THE IUE TWO-GYRO CONTROL SYSTEM AND SCIENCE OPERATIONS STATUS

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Introduction

The IUE recovery started on August 19, 1985, at about 2:50 PM when the command was sent from the IUE Control Center at Goddard to place the onboard computer (OBC) and its new two-gyro plus Fine Sun Sensor attitude control software in actual control of the satellite. Within minutes spacecraft (S/C) telemetry told the story - the satellite was quickly taken from its controlled yaw spin ("sunbath mode") to a three-axis stabilized, stationary pointing. Those present in the Control Center who were not watching at just the right moment missed the smooth transition. Further steps to exercise the control system yielded similar positive results. While a few significant problems were discovered and solved, by and large each OBC function performed as well as or better than expected from ground simulations. IUE is currently operating at a level of accuracy which is nearly identical to that of the former three-gyro system. The only lost observing capability is the ability to observe at beta angles below 15° where the sun is outside the Fine Sun Sensor field of view.

Following the gyro failure on August 17, the IUE Project decided that a serious effort to restart Gyro 6 would not be attempted unless the two-gyro system could not control the S/C. The potential for damaging the remaining gyros (#4 and #5) was deemed too high and the prospects for restarting Gyro 6 too low. The immediate success of the two-gyro system reinforced this decision.

Within two weeks the flight verification of the new control system had progressed to the point where most OBC functions and observing techniques had been tested and some GO programs could be scheduled. Beginning on August 30, four to eight hours per day were devoted to GO observations. By the end of earth shadow season on September 14, 75 to 80 percent of the S/C time was devoted to science programs. During this period several high-priority programs were carried out as previously scheduled, including time-critical programs, collaborative programs, and the Comet Giacobini-Zinner encounter on September 10-12. Normal, 24-hour per day science operations resumed on September 30, 1985.

In this article I will briefly describe the three-gyro and two-gyro plus Fine Sun Sensor control systems and compare their performance and capabilities. I will also discuss some factors affecting observing overhead so that observers may plan to use their observing time more efficiently.

Two-gyro/FSS system description

In the broadest sense the IUE three-gyro and two-gyro/FSS attitude control systems have many similarities. The OBC algorithm monitors the change in the S/C state vector (position and velocity) and computes what corrections are required to maintain the desired attitude (either holding or slewing). The computed pointing corrections are made by controlling the rotation rate of the three orthogonal reaction wheels (pitch, yaw, and roll). The hydrazine gas jets are not used for attitude control except in certain emergency situations.

The three-gyro system maintained attitude by deriving the position change and the rate of change in the pitch, yaw, and roll directions from the three or more functioning gyros. (The gyro package is located outside the S/C body directly behind the telescope tube - see Figure 1.) The three-gyro system had two basic control modes: the OBC either used gyro plus FES star tracking data to keep the telescope pointing fixed in pitch and yaw (the plane of the sky), or it used gyro data only for holding attitude and manuvering.

The two-gyro/FSS system derives the S/C change in position and the rate of change from the Fine Sun Sensor in addition to the two functioning gyros and the FES. The Fine Sun Sensor (FSS) measures the orientation of the sun with respect to the S/C. The two-gyro/FSS system has five distinctly different control modes which use various combinations of FSS, gyro, and FES star tracking data to hold attitude or maneuver. The OBC uses FSS data primarily to control the roll orientation. In this configuration the satellite will follow the apparent solar motion (i.e. the annual motion along the ecliptic) and slowly rotate about the telescope axis. This can amount to a roll motion of up to 2.5 arcminutes per hour.

The Fine Sun Sensor measures two orientation angles of the sun with respect to the S/C. One is the deviation of the S/C from optimum roll orientation for maximum solar array illumination. The second is the angle between the telescope optical axis and the anti-solar direction, more commonly known to IUE obervers as the beta angle. The FSS is an analog device which produces a digitized (binary) measurement through a system of reticle screens. The sensor has two heads, each with a 64° field of view, mounted such that one head covers beta angles 13° to 77°, and the other head beta angles 73° to 137°. The observing limits of 15° < beta < 135° allows a 2° safety margin. Both heads cover ±32° from optimum roll. Each sensor head has two orthogonal pairs of coarse and fine reticles for measuring beta and roll angles (see Figure 2). The fine reticle has a 15 arcsecond resolution, or over 1000 times coarser than that of the gyros.

