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SYSTEM DESIGN OF A UNIQUE MAGNETIC ATTITUDE AND SPIN CONTROL SUBSYSTEM

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16. Abstract

A preferred system for spacecraft spin axis orientation and spin rate control utilizing earth's field magnetic torquing is selected by comparison of alternative spin mode mechanizations. The unique capability of the selected system is its ability to meet unusually stringent weight and power requirements. The Small Scientific Satellite control requirement, used as a baseline for presenting the magnetic system in this report, was met by a subsystem weighing only 2.5 lb and requiring only 3.2 W when energized. An additional feature of the magnetic system presented is its compatibility with automatic turn-on for missions involving elliptical orbits. The system has been thoroughly tested in controlled magnetic fields on a torque measuring instrument.

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INTRODUCTION

In order to achieve scientific objectives, spinning spacecraft frequently require control of the spin axis orientation (attitude mode) and of the spin rate (spin mode). Candidates for performing these control functions are gas and magnetic systems, sometimes used in conjunction with a reaction wheel. Magnetic systems, the subject of this document, develop control torque by the interaction of a generated magnetic moment with the earth's magnetic field and offer the advantage that useful system lifetime is not limited by any factor such as gas storage capacity.

The magnetic system described herein resulted from an extensive system design effort that was performed to supply an attitude and spin control subsystem (ASCS) to the Small Scientific Satellite (SSS) program. Figure 1 shows the four basic components of this subsystem. The unique aspect of the ASCS is its ability to meet unusually stringent weight and power requirements. The ASCS shown in Figure 1 weighs just 2.5 lb and requires only 3.2 W when energized (duty cycle is very low). Although the SSS requirement has been used in this document as a baseline for presenting an optimized system design for a magnetic system, the conclusions reached have general application.

Attitude control with a magnetic system is typically accomplished by the generation of a constant magnetic moment (**M**) aligned with the spacecraft spin axis. The resulting magnetic torque vector remains always perpendicular to the spin axis and lies in the plane perpendicular to the earth's field ($\mathbf{B}_e$), since it is equal to the vector cross product $\mathbf{M} \times \mathbf{B}_e$. Thus, the spacecraft spin axis precesses around the earth's field vector with constant angle for as long as the moment is applied. Desired spacecraft orientations are achieved by activation of the spin axis moment when earth's field directions are favorable. The spin axis precession is described by

$$\mathbf{T} = \bar{\omega}_p \times \mathbf{H} ,$$

where **T** is the torque (developed magnetically), which is perpendicular to the spin axis; **H** is the spacecraft angular momentum about the spin axis; and $\bar{\omega}_p$ is the precession vector. Obviously, the attitude mode is rather simple in design since only the energized time of the constant moment source is involved.

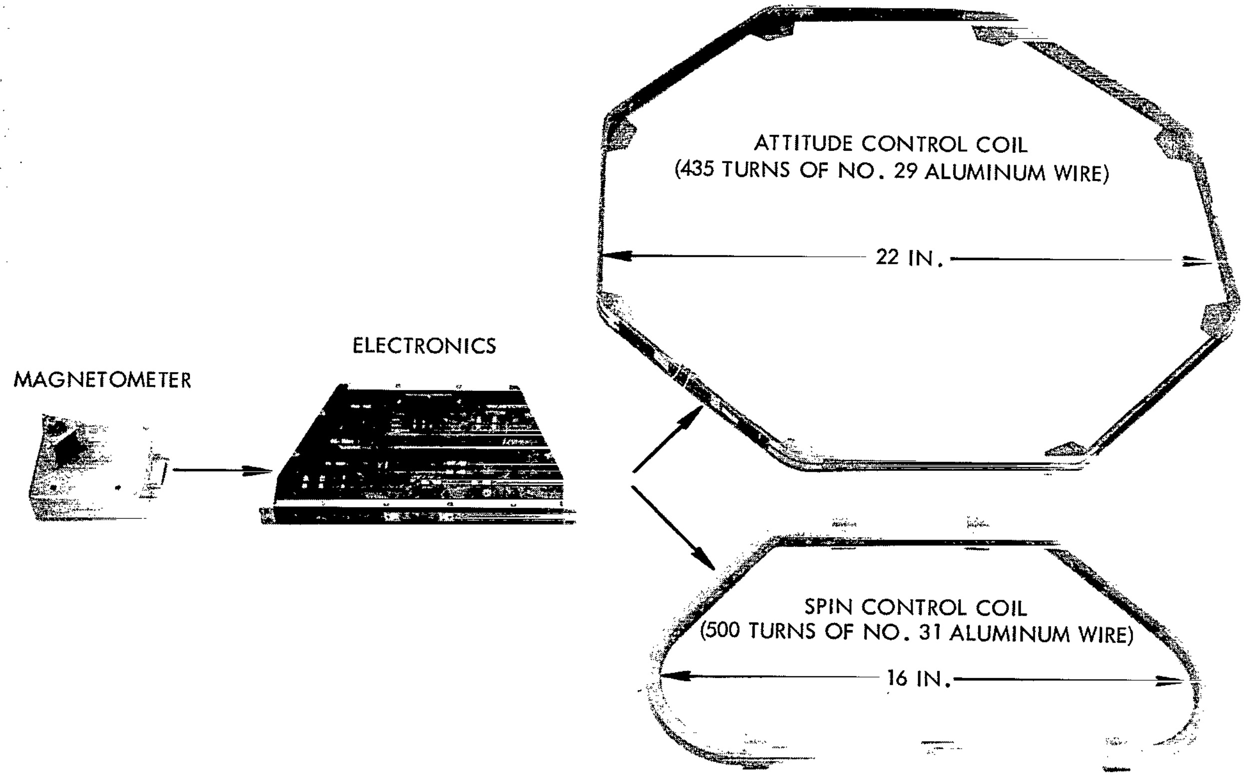


Figure 1—SSS attitude and spin control subsystem.

Magnetic system spin control is typically accomplished by generation of a commutated magnetic moment perpendicular to the spin axis which produces a spin or despin torque along the spin axis. The usual reference for commutation of the spin mode moment source (e.g., a coil) is a magnetometer signal, which makes this mode completely analogous to a brushless dc motor in which the earth's field provides the field for motor action. Of course, any earth's field component along the spin axis (i.e., not in the plane of "motor" action) causes unwanted gyroscopic precession of the spin axis during spin mode activation.

Because the attitude mode is relatively straightforward in design, the analysis in this document emphasizes the system design features of the spin mode. However, many features of the spin mode were used advantageously in the attitude mode also.

ALTERNATIVE SPIN MODE MECHANIZATIONS

The possible system mechanizations to be considered here are one- and two-channel systems and two methods of driving the moment source. To avoid unnecessary complexity, each mechanization will be examined with the assumption that the magnetic field vector lies in the plane of motor action and is invariant with a magnitude of 0.3 G. Further, the magnetic moment source is assumed to be a large-area, multiturn, air core coil having the physical dimensions of that used on the SSS. Air core coils were chosen for the SSS to minimize the magnetization of the spacecraft (since the flux of a coil is distributed) and to eliminate the need for any ferromagnetic materials (the coils are wound with aluminum wire). The four possible spin mode mechanizations are presented below.

Typical Two-Channel System

This two-channel system, depicted in Figure 2, has been used successfully on many spacecraft. The associated waveforms and vector diagram are shown in Figure 3. The sinusoidal variations of B_x and B_y are a direct result of spacecraft rotation as sensed by the magnetometers. The key characteristic of the system mechanization is the proportional (sine) drive of the coil currents. As seen, this results in sine-squared and cosine-squared torque waveforms which yield a constant amplitude resultant torque along the spin axis. The torque output shown in Figure 3 corresponds to that required for the SSS mission and will be used as a reference value for comparison of the four spin mode mechanizations. The system mechanization presently being considered is sized below to determine the coil weight and drive power requirements.

