is effected by means of a flat plate (or paddle) immersed in a closely fitting housing. Water is normally used as the damping fluid, and the damping rate may be varied by changing the fluid level. The depth of fluid not only affects the damping rate but has a significant influence on the effective mass. This was investigated experimentally with water as the damping fluid. The results appear in Figure 2. Therefore, the bare-table inertia is obtained by the addition of the virtual moment of inertia of the damping fluid to the moment of inertia of the rotatable elements: 0.226 N-m-sec^2 (2 lb-in.-sec^2).

As the principal usage of the Mark VI is in the measurement of magnetic torques, the meter itself is of nonmagnetic construction. The structure is composed of an aluminum alloy, and the flexure pivots are made of stainless steel. The pivots were found to be magnetized upon delivery, but they were subsequently demagnetized. Measurements made since this time have shown no remagnetization.

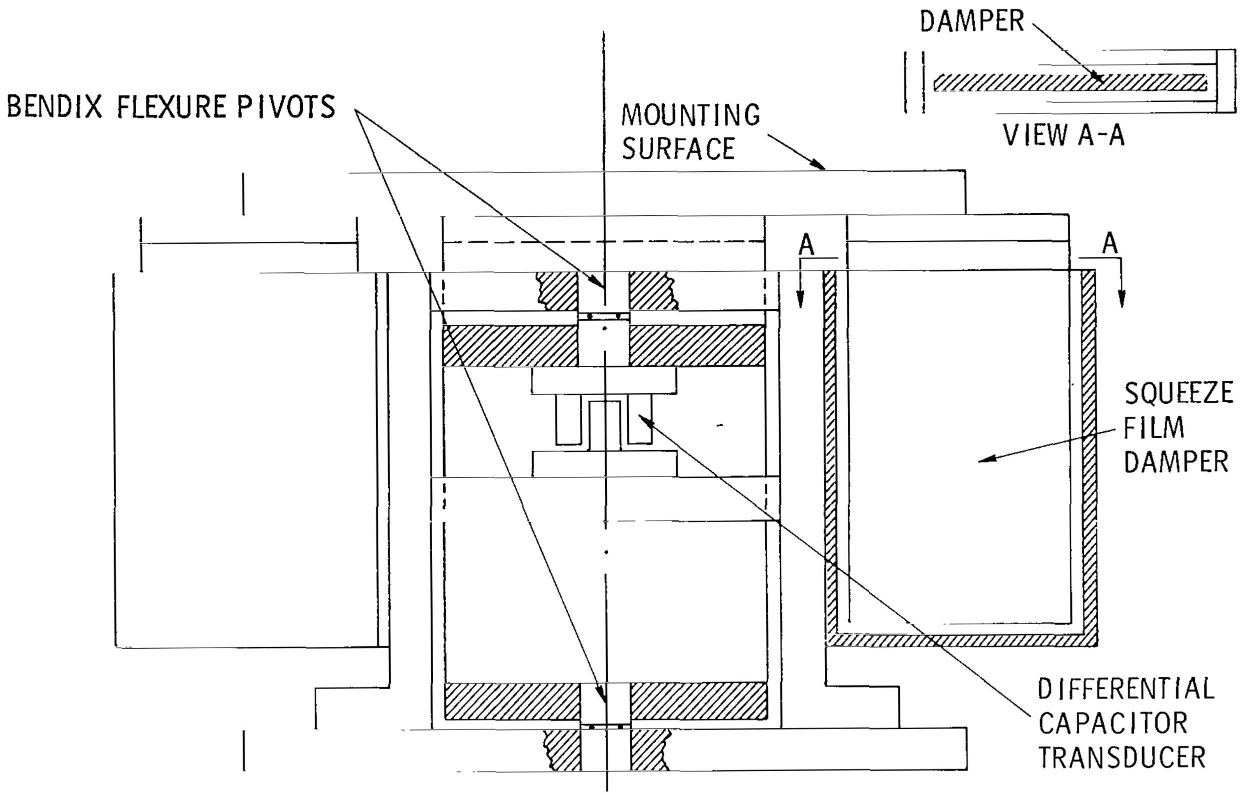

Figure 1—Construction of Mark VI torquemeter (schematic).

The torquemeter and its intermediate electronics are designed to be operable from - 18°C to 49°C in vacuum conditions down to 1.33 X 10^{-4} N/m^2 (10^{-6} torr) if diffusion-pump oil is substituted for water in the dampers.

Circuitry

A block diagram of the principal elements of the torque measuring system is shown in Figure 3. Basically, the application of torque causes a slight rotation of the plates of the differential capacitor transducer, which unbalances an ac bridge circuit. The bridge circuit can be manually rebalanced by the use of the decade dials on the front panel, or the imbalance can be recorded. Noise rejection is accomplished by an electric filter that precedes the recorder.

The intermediate electronics package is located about a meter from the transducer. It conditions the signal from the transducer and permits any desired length of cable to be used between it and the control station.