Two-gyro/FSS system maneuvering

There is a significant difference in the way IUE now maneuvers from target-to-target. The three-gyro system performed maneuvers under gyro control as a sequence of single-axis (great circle) slews about the principal S/C axes. The two-gyro/FSS system maneuvers are performed with both pitch (beta) and roll control on the FSS, keeping the S/C at optimum roll at all times. The maneuvers are executed by slewing in pitch to change the beta angle or by slewing at a constant beta angle. The latter is a small circle slew except in the special case of beta = 90°. The ability to slew at fixed beta is very interesting because it shortens many maneuvers by not "yawing" at beta = 90°. The "yaw", or sunline, maneuver is in fact a combination of yaw and roll motion to maintain a constant beta. The sunline slew distance will be shorter than the yaw slew length

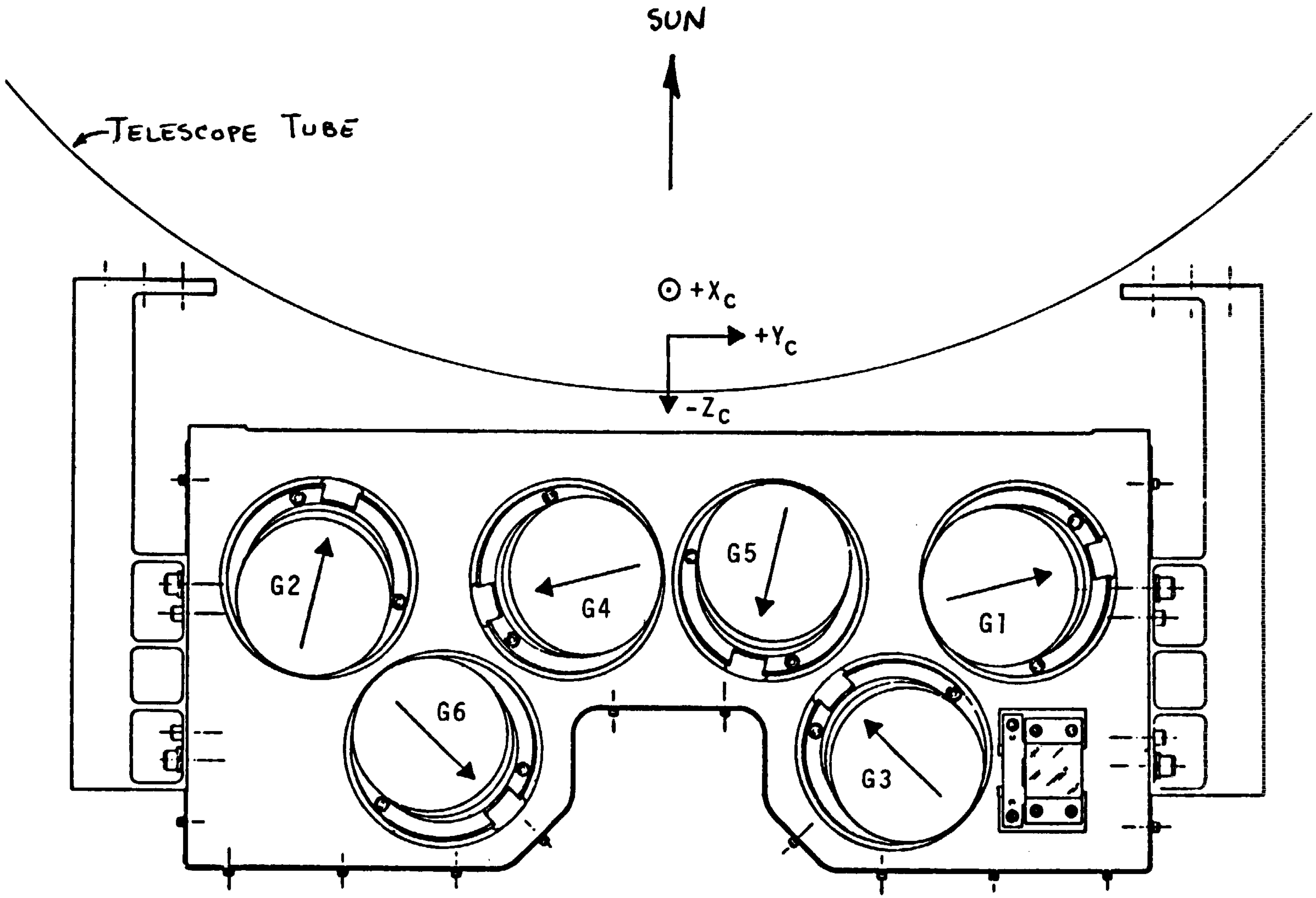
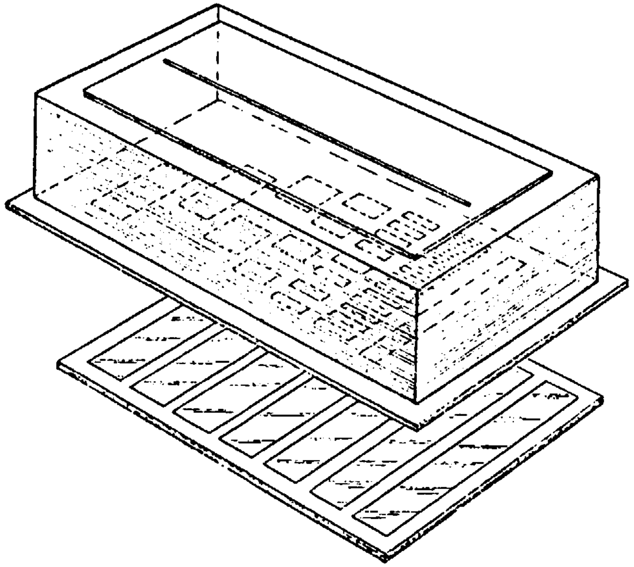
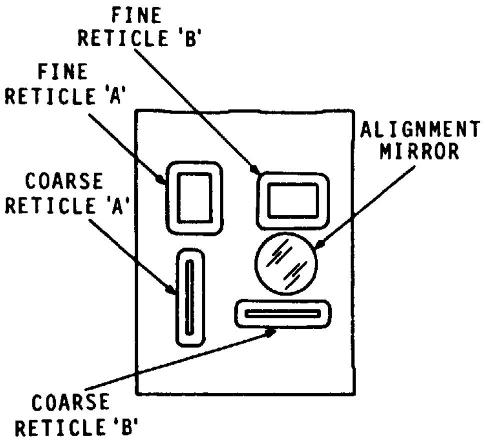