To develop the output torque each coil must generate a peak moment (M_p) of

$$M_p = \frac{T_z}{B_e(\sin 90°)}$$

$$= \frac{506 \text{ dyne-cm}}{0.3 \text{ G } (1)}$$

$$= 1690 \text{ pole-cm (or } 1.69 \text{ A-t-m}^2) .$$

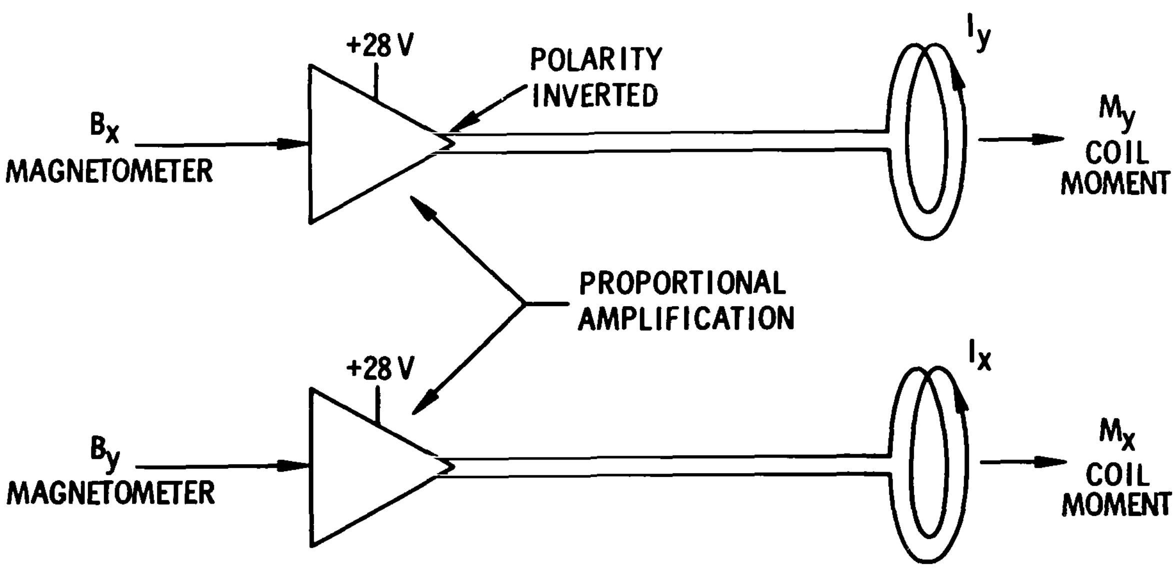


Figure 2—Typical two-channel sine drive system.

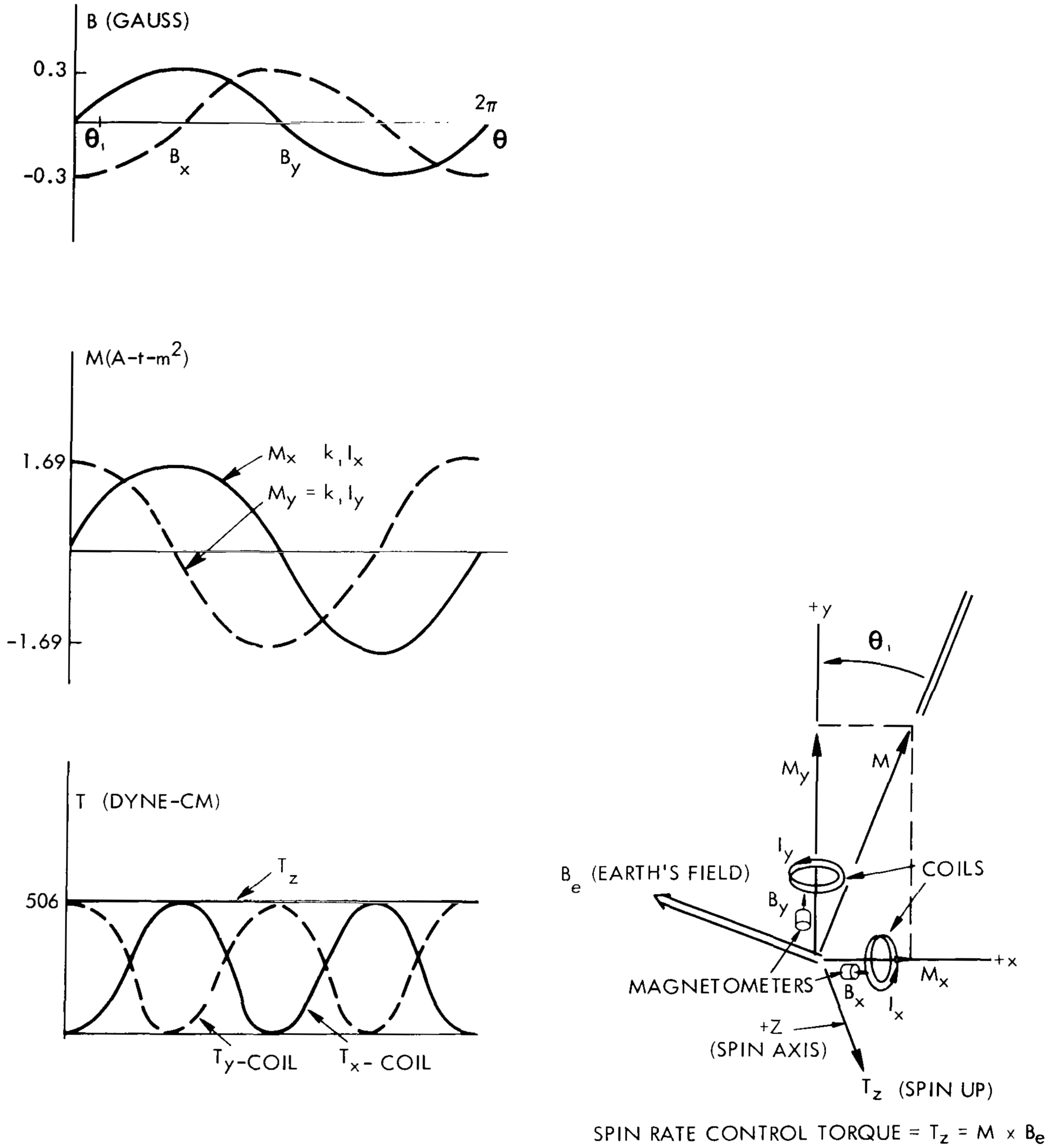


Figure 3—Waveforms for two-channel sine drive system.

For an air core coil, the moment is defined by

$$M = NIA ,$$

where N is the number of coil turns, I is the coil current, and A is the coil area (0.0697 m^2).

If the peak voltage to be applied across the coil terminals is V_p, then

$$M_p = \frac{NV_pA}{(NC\sigma)} ,$$

where C is the coil circumference (3.45 ft) and σ is the unit length resistance of the wire used. Therefore, with 28 V used to generate the required peak coil moment, the unit length resistance of the wire size selected must be

$$\sigma = \frac{V_pA}{M_pC}$$

$$= \frac{(28\ \text{V})(0.0697\ \text{m}^2)}{(1.69\ \text{A-t-m}^2)(3.45\ \text{ft})}$$

$$= 0.335\ \Omega/\text{ft}\ ,\ \text{ or }\ 1/\sigma = 2.98\ \text{ft}/\Omega\ .$$

Aluminum wire size AWG No. 33 has 2.95 ft/Ω and is selected. For comparative purposes, 397 turns are chosen, which yields

$$\text{Coil weight } W_c = NC\ (\text{No. 33 wire unit length weight})$$

$$= (397)(3.45\ \text{ft})(1/21{,}700\ \text{lb/ft})$$

$$= 0.0631\ \text{lb}\ ,$$

$$\text{Coil resistance } R_c = NC\sigma$$

$$= (397)(3.45\ \text{ft})(1/2.95\ \Omega/\text{ft})$$

$$= 464\ \Omega\ ,$$

$$\text{Coil peak current } I_p = \frac{28\ \text{V}}{464\ \Omega}$$

$$= 0.0603\ \text{A (when 1.69 A-t-m}^2\text{ are produced)}\ ,$$

$$\text{Coil drive average power } P = (0.0603\ \text{A})(28\ \text{V})(2/\pi)$$

$$= 1.08\ \text{W}\ .$$

Some explanation is in order for the above power calculation. It is assumed that the sinusoidal coil current is developed from a constant 28-V source (i.e., a perfect supply with no internal resistance). Thus, the drive power waveform is a rectified sine wave having a peak value of 1.69 W. The $2/\pi$ factor reduces the peak value of this waveform to its average value.

As a check on calculations and as an indication of the value of k_1 in Figure 3, the following is presented:

$$\begin{aligned} M_p &= NAI_p \\ &= k_1 I_p \\ &= (397)(0.697\ \mathrm{m}^2)(0.0603\ \mathrm{A}) \\ &= (27.7\ \mathrm{t\text{-}m}^2)(0.0603\ \mathrm{A}) \\ &= 1.67\ \mathrm{A\text{-}t\text{-}m}^{2*}\ . \end{aligned}$$

Since this system mechanization requires two coils, total coil weight and drive power requirements are 0.126 lb and 2.16 W.

