IUE: ONE YEAR WITH ONLY TWO GYROSCOPES

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ABSTRACT

The International Ultraviolet Explorer satellite lost gyroscope #3 on August 17, 1985. Only two from the original set of six gyroscopes were left and three axis stabilization on gyroscopes alone was no longer possible.
The On-Board-Computer memory of the S/C was reprogrammed with a new control system that uses a sun tracker (Fine Sun Sensor) to overcome the absence of the failed gyroscope. 3 axes control was retrieved. Operational considerations on the 2 GYRO - FSS control system are presented here.

Keywords: Three axes attitude control, Roll control in two Gyro System, OBC, Satellite manoeuvres.

1. INTRODUCTION

IUE is an elliptical geosyncronous orbit (26.5 deg. inclination), 3 axes stabilized S/C. Accuracy and stability requirements are of 1 arc. second in pitch and yaw per hour; 1 arc. minute in roll and 8 arc. minutes slew accuracy for any slew angle.

The satellite carries a 45 cm clear aperture Ritchey-Chretien telescope with an useful circular field-of-view of 16 arc. minutes in diameter.

4 UV cameras (total range 1150A to 3200A), 2 FES cameras and various types of sensors allow IUE to study celestial objects and acquire their UV spectra.

1.2 S/C control axes

IUE control axes are defined as:

X= Roll axis
Y= Pitch axis
Z= Yaw axis

Sun is required to be always in the X, +Z hemiplane at zero Roll.

Beta angle is measured from -X axis to Sunline, in the plane defined by Sun and X axis.

Roll is defined as the angle from +Yaw axis to Sunline projection over YZ plane.

$$\text{Tan (ROLL)} = Y/Z \qquad (1)$$

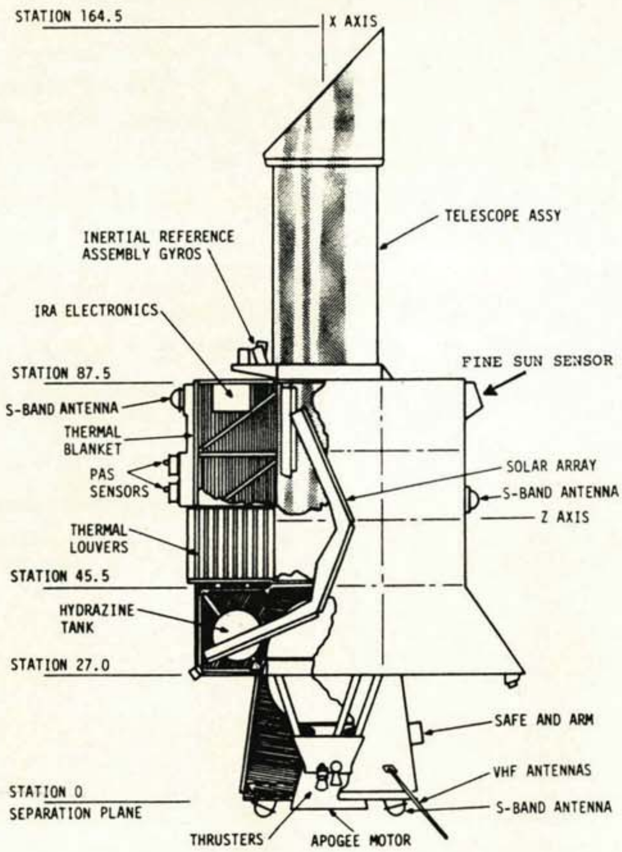

Figure 1. IUE Control axes & Features

Proceedings of the Second International Symposium on Spacecraft Flight Dynamics, Darmstadt, FR Germany, 20–23 October 1986 (ESA SP-255, Dec. 1986)

1.3 The FSS and FES sensors

The Fine-Sun-Sensor is a redundant system, 2 sensors, 2 heads each, used to measure the Beta angle and hold S/C Roll attitude. The field of view of each sensor is +/- 32 degrees in two orthogonal axes, with a total coverage from Beta=13 to Beta=137 degrees.

The transition accuracy is better than 1 min. of arc and average resolution of data output is 15 arc seconds. Processed data for the two axes are: Nb=Roll counts, and Na=Beta angle.