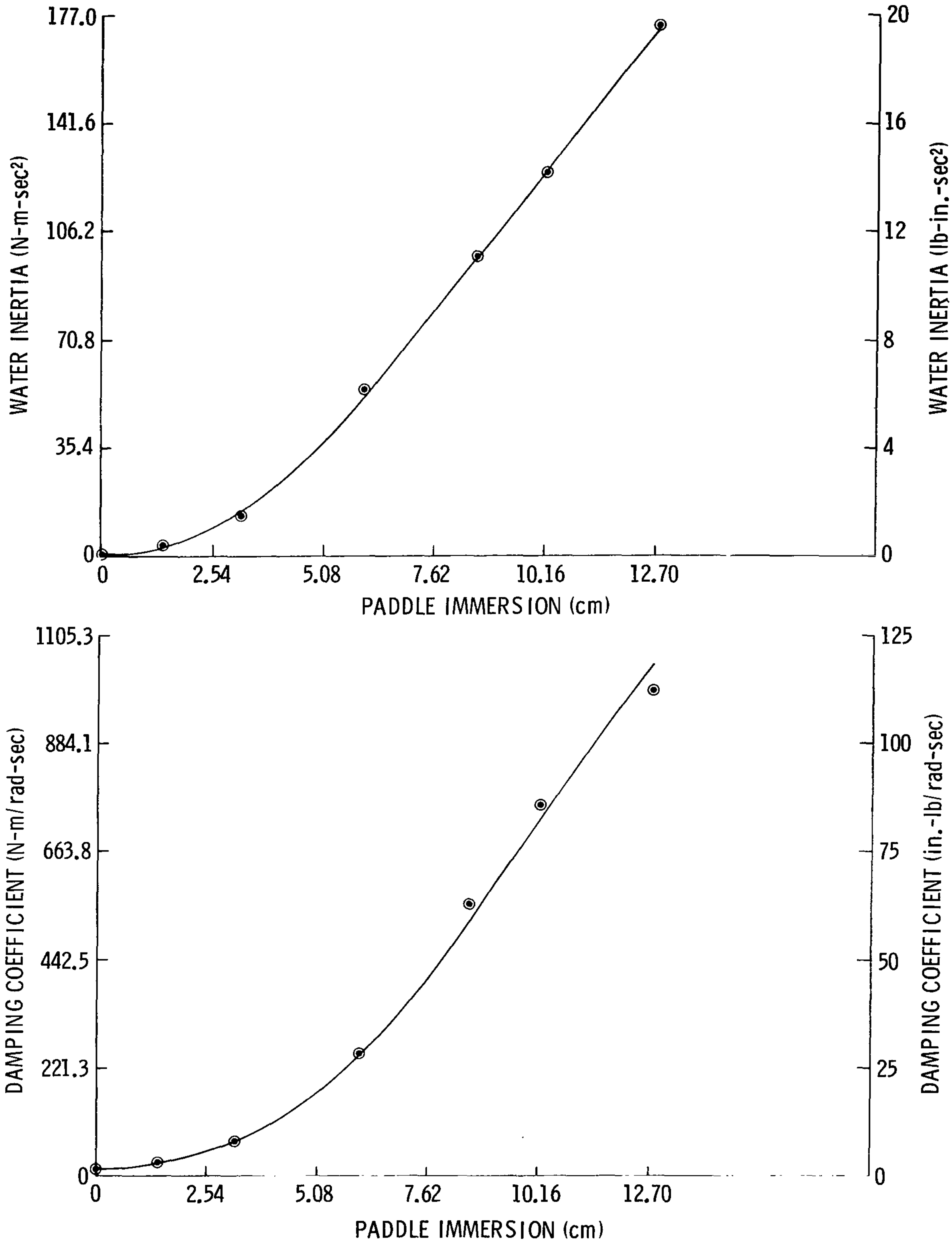

Figure 2—Mark VI damper characteristics.

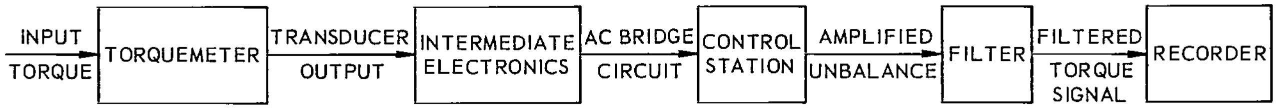

Figure 3—Block diagram of measuring system.

OPERATION

Calibration

Mechanical calibration can be performed with a small bellcrank having a flexure pivot of negligible torsional stiffness. The arrangement is shown in Figure 4. Two precision weights are available and can be hung from either notch on the bellcrank. The torques that can be applied using the various combinations of weights and lever arms are listed in Table 2. In addition, a third weight is available that is designed to be applied or removed by remote control with an electromagnetic actuator. When this weight (89.18×10^{-5} N) is applied at the 7.62-cm radius, the resulting torque is 681×10^{-7} N-m.