One-Channel Version of a Typical System

We now consider a single-coil system mechanization that is merely one channel of the foregoing system. Associated waveforms are shown in Figure 4. The system is sized below for the same average torque output as the preceding system (506 dyne-cm).

To generate the required peak moment shown, the coil must be wound with No. 30 wire (5.91 ft/Ω), since

$$\begin{aligned} \sigma &= \frac{(28\ \mathrm{V})(0.0697\ \mathrm{m}^2)}{(3.38\ \mathrm{A\text{-}t\text{-}m}^2)(3.45)} \\ &= 0.167\ \Omega/\mathrm{ft}\ , \quad \text{or} \quad 1/\sigma = 5.98\ \mathrm{ft}/\Omega\ . \end{aligned}$$

Again for comparison of systems, 397 turns are chosen, which yields

$$\begin{aligned} W_c &= (397)(3.45\ \mathrm{ft})(1/10{,}825\ \mathrm{lb/ft}) \\ &= 0.1265\ \mathrm{lb}\ , \end{aligned}$$

$$\begin{aligned} R_c &= (397)(3.45\ \mathrm{ft})(1/5.91\ \Omega/\mathrm{ft}) \\ &= 232\ \Omega\ , \end{aligned}$$

*This does not exactly equal the original 1.69 A-t-m² because of the discreteness in wire-size tables.

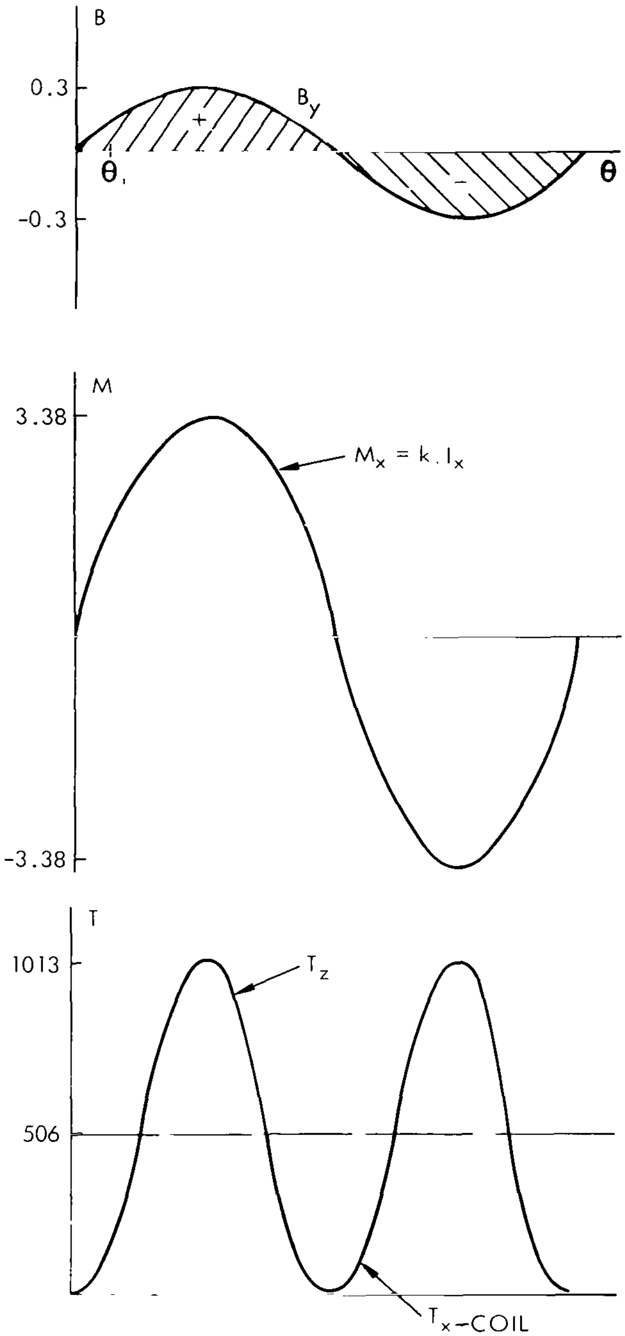


Figure 4—Waveforms for one-channel sine drive system.

$$I_p = \frac{28\ \text{V}}{232\ \Omega}$$

$$= 0.121\ \text{A}\,,$$

$$P = (0.121\ \text{A})(28\ \text{V})(2/\pi)$$

$$= 2.15\ \text{W}\,,$$

$$M_p = k_1 I_p$$

$$= (27.7\ \text{t-m}^2)(0.121\ \text{A})$$

$$= 3.34\ \text{A-t-m}^2\,.$$

Two-Channel Constant Level System

The two-channel constant level system is another two-coil system mechanization. The key characteristic is that the coils are driven at a constant current level, which is switched in direction as a function of the magnetometer signal polarity. The system is depicted in Figure 5, and waveforms and vector diagram are shown in Figure 6. As seen, the magnetometer need only sense the polarity of the field involved; no proportional coil current drive is required. Thus, the system operation can be of a digital nature, eliminating sensitivity to several variables. The sizing of this system for the same average torque output as previously used follows.

To generate the required moment, each coil must be wound with No. 34 wire (2.34 ft/Ω), since

$$\sigma = \frac{(28\ \text{V})(0.0697\ \text{m}^2)}{(1.33\ \text{A-t-m}^2)(3.45\ \text{ft})}$$

$$= 0.4253\ \Omega/\text{ft}\,,\ \text{or}\ \ 1/\sigma = 2.35\ \text{ft}/\Omega\,.$$

For comparison with the sine drive system, 500 turns are chosen, which yields,

$$W_c = (500)(3.45\ \text{ft})(1/27{,}400\ \text{lb/ft})$$

$$= 0.0632\ \text{lb}\,,$$

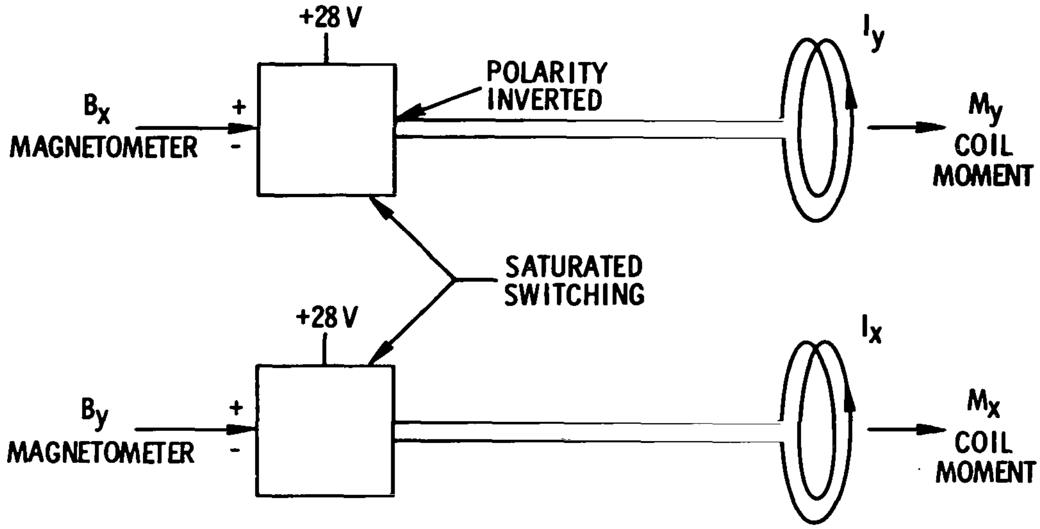


Figure 5—Two-channel constant level system.

$$R_c = (500)(3.45\ \text{ft})(1/2.34\ \Omega/\text{ft})$$

$$= 737\ \Omega\ ,$$

$$I_p = \frac{28\ \text{V}}{737\ \Omega}$$

$$= 0.0380\ \text{A}\ ,$$

$$P = (28\ \text{V})(0.0380\ \text{A})$$

$$= 1.06\ \text{W}\ ,$$

$$M_p = k_2 I_p$$

$$= (500)(0.0697\ \text{m}^2)(0.0380\ \text{A})$$

$$= (34.8\ \text{t-m}^2)(0.0380\ \text{A})$$

$$= 1.32\ \text{A-t-m}^2\ .$$

Since two coils are required, total coil weight and drive power requirements are 0.126 lb and 2.13 W.