The Fine-Error-Sensor is also redundant. It is composed by two orthogonal cameras sensible to optical light and capable of multimode operation. Only one FES is on at a time on IUE and performs the dual task of Field Camera (target recognition and acquisition) and two axes Error Sensor (in Pitch and Yaw) for fine pointing and guidance.

The FES field of view is the same as the telescope, circular, 16 arc minutes in diameter. With the S/C axes Pitch and Yaw projected into it, a 28.31 degrees rotation transforms X and Y position deltas, that are the normal FES output, into Pitch and Yaw movement. The measurement accuracy is of .27 seconds of arc.

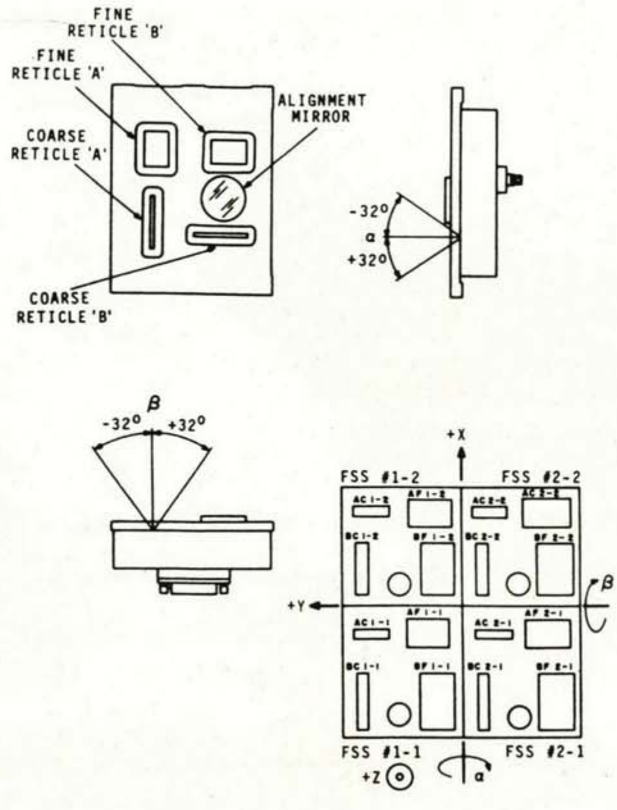

Figure 2. Fine Sun Sensor System

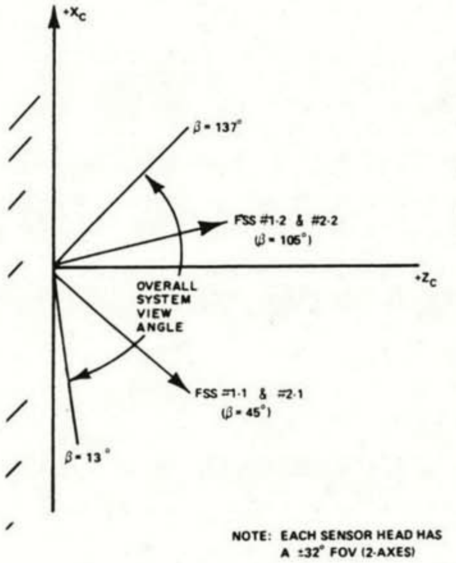

Figure 3. FSS Head Location

1.4 The Gyroscopes

IUE has two pulse rebalanced, rate integrating gyroscopes, with their input axes skewed mutually and relative to the S/C control axes.

Direction cosines from 2 gyroscopes plus a constraint equation that assumes sun held at zero roll in the XZ plane solve for 3 body rates:

Gyro 1 direction cosines: L1X, L1Y, L1Z.
Gyro 2 direction cosines: L2X, L2Y, L2Z
Roll rate=WX, Pitch rate=WY, Yaw rate=WZ
Gyro 1 sensed rate= W1
Gyro 2 sensed rate= W2

$$W1 = L1X*WX + L1Y*WY + L1Z*WZ \quad (2)$$
$$W2 = L2X*WX + L2Y*WY + L2Z*WZ \quad (3)$$
$$0 = SIN(BETA)*WX + COS(BETA)*WZ \quad (4)$$