Calibration can also be performed by means of an air-core coil mounted on the torquemeter. The coil in use has a constant of 575×10^{-3} A-m^2/A (575 pole-cm/A). When a controlled field is applied orthogonal to the coil, a torque L is applied equal to

$$L = CIB ,$$

where

C = coil constant = 575×10^{-3} A-m^2/A (575 pole-cm/A),

B = flux density = 0.6×10^{-4} T (0.6 gauss) max,

and

I = coil current = 10 A max.

Thus, the maximum calibrating torque available by this technique is

$$L = 575 \times 10^{-3} \times 10 \times 0.6 \times 10^{-4}$$

$$= 3450 \times 10^{-7} \text{ N-m (3450 dyne-cm)} .$$

Lesser torque values can be applied by means of reduced values of current or applied field.

Calibration with the coil and field method has the advantage that it obviates the necessity for personnel to enter the vicinity of the torquemeter. During a test, the equipment is surrounded by a plastic enclosure similar to a tent, which minimizes the effect of air currents. When a person enters this enclosure, he creates a disturbance that causes the mechanical calibration to be noisy, and that does not subside for a considerable period.

Table 2—Mechanical calibration loadings.

Weight	Radius	Torque (N-m)
Small (.00257 N)	Inner (2.54 cm)	653×10^{-7}
Small	Outer (7.62 cm)	1960×10^{-7}
Large (.00776 N)	Inner	1960×10^{-7}
Small and large	Inner	2613×10^{-7}
Small and large	Outer-inner	3920×10^{-7}
Large	Outer	5880×10^{-7}
Small and large	Inner-outer	6533×10^{-7}
Small and large	Outer	7840×10^{-7}

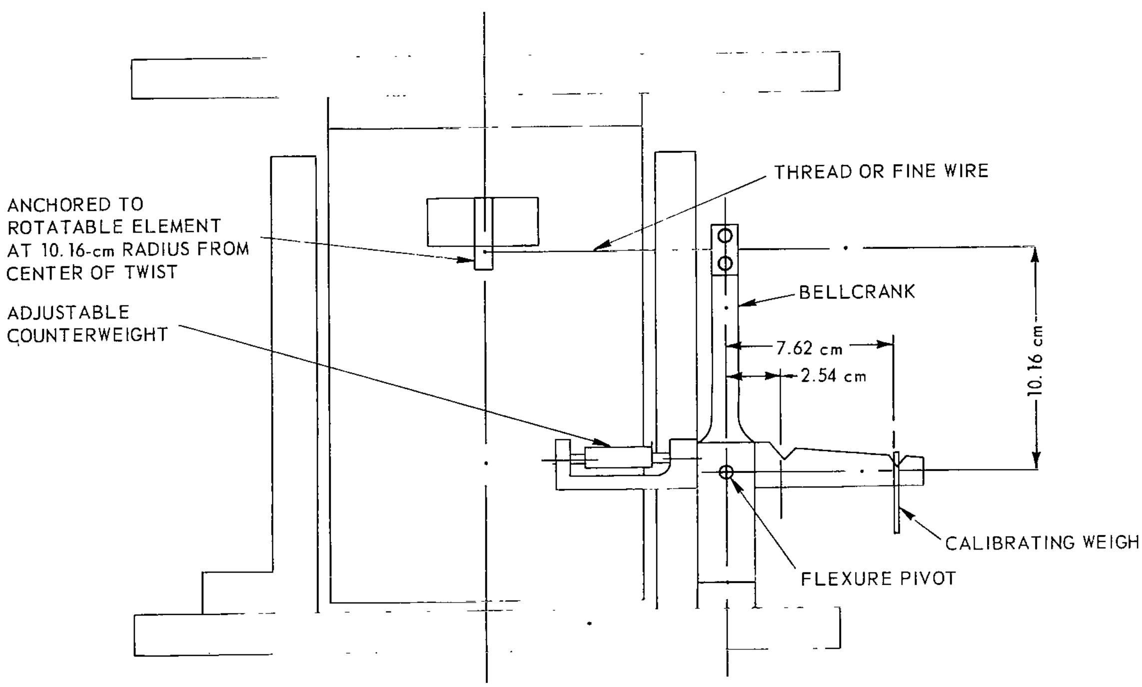

Figure 4—Mechanical calibrator.

Magnetic Tests

Permanent Moments

The Mark VI is used primarily to measure magnetic torques due to interactions between the net dipole moment of the test object and the applied field. If the dipole moment is as steady as the permanent moment for example, a fixed magnetic field vector can be applied and the static torque response can be measured.

Assume the axes of the spacecraft or subsystem under test are oriented as shown in Figure 5 and that the permanent moment has components M_x, M_y, and M_z. The components M_x and M_y can be determined from the torque produced about the vertical axis. Since, in general, $\mathbf{L} = \mathbf{M} \times \mathbf{B}$,

$$L_1 = M_x B_e$$

and

$$L_2 = M_y B_n \, ,$$

where

L_1, L_2 = torques,

B_e = applied field directed east,

and

B_n = applied field directed north.