One-Channel Version of Constant Level System

Now we consider a single-coil system mechanization that is again just one channel of the previous system. Waveforms are given in Figure 7, and the system is sized below for the same average torque output.

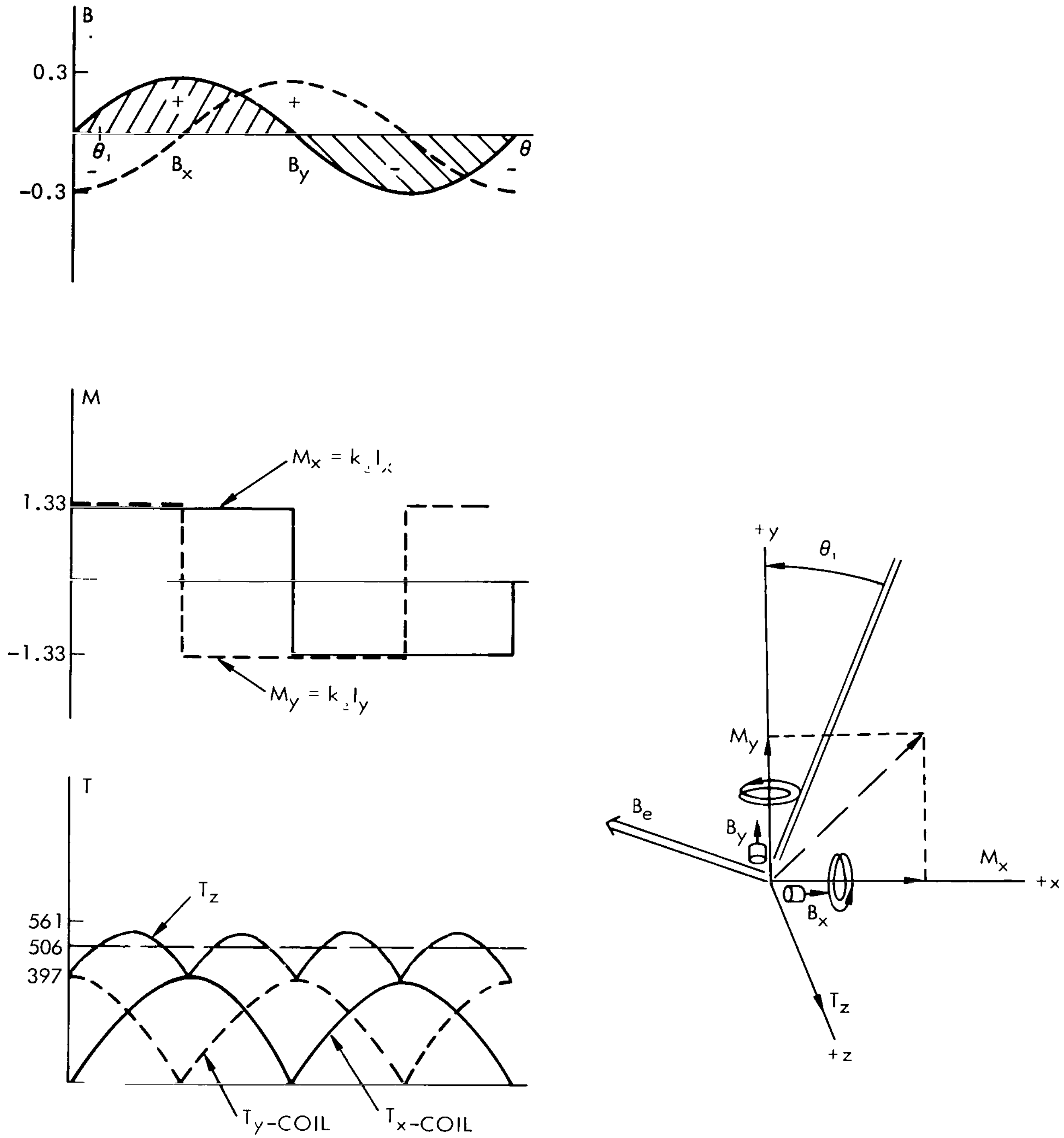


Figure 6—Waveforms for two-channel constant level system.

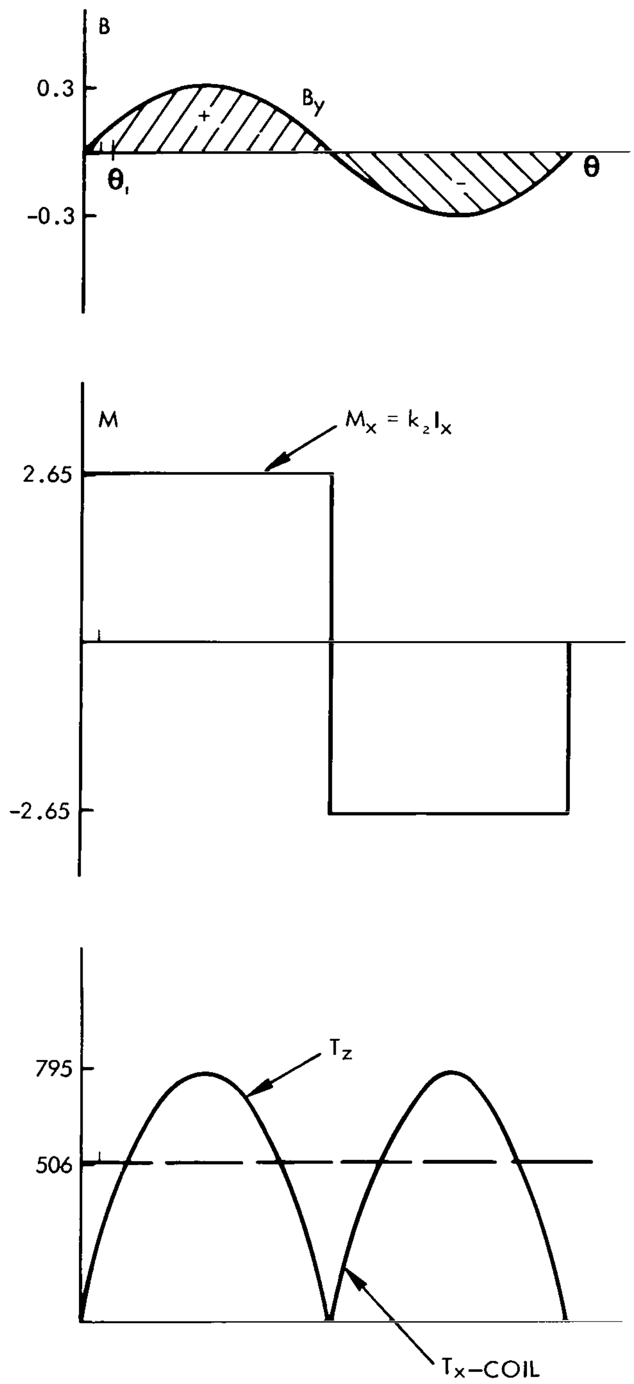


Figure 7—Waveforms for one-channel constant level system.

To generate the required moment, the coil must be wound with No. 31 wire (4.68 ft/Ω), since

$$\sigma = \frac{28 \text{ V } (0.0697 \text{ m}^2)}{2.65 \text{ A-t-m}^2 \text{ } (3.45 \text{ ft})}$$

$$= 0.214 \ \Omega/\text{ft}, \text{ or } 1/\sigma = 4.68 \text{ ft}/\Omega .$$

Using 500 turns for comparative purposes yields

$$W_c = (500)(3.45 \text{ ft})(1/13{,}645 \text{ lb/ft})$$

$$= 0.126 \text{ lb},$$

$$R_c = (500)(3.45 \text{ ft})(1/4.68 \ \Omega/\text{ft})$$

$$= 369 \ \Omega,$$

$$I_p = \frac{28 \text{ V}}{369 \ \Omega}$$

$$= 0.0760 \text{ A},$$

$$P = (28 \text{ V})(0.0760 \text{ A})$$

$$= 2.13 \text{ W},$$

$$M_p = k_2 I_p$$

$$= (34.8 \text{ t-m}^2)(0.0760 \text{ A})$$

$$= 2.65 \text{ A-t-m}^2 .$$

COMPARISON OF SPIN MODE MECHANIZATIONS

From the results of the previous section, features of the four system mechanizations are summarized in Table 1. Torque ripple was determined on the basis of rms torque ripple relative to average torque output and will be discussed more fully below. Also, it should be recalled that the one-channel systems have zero torque twice per cycle, whereas this condition is avoided in the two-channel systems.