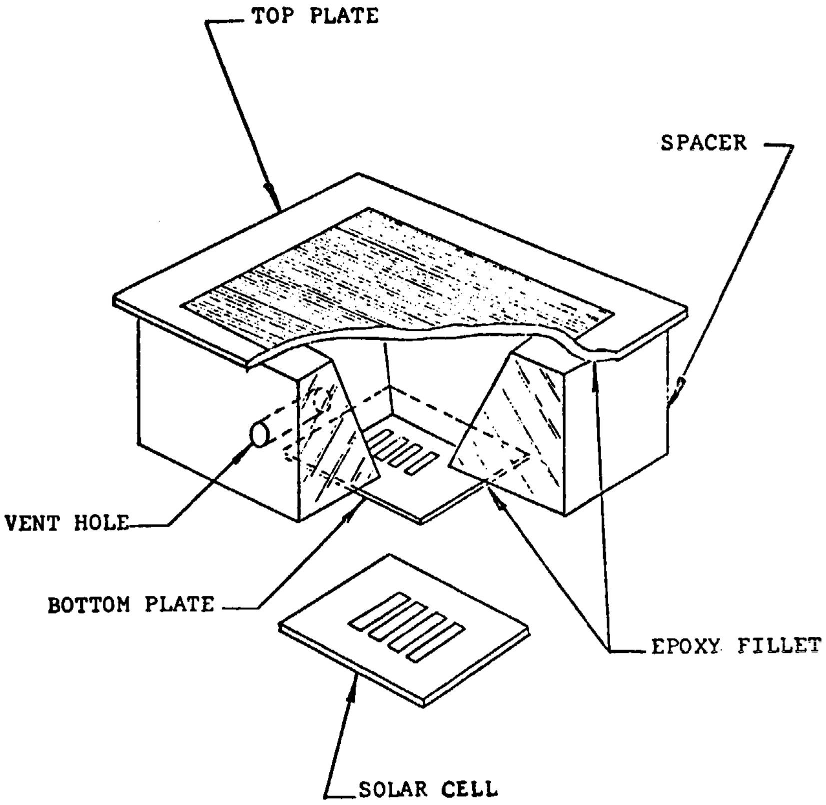
Figure 1 - IUE Gyro input axes orientation