For a determination of M_z, the test specimen can be rotated 90 degrees, say about the x-axis, giving the orientation shown in Figure 6. A field directed north produces the relationship

$$L_3 = M_z B_n \, ,$$

from which the third component, M_z, may be calculated.

In some instances, it may not be practical to rotate through 90 degrees. This is shown in Figure 7, in which the rotation angle is θ. In this case the components of M_y and M_z lie along the east-west axis. When a north-directed field is applied,

$$L_3 = (M_y \cos\theta - M_z \sin\theta) B_n \, ,$$

which can be solved for M_z, since M_y has already been determined.

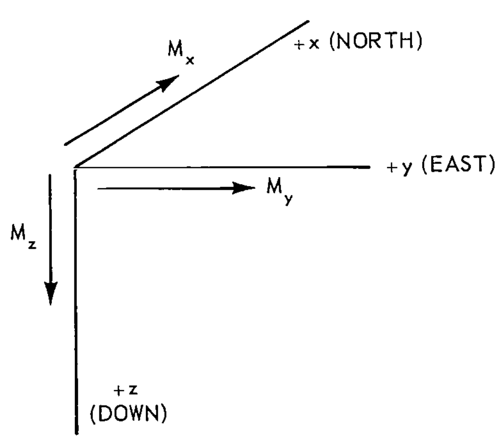

Figure 5—Components of dipole moment.

In some tests there is sufficient magnetically permeable material present to produce a significant induced torque.

In Figure 8, a rod of permeable material is oriented at an angle θ with the x-axis. The permanent moment components M_x and M_y are also present.

If a field were applied along the $+x$-axis, a moment would be induced along the axis of the permeable rod, resulting in a counterclockwise induced torque. If the field were reversed, the induced moment would also reverse, but the torque would still be counterclockwise. This phenomenon

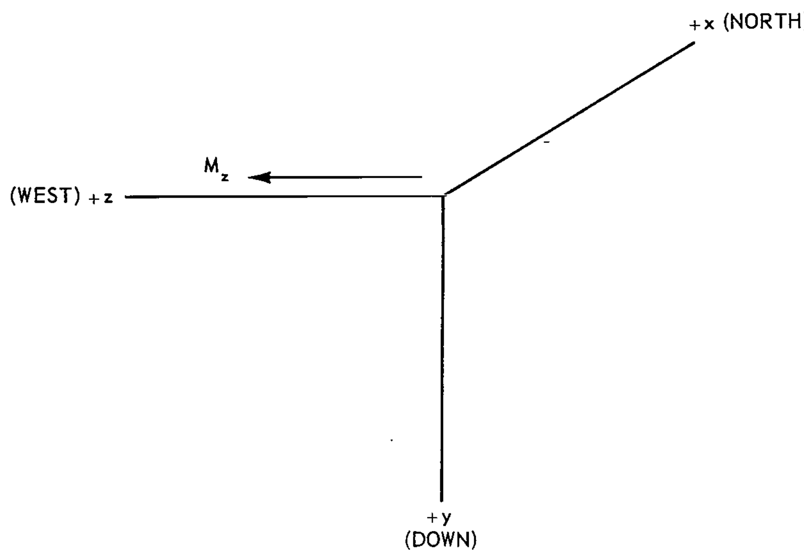

Figure 6—Coordinates of subsystem.

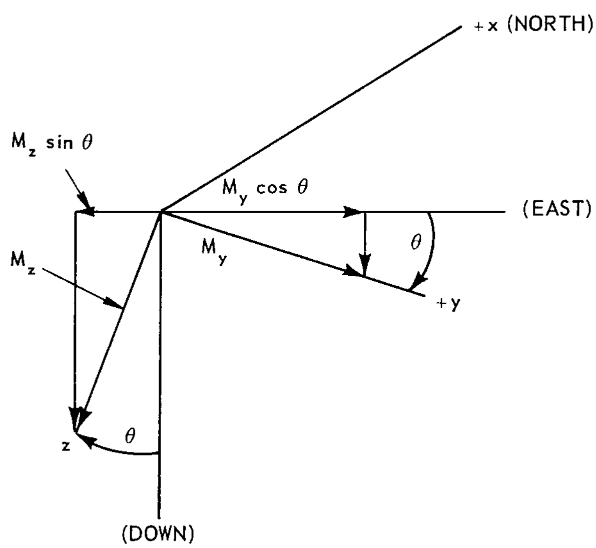

Figure 7—Rotation through angle θ.