Since the number of turns for all the coils was selected to give the same coil wire weight, a direct comparison of all the systems on a coil drive power basis is directly available from Table 1. As seen,

Table 1—Comparative table of spin control mechanizations for output torque of 506 dyne-cm.

System	Number of coils	Number of magnetometers	Coil drive power requirement (W)	Coil weight requirement (lb)	Torque ripple (%)	Commutation technique	Coil peak moment requirement (A-t-m^2)	Sweep angle of resultant moment (deg)
Two-channel sine drive	2	2	2.15	0.126	0	Proportional amplification	1.69 (ea.)	0
Two-channel constant level	2	2	2.13	0.126	9.5	Saturated switching	1.33 (ea.)	90
One-channel sine drive	1	1	2.15	0.126	70.7	Proportional amplification	3.38	180
One-channel constant level	1	1	2.13	0.126	48.2	Saturated switching	2.65	180

all of the systems are essentially equally efficient in producing the required torque output. It should be realized that if different values for coil turns had been used in the four mechanizations, the product of the coil weight and drive power requirements would still be the same as those available from Table 1. That is, changing the number of turns on a coil does not change the product of the coil weight and drive power requirements, nor does the generated magnetic moment at a given applied voltage change since that is fixed by the wire size selected.

A further aspect of the four mechanizations shown in Table 1 is the angular sweep made by the resultant moment vector. The significance of this is the gyroscopic precession associated with spin mode activation if any z-axis field component is present. The expression describing this precession was given in the Introduction. A major point with regard to this aspect is that the average position of all the resultant moment vectors is perpendicular to the field vector.

The variations in coil peak moment requirements of the four systems is one of the more important differences among the systems. The two constant-level system mechanizations provide a 21% savings in moment requirement. This is a very worthwhile decrease in terms of how much a spacecraft will be magnetized by activation of the ASCS. It is particularly important to the SSS mission because of the desire to provide a magnetically "clean" spacecraft for experimenters.

The last distinguishing feature among the systems is the percent torque ripple in the output torque developed. The standard basis for this quantity was mentioned earlier, but it is not a trivial calculation since the torque ripple waveform must be described about the average torque value for each case. A sample calculation of torque ripple is provided below for the two-channel constant level system mechanization; other torque ripple percentages were calculated similarly.

From Figure 6, each cycle of the output torque can be recognized as the top portion of a rectified sine wave. (This is particularly obvious when it is noted that the resultant moment of the system is a vector of constant magnitude that sweeps through an angle of 90°.) Therefore, it is necessary only to determine the rms value of the top portion of a sine wave about the average value shown in Figure 6. [The average value shown in Figure 6 was readily determined as $(2)(2/\pi)(397$ dyne-cm).] Figure 8 shows the waveform that gives the desired expression for rms torque ripple, which is

$$\text{rms torque ripple} = \left[\frac{1}{\pi/2}\int_{\pi/4}^{3\pi/4} (561 \sin\phi - 506)^2 \, d\phi\right]^{1/2} .$$

Evaluation of this integral gives an rms ripple value of 48 dyne-cm. Therefore, percent torque ripple is

$$\frac{\text{rms torque ripple}}{\text{average output torque}} = \frac{48 \text{ dyne-cm}}{506 \text{ dyne-cm}}$$
$$= 0.095 \text{ , or } 9.5\% .$$

SELECTION OF A SPIN MODE MECHANIZATION

The one-channel constant-level system mechanization was selected for the SSS and is considered a preferred mechanization. It offers the following advantages:

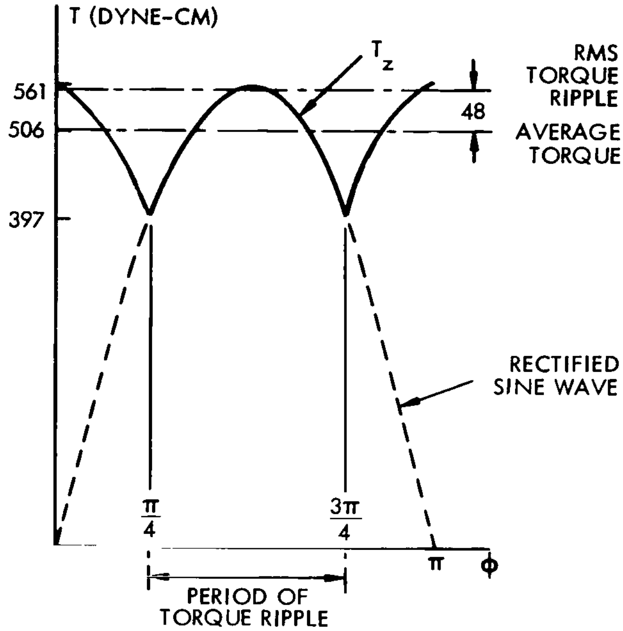


Figure 8—Torque ripple of two-channel constant level system.

(1) Only a one-axis magnetometer and single coil is required. This provides savings on fabrication and integration effort. Also, it saves the weight and power associated with a second magnetometer channel.

(2) Saturated electronics can be used for the coil drive with the coil resistance itself limiting the current. This provides the simplest and most reliable coil drive possible.

(3) Coil moments are smaller than those used in the sine drive system.

For the SSS A system the polarity sensing of the earth's field is performed in such a way that the added bonus of automatic turn-on and turn-off of the system torque development occurs. (The system must first be enabled by command.) Automatic operation is possible because of the highly elliptical SSS A orbit ($5.2r_e$ by 120 n. mi.), which results in the rotating field seen by the ASCS magnetometer increasing in amplitude at perigee. Thus, by setting the polarity sensing level of the magnetometer at 0.075 G, the system is activated for approximately 44 min during the perigee pass. The system operation in a 0.3-G (near maximum) field at perigee is illustrated in Figure 9. Obviously, this variable pulse-width (and variable torque amplitude) operation results in more torque ripple than is indicated by the previous calculation for the system (48.2%). The percent torque ripple for the operation depicted in Figure 9 is calculated below.

First it is necessary to determine the average torque, since torque ripple is referenced to this value. Figure 10 shows the waveform involved for one cycle of output torque, and average torque (T_a) is

$$T_a = \frac{\int_{0.080\pi}^{0.920\pi} 795 \sin \theta \, d\theta}{\pi}$$

$$= 490 \text{ dyne-cm} .$$

As before,

$$\text{rms torque ripple} = \left\{ \frac{\left[\int_{0.080\pi}^{0.920\pi} (795 \sin \theta - 490)^2 \, d\theta \right] + 2(0.080\pi)(490)^2}{\pi} \right\}^{1/2} ,$$