2a. Coarse reticle



2c. FSS head with roll (A) and beta (B) reticles



2b. Fine reticle

Figure 2 - IUE Fine Sun Sensor (FSS)

at beta = 90° by a factor of sin(beta). Thus, the slewing distance for many two-gyro/FSS system maneuvers may be shorter by 10, 20, perhaps even 50 percent, compared to their three-gyro system counterparts. Slewing times are generally about the same, but some slews may be shorter in time by 10 to 25 percent.

Maneuver accuracy is somewhat improved over the three-gyro system. Maneuver errors are usually 3 to 5 arcminutes. Occasionally maneuvers having large changes in beta will have errors greater than 6 arcminutes.

Target acquisition

The two-gyro/FSS system telescope pointing stability is ±0.25 arcseconds in pitch and yaw and ±10.4 arcseconds in roll for the normal acquisition control mode. The pitch and yaw figures are the same as for the three-gyro system, while the FSS roll control is poorer (±2 arcseconds for three-gyro). Small roll motions have virtually no effect on the positioning of stars within the FES field of view.

The short fixed-rate maneuver accuracy, such as slews from the FES reference point to one of the spectrograph apertures, is within the measurement limitations of the FES (0.26 arcsecond resolution). This was also true for the three-gyro system. However, the aperture centering accuracy when setting up a given exposure will depend on the precision of the roll axis control at the moment the slew to the aperture is executed. Additional time (5 to 20 minutes) may be needed to achieve the 0.26 arcsecond accuracy in pitch and yaw of which the system is capable.

Trailed exposure techniques are as accurate as with the old system. In fact, we have recently obtained a well-exposed low dispersion spectrum of Vega. This was a very fast trailed exposure with an effective point-source exposure time of 0.045 seconds. The minimum commandable point-source exposure time is 0.4096 seconds. The trailed spectrum was obtained by slewing Vega across the large aperture at a rate of 120 arcseconds/second, starting from 1.5° away. This was the first successful exposure at the maximum trail rate.

There have been no difficulties tracking and observing moving targets. Comet Giacobini-Zinner, Comet Halley, several planets, and Jovian satellites have been successfully observed with the two-gyro/FSS system. Drift rates of up to 0.1°/hour have been used. The ability of IUE to observe another Comet IRAS-Araki-Alcock (>1°/hour) is unknown.

Blind offset acquisitions have also been successfully performed. We now expect offset slew errors to be less than 2 arcseconds for maneuvers less than 15 arcminutes in length. Offset stars do not need to be within the FES field of view. Blind offsets are discussed in more detail in an accompanying article in this newsletter.

Non-optimum roll exposures are not being performed at this time. Such exposures might be considered if accompanied by extraordinary scientific justification. Prior approval of the Project would be required.

On-board star tracking (offset guiding)

There are now two OBC tracking modes to maintain a fixed telescope pointing by using a guide star. The three-gyro system had only one such tracking mode. Ground simulations of the two-gyro system indicated that the telescope pointing would "jump" 2 to 8 arcseconds in an unpredictable direction when the OBC was commanded to a tracking mode. Much to everyone's relief, S/C behavior of this type has not been seen.

1. The two-gyro tracking mode most like the three-gyro tracking still uses FES and gyro data to control pitch and yaw, but now the roll axis is controled by FSS data. The tracking accuracy is only slightly degraded.