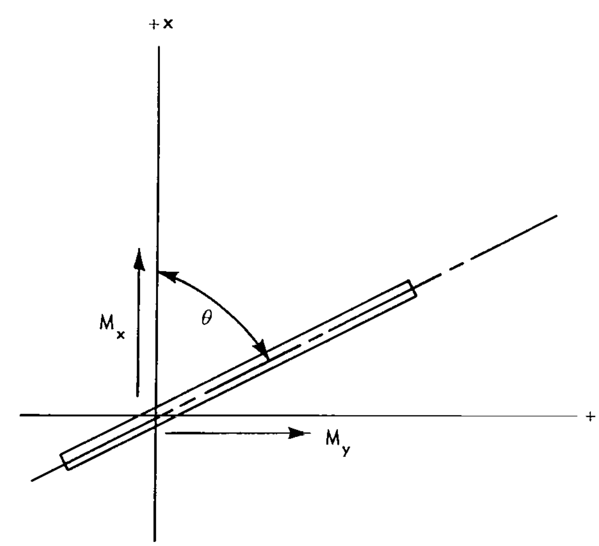

Figure 8—Permeable rod in the magnetic field.

can be used to separate the torques due to the permanent and induced moments with the following algebraic technique:

$$\mathbf{L}_1 = \mathbf{M}_y \times \mathbf{B}_{+x} + \mathbf{M}_i \times \mathbf{B}_{+x} \quad \text{for a } +x \text{ field}$$

and

$$\mathbf{L}_2 = \mathbf{M}_y \times \mathbf{B}_{-x} + \mathbf{M}_i \times \mathbf{B}_{-x} \quad \text{for a } -x \text{ field .}$$

These vector equations yield the scalar equations

$$L_1 = -M_y B_x - M_i B_x$$

and

$$L_2 = M_y B_x - M_i B_x \, ,$$

which can be solved simultaneously to yield

$$M_i = \frac{-L_1 + L_2}{2B_x}$$

and

$$M_y = \frac{-L_1 - L_2}{2B_x} \, .$$

Similarly, M_x and M_z can be separated from the induced moment components.

The data acquisition techniques described above involve the application of static fields and result in static torques. When very small torques are to be measured, accuracy is limited by noise and drift.

This situation can be improved by use of a dynamic technique in which the applied field is oscillated sinusoidally. If the field is oscillated at a frequency that has a low noise level, and if the filter is operated in the band-pass mode, a favorable signal-to-noise ratio can be obtained. In addition, the problem of drift is eliminated.

When the torquemeter operates in this fashion, a dynamic calibration with the calibrating coil is necessary. A known coil current is applied to produce a known moment, and a known field is oscillated at right angles to the axis of the coil. If the calibrating coil is energized and an oscillating field applied, the torquemeter response will be proportional to the sum of the calibrating coil moment and the unknown spacecraft moment. This can be expressed as

$$R_1 = K(M_c + M_u) \, ,$$

where

R_1 = torquemeter response,

K = proportionality constant,

M_c = known calibration coil moment,

and

M_u = unknown moment.

If the calibrating coil is open-circuited and the same oscillating field applied, the torquemeter response will be proportional to the unknown spacecraft moment:

$$R_2 = KM_u \, .$$

These two equations can be combined to give

$$M_u = \frac{M_c}{R_1/R_2 - 1} \cdot$$

A phase lag can exist between the input and output of the torquemeter, and this lag should be noted in a determination of the sense of the moment. This phase relation will be measurable during the calibration with the air-core coil.

Induced Moments

If an induced moment component is present, the resulting torque will oscillate at twice the frequency of the applied field. The band-pass filter will, therefore, tend to reject torques due to the induced moment.

Attitude Control

The Mark VI is also used to evaluate attitude-control systems, particularly those used on spinning satellites in which the spin rate and spin axis attitudes are controlled by magnetic torquing. In an evaluation of these systems, the applied field is rotated at the satellite spin rate, simulating the rotation of the spacecraft in the ambient orbital field.

If the control system produces a constant torque, this torque can be measured by the static technique described above. Some control systems, however, produce a pulsating torque such as that shown in Figure 9.

Under these circumstances, the response rate of the torquemeter will decide how closely the response resembles the input torque pulses. If the period of the torquemeter is short compared with the duration of the pulse and if the damping is of the order of 0.5 to 0.7 of critical, the response can be

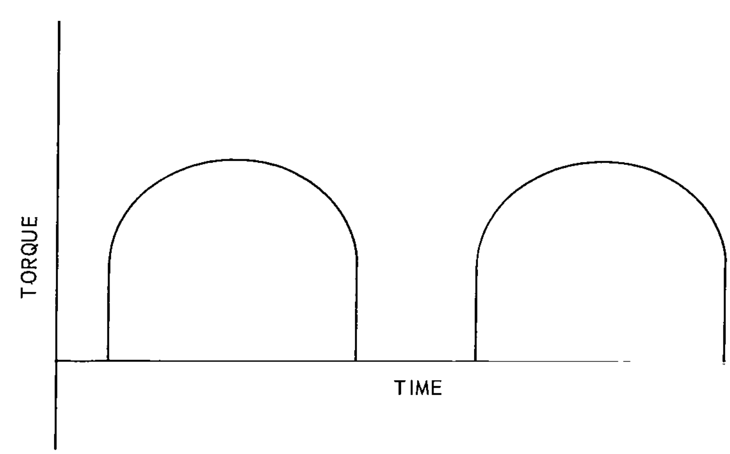

Figure 9—Pulsating torque.

expected to represent the actual input pulse fairly faithfully. If the torquemeter period is not short compared with the duration of the pulse, then the output will be considerably distorted.