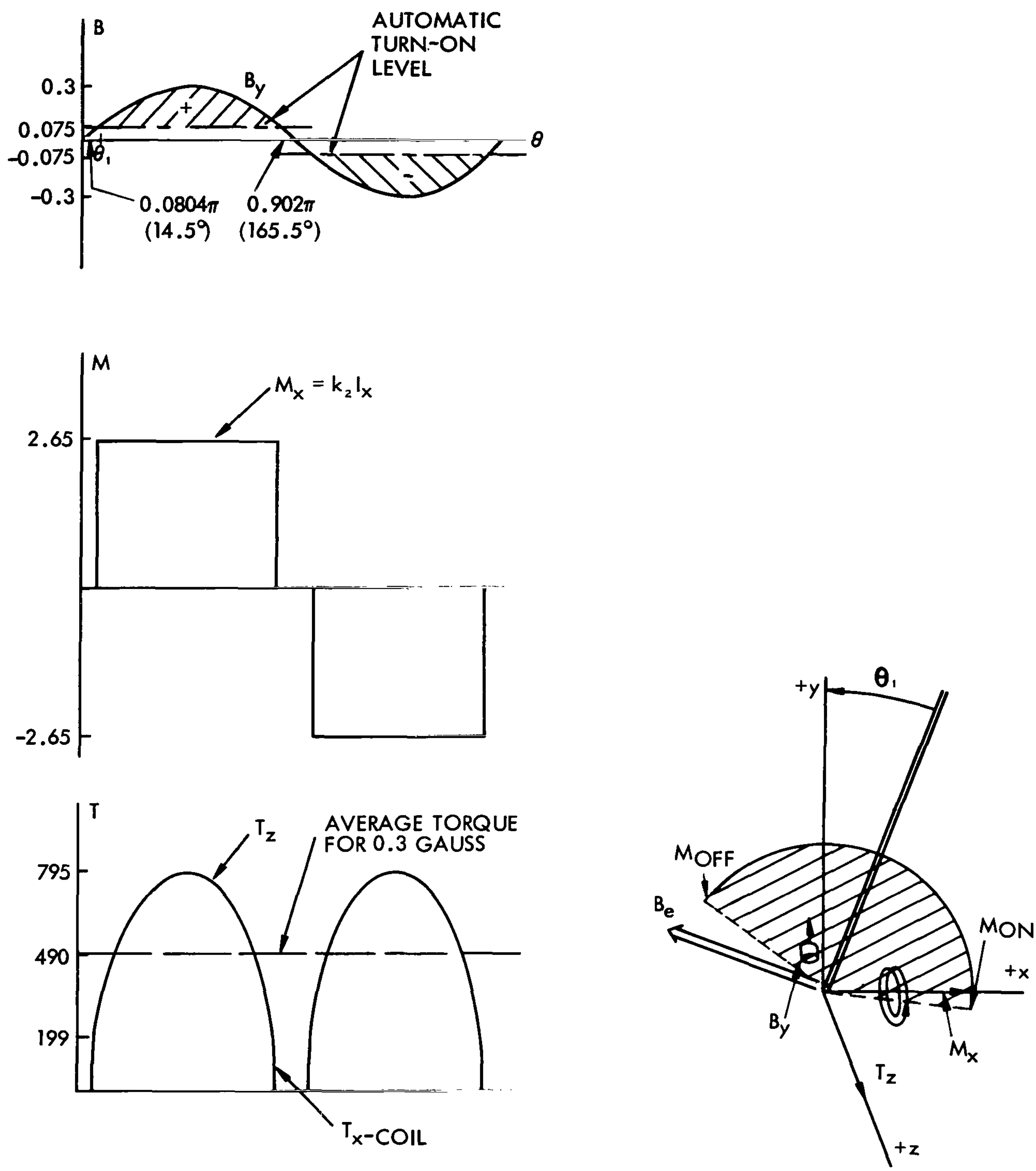


Figure 9—Automatic turn-on system in 0.3-G perigee field.

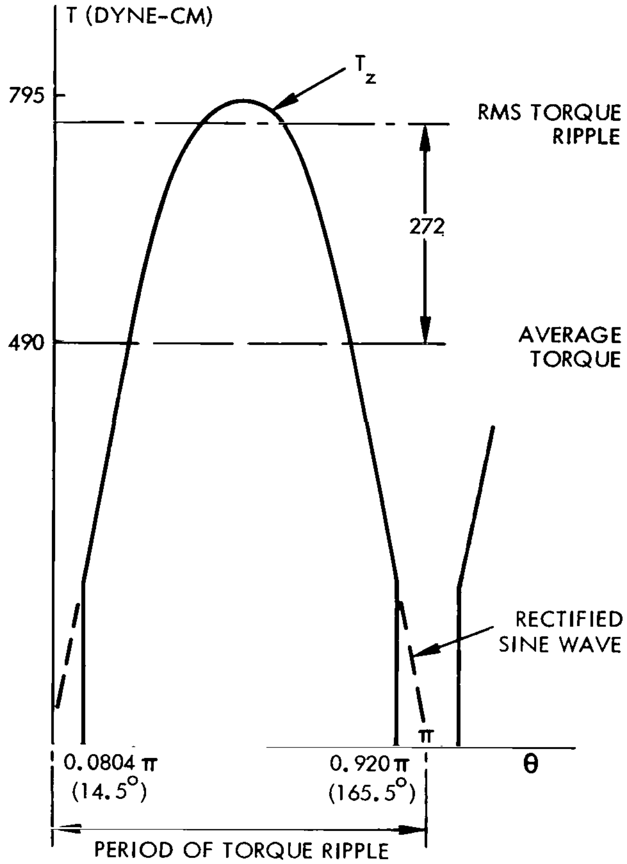


Figure 10—Torque ripple of SSS-A system in 0.3-G perigee field.

where the last terms in the numerator account for the zero torque portions of the cycle. The rms torque ripple from evaluation of the above expression is 272 dyne-cm. The percent torque ripple, therefore, is

$$\frac{272 \text{ dyne-cm}}{490 \text{ dyne-cm}} = 0.554 \text{ , or } 55.4\% .$$

THE ATTITUDE MODE

As noted in the Introduction, the design of the attitude mode is relatively straightforward. For this reason, only key features of the SSS system will be presented. Essentially, these are features used in the spin mode.

One such feature is automatic turn-on and turn-off of the system at spacecraft perigee. Here, the same technique is used and the only addition is a time-constant circuit, which keeps the attitude coil constantly energized despite the sinusoidal variations in the magnetometer signal. The same turn-on level (0.075 G) was chosen, so the on-time for the attitude coil is also approximately 44 min (for a selected perigee). The spin mode and attitude mode will not both be activated on a single perigee pass.

Another feature of the spin mode used in the attitude mode is saturated electronics for the coil drive with the coil resistance itself limiting the current. To satisfy maneuvering requirements, the SSS attitude coil was sized as follows:

$$W_c = NC \text{ (No. 29 wire unit length weight)}$$

$$= (435)(6.18 \text{ ft})(1/8{,}583 \text{ lb/ft})$$

$$= 0.313 \text{ lb} ,$$

$$R_c = (435)(6.18 \text{ ft})(1/7.45\ \Omega/\text{ft})$$

$$= 361\ \Omega ,$$

$$I_p = \frac{28 \text{ V}}{361\ \Omega}$$

$$= 0.0776 \text{ A} ,$$

$$P = (28\ \mathrm{V})(0.0776\ \mathrm{A})$$

$$= 2.17\ \mathrm{W}\,,$$

$$M_p = (435)(0.0776\ \mathrm{A})(0.269\ \mathrm{m}^2)$$

$$= 9.08\ \mathrm{A\text{-}t\text{-}m}^2\,.$$

A final feature of the SSS attitude mode is a backup mode (termed Direct Attitude) which, upon command, permits the attitude coil to be energized directly from the spacecraft main power bus.

SUBSYSTEM TESTING

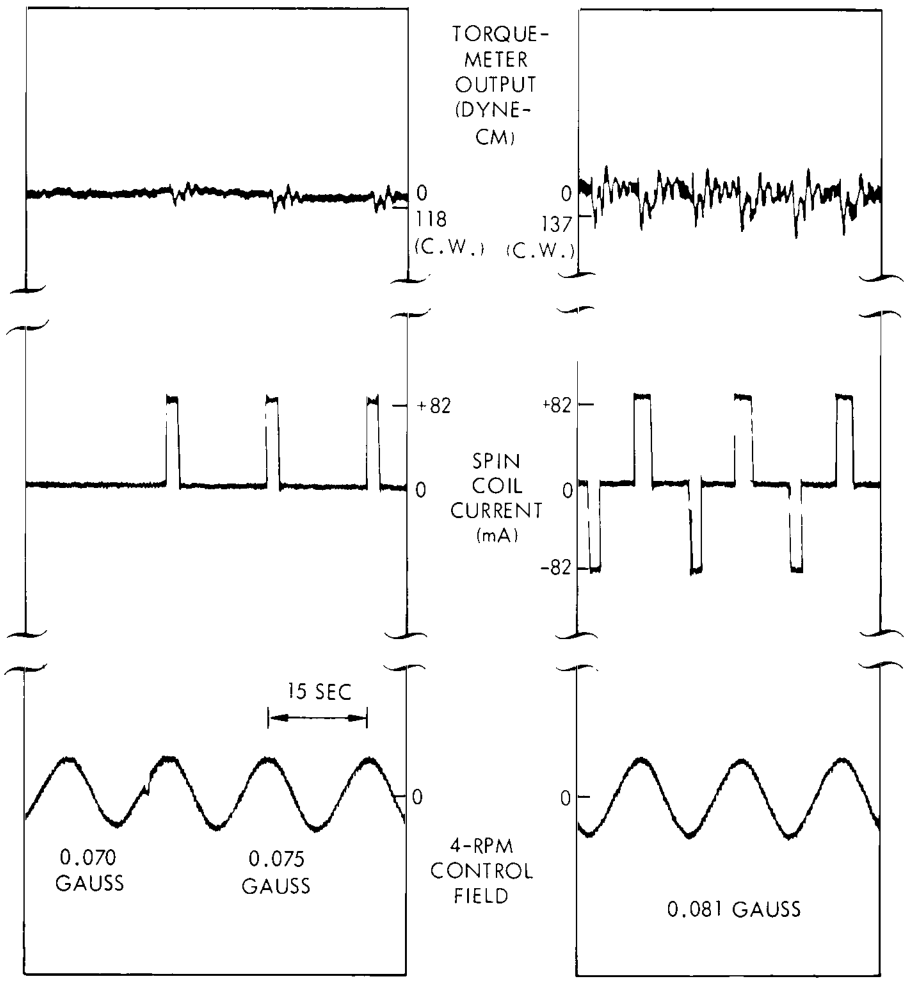
The magnetic ASCS developed for SSS (again see Figure 1), which incorporates the preferred mechanizations previously noted in this document, has undergone a thorough test program. This testing included vibration and thermal-vacuum magnetometer calibration, and subsystem tests in static and rotating* controlled magnetic fields. The most comprehensive functional test performed was on the Mark VI Torque-Meter located at the GSFC Magnetic Test Site. This unique facility has enabled a complete checkout of the subsystem in controlled field environments by providing direct recordings of the magnetically developed torques. A discussion of this testing follows.