Pitch and yaw axis standard deviations:

±0.24 arcseconds (2-gyro) vs. ±0.09 arcseconds (3-gyro)

Roll axis standard deviation:

±10.4 arcseconds (2-gyro) vs. ±0.37 arcseconds (3-gyro)

Analysis of high dispersion emission and absorption spectra reveal that the slight increase in tracking noise does not effect the point spread function (Grady 1985, Scott 1985 - reports to the Three-Agencies, October 1985). This mode can track stars as faint as $m_V=13.5$, as with the three-gyro system.

With the roll axis controlled by the FSS, the S/C rolls very slowly to follow the apparent solar motion. This induces a roll drift about the guide star position. The motion of the target in the aperture could be large enough to effect the spectral image quality, depending on the distance of the guide star from the target. The worst case is that of a guide star 7 arcminutes from the target where the solar motion in roll is 2.5 arcminutes/hour (the maximum rate). In this situation the target will move about 2 arcseconds during a 7 hour exposure.

2. The other OBC tracking mode was created for the two-gyro system. It controls pitch and yaw with FES star tracking data only, leaving the gyro data free to be used to control the roll axis. This mode has the advantage that the S/C is held inertially. At the present, however, it can only guide on stars brighter than $m_V=11.8$ (i.e. it functions only in the FES fast track mode). The pointing accuracy is poorer than the other mode (pitch and yaw noise is about ±0.8 arcseconds). This mode is also used when a roll maneuver must be performed.

Observing overhead and pointing stability problems

Compared with the three-gyro system, the two-gyro system operations occasionally requires additional time to maneuver to the next target or set up the next exposure, even though the slew may be faster. The overhead typically amounts to 10 to 30 minutes per maneuver or exposure when certain situations arise, which is not very often. There are several sources of this overhead.

There are problems associated with the calculation of maneuvers in the ground command computer which often require additional maneuver calculations and sometimes an additional wheel unload before the S/C can be slewed to another target. The need for an unload before maneuvering may legitimately arise because of the new S/C maneuvering modes. In other situations the maneuver calculation constraint is the result of programming "bugs" in the maneuver processor. These problems are being given urgent attention by the ground system programmers.

Allowing 5 minutes per unload and maneuver calculation, problems with maneuver and wheel speed constraints may require an additional 10 to 20 minutes per target. This is most frequently a problem after observing at one location for several hours or more.

Pre- and post-maneuver S/C configuration may require up to an additional 5 minutes per target.

The most significant operational problem has to do with the stability of the S/C roll axis. At low beta angles (beta < 40° - 45°, but occasionally at 45° < beta < 55°) the roll axis will oscillate ±60 to 120 arcseconds about optimum roll with a period of 20 to 90 seconds. This motion couples into pitch and yaw, introducing a ±3 to 6 arcsecond oscillation in these axes. This motion makes it impossible to perform normal target acquisition or exposure activities. There are several techniques which have been used to damp the roll oscillations. Some are usually more successful than others. The one solution which always works is also the most time consuming: slew to a higher beta angle. Severe roll oscillation problems have cost as much as an hour of observing time. These have all been at beta angles less than 40°. It is more typical that 5 to 15 minutes are needed to damp the oscillations.

The occurance of roll oscillations have been associated with wheel unloads at the target or the maneuver to the target, especially when the maneuver ends with a sunline slew (which is a combination of yaw and roll motion). The precise cause of the oscillations and the reasons the OBC roll control algorithm is occasionally unable to stabilize the roll axis are unknown. The fact that the oscillations only occur at low beta angles suggests that the orientation of the FSS hardware versus the S/C control axes may be responsible. Goddard attitude control system design engineers are working on the problem. S/C engineering tests are performed occasionally to collect data for these studies.

Spacecraft solar array power

One final piece of good news is that the power requirements of the satellite appear to be slightly lower than would have been the case had Gyro 3 not failed. Now that Gyro 3 is turned off, the beta angle range without power constraints is no worse, and possibly larger, than that described by Sonneborn (1985, NASA IUE Newsletter No. 27, p. 20). The major uncertainty is the intermittant, but larger, power load needed for roll axis control. Several months of solar array data and two-gyro/FSS system operations experience are needed before revised power predictions can be generated.