Regardless of how well the response matches the instantaneous form of the input torque, the average value of the input can still be determined. The following analysis shows that the average value of the torquemeter's output is equal to the average value of the input spin-control torque.

Figure 10 shows the displacement and velocity response of the torquemeter to the input pulse (shown in dotted lines and labeled L. This is the steady-state, cyclic response that would occur with moderate damping if the pulse period were long with respect to the natural period of the torquemeter. The shapes of the response curves might be drastically different with different ratios of pulse to natural period and different damping ratios, but this would not affect the argument that follows.

The total torque impulse applied to the spacecraft and rotor of the torquemeter will be equal to the change in the torquemeter's angular momentum expressed by the equation

$$\int_1^2 L\,dt + \int_1^2 K\theta\,dt + \int_1^2 C\dot{\theta}\,dt = I(\dot{\theta}_2 - \dot{\theta}_1)\ ,$$

where

L = applied torque,

$K\theta$ = torsional spring restraint of torquemeter,

$C\dot{\theta}$ = damping restraint of torquemeter,

and

I = moment of inertia of spacecraft and torquemeter rotor.

If the time interval of the integration is taken equal to the period, T,

$$\int_0^T L\,dt + \int_0^T K\theta\,dt + \int_0^T C\dot{\theta}\,dt = I(\dot{\theta}_T - \dot{\theta}_0)\ ;$$

but over a full cycle:

$$\dot{\theta}_T = \dot{\theta}_0\ .$$

Thus,

$$\int_0^T L\,dt + \int_0^T K\theta\,dt + \int_0^T C\dot{\theta}\,dt = 0\ ,$$

and

$$\int_0^T C\dot{\theta}\,dt = \int_{\theta_0}^{\theta_T} C\,d\theta$$

$$= C(\theta_T - \theta_0)\ .$$

Again, over a full cycle

$$\theta_T = \theta_0 \ ;$$

therefore,

$$\int_0^T C\dot{\theta}\, dt = 0 \ ,$$

and

$$\int_0^T L\, dt + \int_0^T K\theta\, dt = 0 \ .$$

Divided by T and transposed, the equation is of the form

$$\int_0^T \frac{L}{T} dt = - \int_0^T \frac{K\theta}{T} dt \ .$$

Finally

$$L_{av} = - K\theta_{av} \ ,$$

where L_{av} and $K\theta_{av}$ are the average values of input torque and spring torsional restraint.

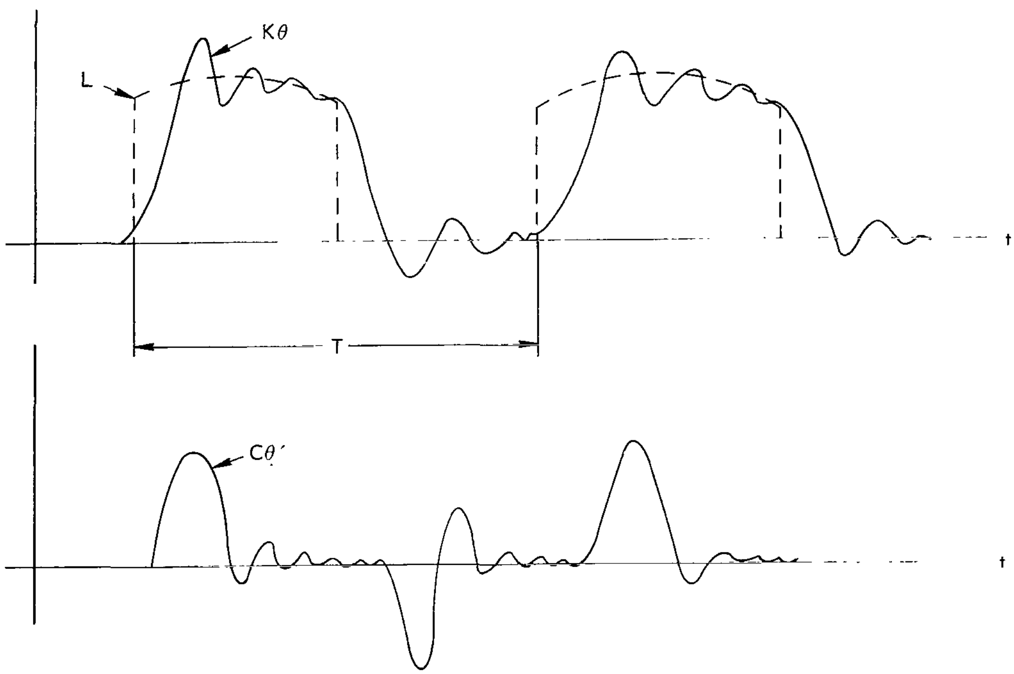

Figure 10—Response of torquemeter to pulsating input.