The testing was performed with the spacecraft containing the ASCS mounted on top of the torque-meter† with the spin axis vertical. The controlled field was provided in the horizontal plane. When a rotating field was used (at the nominal SSS rate of 4 rpm), the field magnitude was changed stepwise to simulate the field buildup and decay associated with an SSS perigee pass. When attitude mode torque tests were performed, the spacecraft was tilted 10° from the vertical to provide a measurable horizontal component to the spin axis moment (since the torque-meter responds only to vertical torques).

The spin mode was tested for complete perigee pass operation from automatic turn-on at 0.075 G to the peak field value of 0.274 G and then to automatic turn-off. Figures 11 and 12 indicate the key features of this test data where the subsystem is operating as depicted in Figure 9. Figure 11a shows the automatic initiation of spin coil commutation as a result of the controlled field's being increased from 0.070 to 0.075 G. The control field data is that seen by the ASCS magnetometer. The value indicated for the torque-meter output is the peak value of the magnetically developed torque pulses. Figure 11b shows the subsystem operation just after turn-on. It is not disturbing that slight asymmetries in the subsystem hardware caused only half-frequency coil commutation at the time of system turn-on in Figure 11a, since little angular momentum was involved at that time compared to that of the total perigee pass. Figure 12 shows the system operation at the peak of the simulated perigee pass. Note that the spin coil is energized over 80% of the time at this high field level. Figure 13 illustrates data similar to those shown on the previous two figures and is provided to show the recorded torque pulses in greater detail.

*For static testing of nominally spinning spacecraft, the rotating field gives correct relative field rotation.

†As an oversimplification, the torque-meter can be thought of as a very stiff torsional spring device with adjustable damping, which deflects a few seconds of arc for full scale vertical torques.



(a) Automatic turn-on

(b) Low field operation

Figure 11—Spin mode torque-meter testing at low field levels.

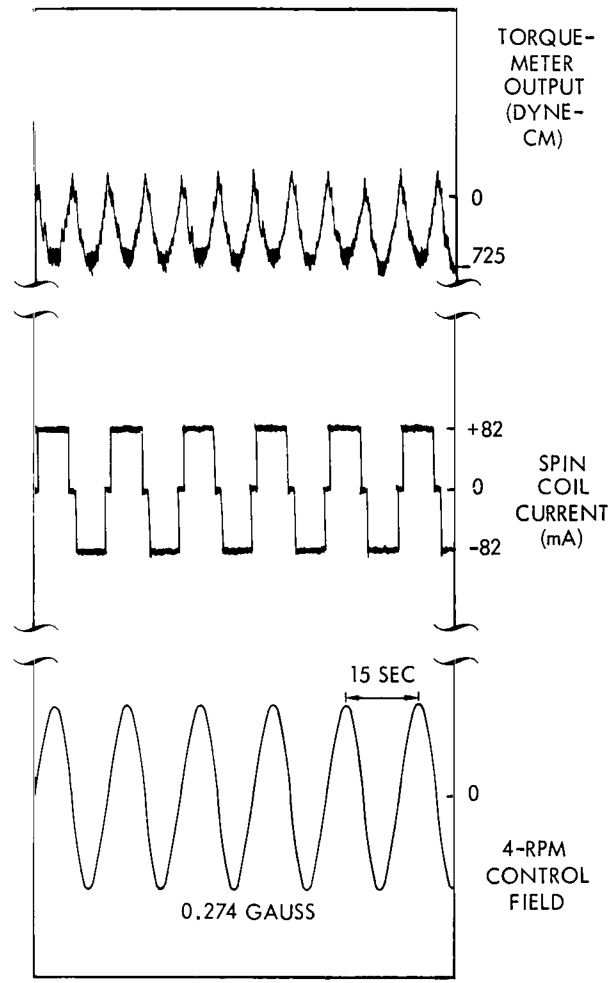


Figure 12—Spin mode torque-meter testing at high field levels.

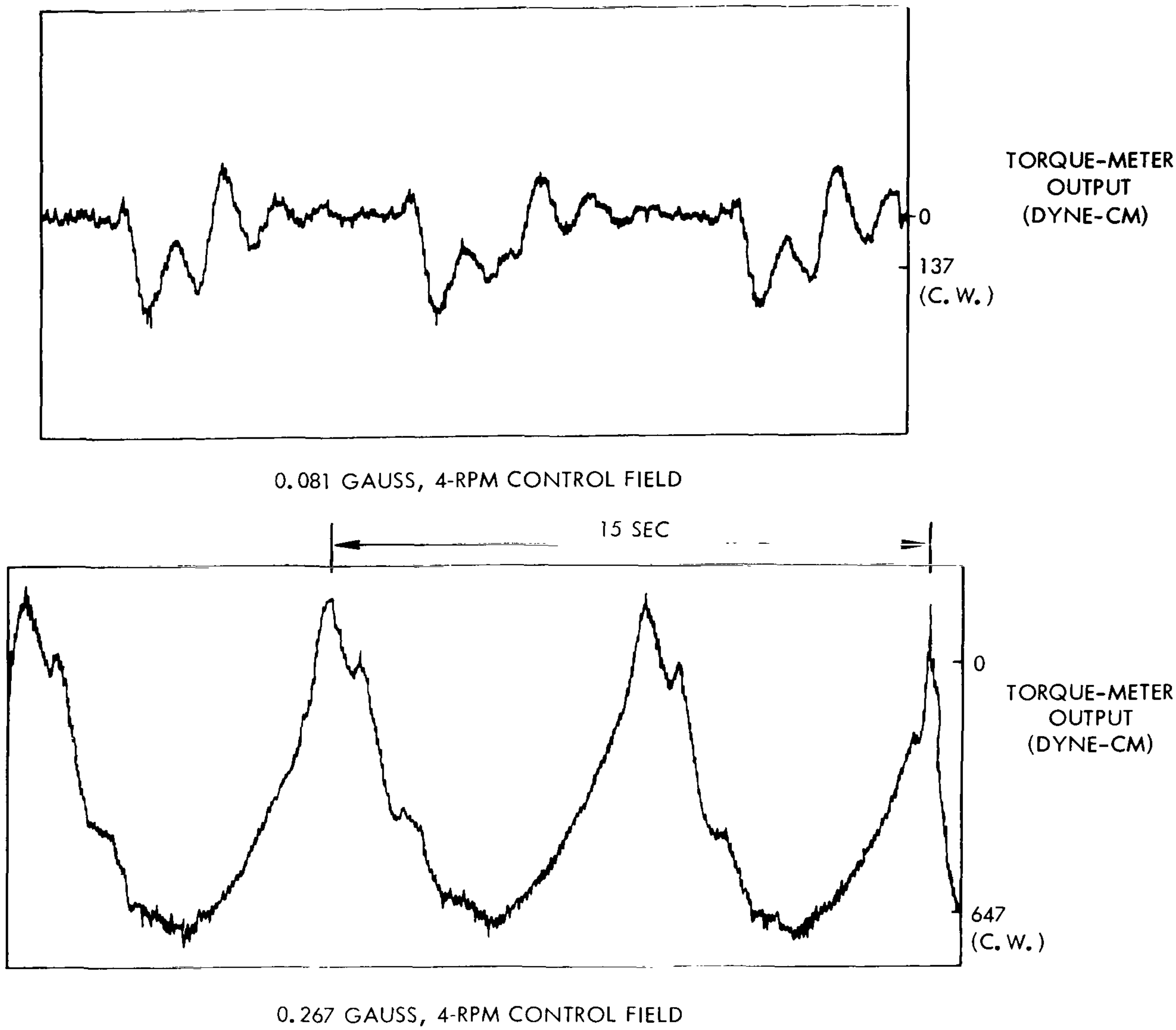
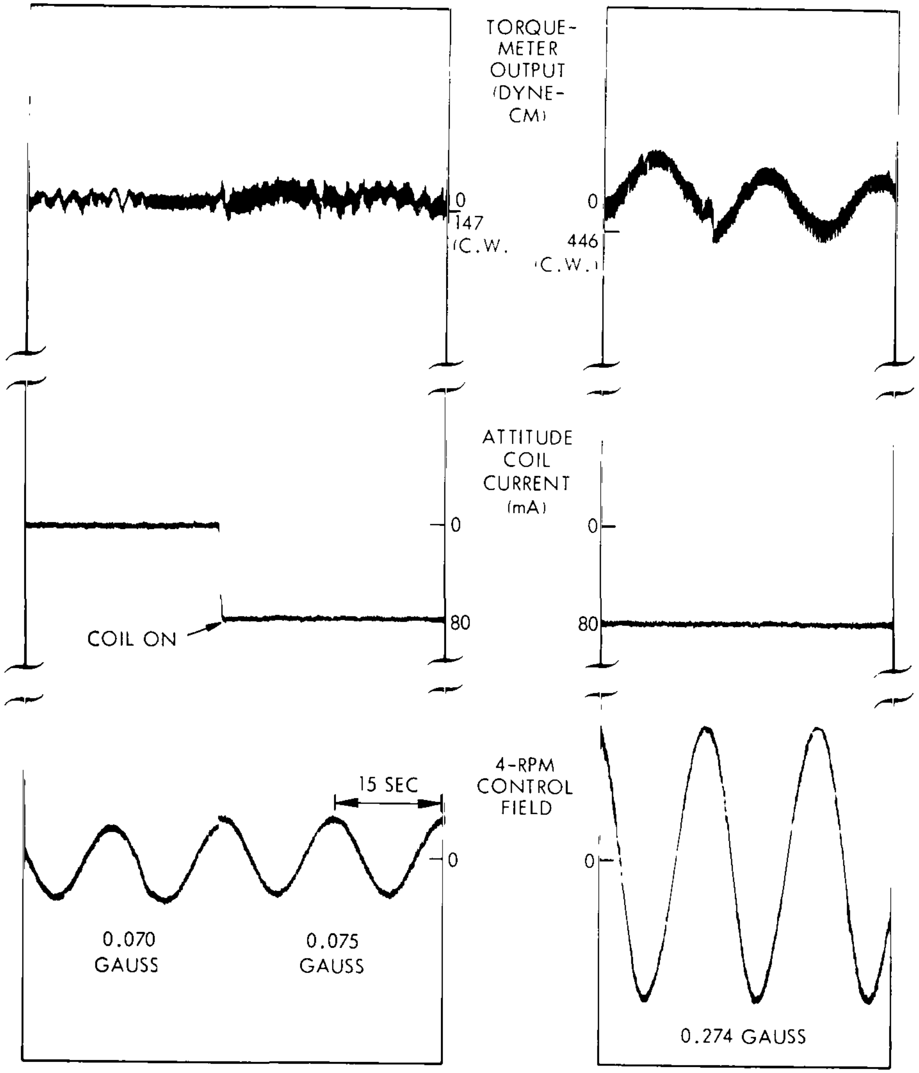


Figure 13—Enlarged spin mode torque-meter pulses at low and high field levels.

The attitude mode was also tested for automatic operation during a simulated perigee pass. This was made possible by the selection of the tilt direction of the spacecraft such that the ASCS magnetometer remained horizontal. Thus, the rotating field provided a representative measurement of developed perigee torque twice per field rotation (i.e., the peaks of the torque-meter output). This data is illustrated in Figure 14. Figure 14a shows the automatic turn-on of the attitude coil. As mentioned earlier, this coil is kept on by a time constant circuit so that desired precession maneuvers can be achieved. Figure 14b shows the system operation at the peak of the simulated perigee pass. To determine developed perigee torque values from the torque-meter values indicated in Figure 14, a multiplying factor of 5.61 must be applied to account for the 10° spacecraft tilt. For example, in Figure 14b about 2600 dyne-cm of precession torque is actually being developed.



(a) Automatic turn-on

(b) High field operation

Figure 14—Attitude mode torque-meter testing with rotating field.

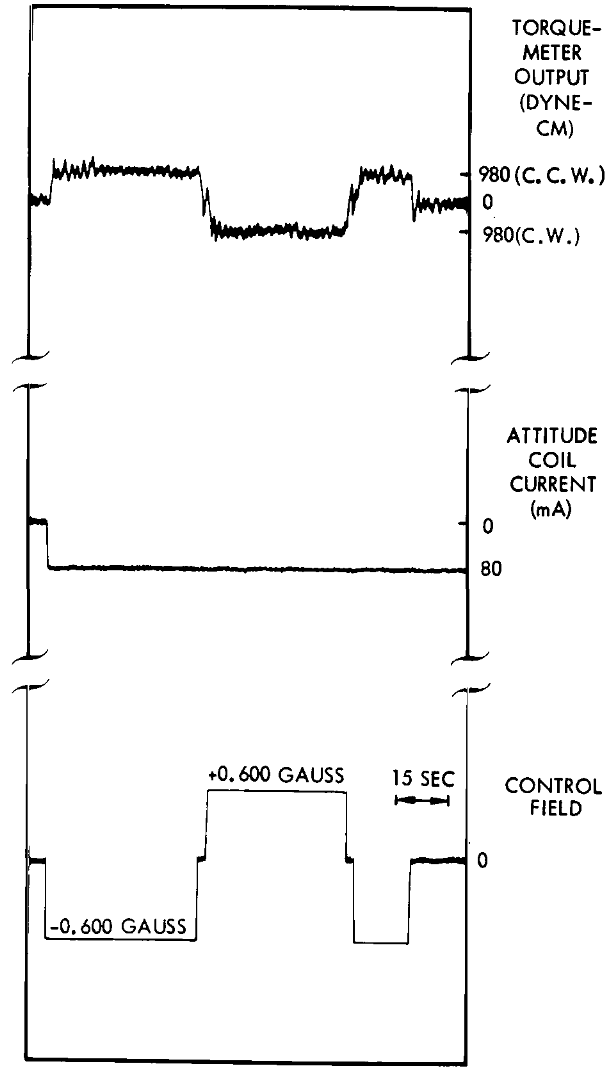


Figure 15—Attitude mode torque-meter testing with static fields.

The attitude mode torque was also measured with static control fields. Again the tilted spacecraft technique was used. Fields of +0.600 and −0.600 G were applied perpendicular to the horizontal component of the spin axis moment. The results are shown in Figure 15. When the indicated torquemeter output value is scaled for the field levels involved, the static torque measurement is in good agreement with the peak torque measurements shown in Figure 14.

CONCLUSION

A comprehensive evaluation of alternative magnetic spin control mechanizations has led to the selection of a system design that offers the advantage of simplicity without loss of performance. The result is a magnetic subsystem for spacecraft spin axis orientation and spin rate control which can meet unusually stringent weight and power requirements. Additionally, the design is adaptable to automatic turn-on for missions involving elliptical orbits (e.g., SSS A).

RECOMMENDATIONS

Two areas that warrant future investigation emerge from this system design effort.

The first is the desirability of a simple polarity-sensing magnetometer suitable for detection of the earth's field. Such a device would be an excellent complement to the inherent simplicity of the constant-level spin mode mechanization. Present versions of the system require use of the typical fluxgate magnetometer approach, whereas only polarity information is actually required.

A second area which should be studied is the applicability of the ASCS design to the performance of earth resources missions. In this instance, a spacecraft would be placed in a circular, equatorial orbit, and alignment of the spin axis with the orbital plane would be achieved. Following this, earth pointing would be maintained by magnetic precession of the spin axis at a rate equal to the spacecraft's orbital angular velocity. Success of this concept would depend upon the relative phasing of the orbital pole and the local magnetic field vector, which should be the most favorable in an equatorial orbit.

ACKNOWLEDGMENT

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