Thus, even if the instantaneous input cannot be faithfully followed by the response, the average value of the input torque can be obtained. If, in fact, the moment generated by the torquing coil is known to be constant (if the coil current is monitored, for example) and if the rotating field vector is known, the input torque function can be reconstructed.

The coil current of a typical satellite spin-control system is triggered on to a constant value when the ambient field reaches a certain value and is triggered off when the field falls below this value. When the field reverses, the current reverses, giving rise to the condition shown in Figure 11. Curves of flux density, B, attitude coil moment, M, and resultant torque, L, are given. The angles θ_1, θ_2, θ_3, and θ_4 are the points at which the torque coil triggers on and off. B is the component of the rotating flux that is in quadrature with the moment vector, M. The relationship can be expressed as

$$\mathbf{L} = \mathbf{M} \times \mathbf{B} .$$

Since

$$B = B_0 \sin \omega t ,$$

$$L = MB_0 \sin \omega t .$$

The average value of the torque pulse, L_{av}, is given by

$$L_{av} = \frac{\int_{\theta_1}^{\theta_2} MB_0 \sin \omega t \, d(\omega t) - \int_{\theta_3}^{\theta_4} MB_0 \sin \omega t \, d(\omega t)}{2\pi}$$

$$= \frac{MB_0}{2\pi} (\cos \theta_1 - \cos \theta_2 - \cos \theta_3 + \cos \theta_4) .$$

In terms of the spring torsional restraint, $K\theta_{av}$, this is

$$-K\theta_{av} = \frac{MB_0}{2\pi} (\cos \theta_1 - \cos \theta_2 - \cos \theta_3 + \cos \theta_4) ,$$

which can be solved for M:

$$M = \frac{-2\pi K\theta_{av}}{B_0(\cos \theta_1 - \cos \theta_2 - \cos \theta_3 + \cos \theta_4)} .$$

If the torque coil triggers on and off at the same field magnitudes, then

$$\theta_2 = \pi - \theta_1 , \quad \cos \theta_2 = -\cos \theta_1 ;$$

$$\theta_3 = \pi + \theta_1 , \quad \cos \theta_3 = -\cos \theta_1 ;$$

and

$$\theta_4 = 2\pi - \theta_1 , \quad \cos \theta_4 = \cos \theta_1 .$$

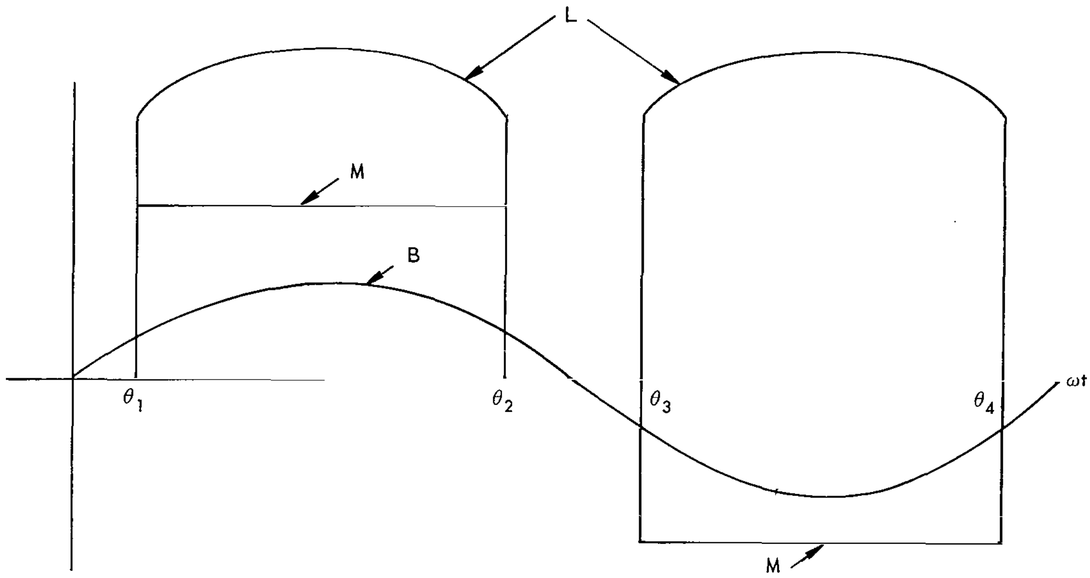

Figure 11—Variation of moment (M) and torque (L) with magnetic field (B).

Substitution of these values yields an expression for M:

$$M = \frac{-2\pi K\theta_{av}}{B_0(\cos\theta_1 + \cos\theta_1 + \cos\theta_1 + \cos\theta_1)}$$

$$= \frac{-\pi K\theta_{av}}{2B_0 \cos\theta_1}.$$

Nonmagnetic Tests

The Mark VI can be used for other, nonmagnetic tests. For instance, it has been used to measure the impulse torques that result from the starting and stopping of the tape transport of a recorder for OGO-6.* It was also used for the torque calibration of a linear induction motor in a test of the ATS-E mechanically despun antenna.** In the latter work, the meter was required to measure torques as high as 0.35 N-m (353×10^6 dyne-cm). This is in contrast to the usual requirement of measuring 10^{-6} to 10^{-4} N-m (10 to 1000 dyne-cm).

ACCURACY

Noise in the torquemeter output results from vibrational inputs through the base and from air currents and gusts. The Mark VI is used in a fairly quiet location somewhat remote from traffic and

*Boyle, J. C., and Mosher, E. J., "Torque Test of OGO-F Tape Recorder," NASA–Goddard Space Flight Center Memorandum Report 685-015, Goddard Space Flight Center, Greenbelt, Maryland, July 1968.

**Boyle, J. C., and Stewart, R. W., "Calibration of Linear Induction Motor Using GSFC Mark VI Torquemeter," NASA–Goddard Space Flight Center Document X-325-70-229, Goddard Space Flight Center, Greenbelt, Maryland, May 1970.

industrial noises, and a plastic enclosure completely surrounds the torquemeter and spacecraft under test. Nonetheless, the noise level is sometimes objectionably high. Electrical filtering is used, and this does help considerably. When static measurements are made, the filter is used in a low-pass mode and the higher frequency disturbances are eliminated. When dynamic measurements are made (as with an oscillating field), the filter is used in a band-pass mode that tends to exclude all but the frequency of interest. The frequency selected should be one at which the noise spectrum is reasonably low, in order to yield a good, clean signal.

The Sanborn strip chart presently in use as a recorder provides a maximum resolution of about 1 percent. Noise level is dependent upon the weight and bulk of the spacecraft under test, rendering it impossible to assign a specific value. Under favorable circumstances, small torques have been measured with an error of less than 5×10^{-7} N-m (5 dyne-cm).

CONCLUSIONS AND RECOMMENDATIONS

The Mark VI torquemeter has proven to be a very satisfactory instrument, with the load capacity and accuracy necessary for magnetic testing of the majority of GSFC satellites. Within the past year, it has been used in testing of the SSS A (Small Scientific Satellite), SAS A (Small Astronomical Satellite), and UK-IV, a British scientific satellite. In these tests, it has been used to measure both dipole moments and magnetic control torque. The Mark VI has also been used to measure torque impulses due to starting and stopping of an OGO tape recorder, to measure the torque-voltage characteristics of a linear induction motor system, and to evaluate a proposed magnetic technique for satellite despin.

In some instances, torque measurements and magnetic field measurements have been taken simultaneously, permitting a comparison between magnetic moments calculated by the two techniques. These indicate that comparable accuracies are attainable. In general, the torquemeter is favored for spacecraft tests when magnetic data is difficult to interpret (such as when measured field values are approaching the noise level or when the magnetic sources within the spacecraft are spread over a large volume, giving rise to significant higher order multipole magnetic sources). The torquemeter is favored also in testing magnetic attitude control systems where the quantity of primary interest is the torque itself. Although it is not yet used for such measurements, its vacuum compatibility makes the instrument particularly applicable for measurements of microthruster torques or for other tests that require a vacuum environment.

ACKNOWLEDGMENT

The torque transducer and associated electronic circuitry described are essentially copies of equipment provided by the Republic Aviation Division of Fairchild-Hiller to GSFC under Contract NAS 5-9383.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, December 4, 1970
039-80-01-11-51

REFERENCES

1. Wooley, R. P., and Smith, J. E., Jr., "Magnetic Balance of the OSO-C," Ball Brothers Research Corporation, Boulder, Colorado, July 1965.

2. Boyle, J. C., and Greyerbiehl, J. M., "A Method for the Measurement of Extremely Feeble Torques on Massive Bodies," NASA Technical Note D-3711, National Aeronautics and Space Administration, Washington, D.C., November 1966.

3. Tossman, Barry E., "A Resonance Technique for Measurement of Satellite Magnetic Dipole Moment," Applied Physics Laboratory Technical Memorandum No. 33-216, John Hopkins University, Applied Physics Laboratory, Silver Spring, Maryland, March 1965.

NASA-Langley, 1971 —— 14

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AI
SPACE ADMINISTRATION

022 001 C1 U 14 710813 S00903DS
DEPT OF THE AIR FORCE
AF SYSTEMS COMMAND
AF WEAPONS LAB (WLOL)
ATTN: E LOU BOWMAN, CHIEF TECH LIBRARY
KIRTLAND AFB NM 87117

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Retur

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546