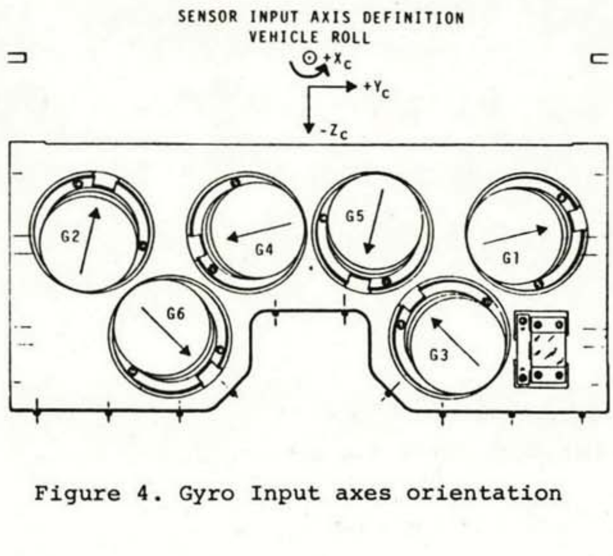

Figure 4. Gyro Input axes orientation

2. THE SLEW/HOLD MODES

Worker 0, an application program residing in OBC memory, is used to control the IUE Hold/Slew modes of operation.

Inputs to Worker 0 during manoeuvres are gyroscopes digital output and two axis (pitch + roll) information coming from the FSS.

During Hold modes, the OBC (W0) receives information from the FES (pitch + yaw); FSS information (Beta + roll) and finally the sensed rates from the gyroscopes.

2.2 The Mode Bits

Mode Bits are software flags that indicate to the OBC the information to use when in different control modes. They also define the type of control. Ususally mode bits are commanded from ground but a MODE INTERLOCK LOGIC allows the OBC to change control modes by itself if an erroneous situation is detected.

Some Mode bits are defined below:

MA- FES star presence indicator- 0=NO
1=YES

MB-control mode.
0=Kalman filter
1=Raw Gyro
2=Raw FSS (Roll axis only)
3=Raw FSS+Gyro (Pitch axis only)
This bit specifies if control mode is to be filtered or not. The OBC residing KALMAN FILTER is used at times to smooth data employed for control.

MC-Kalman filter mode, only active if MB=0.
1= Gyro only
2= FES only
3= Gyro + FES

MD- Slew flag- 1= Slew
0= No slew

ML- FES processor- 0 or 1-processor off
2 or 3-processor on
if star presence.

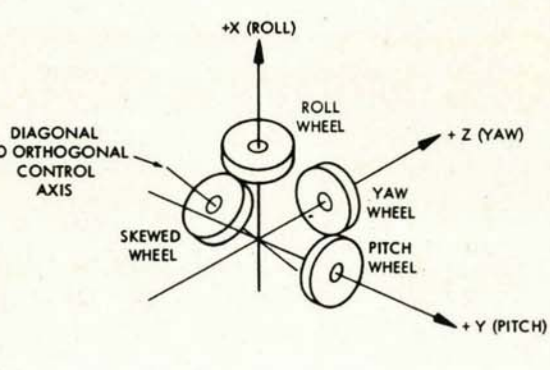

Figure 5. IUE wheel configuration

2.3 The slew concept

With 3 gyroscopes, manoeuvering from one target to another was accomplished via Pitch, Yaw and Roll slews - called legs -, one axis at a time, using the torque produced by electrically accelerating the inertial wheels of the S/C. IUE has three wheels each one perpendicular to one of the satellite axes. (Plus a fourth wheel, in a diagonal to orthogonal arrangement, powered down at present and intended as backup in case of failure of any one of the 3 operational wheels).

All manoeuvres were composed by 3 legs and the Manoeuvre Generator (a ground computer task) produced up to 24 combinations to go from one star to another. The best possible one was selected (usually the shortest in time), uplinked and stored into the OBC. Upon reception, the OBC looked into the contens (legs sequence and magnitude) of the manoeuvre and started it via Manoeuvre Processor, a program residing in memory.

A 3*3 matrix gave gyro digital information of the sensed movement to the OBC which in turn, negating the difference between the desired slew magnitude and the sensed movement, was able to control start and completion of each individual slew along great circles of the celestial sphere.

With only 2 gyroscopes this is no longer possible and FSS data assumes an important role in manoeuvres. In this system loss of FSS sun presence means loss of attitude control.

Control of each axis is assigned via MODE BITS:
Pitch axis on gyroscopes and raw FSS.
MB(Pitch)=3
Yaw axis on raw gyroscopes only.
MB(Yaw)=1
Roll axis is controlled on raw FSS.
MB(Roll)=2

The new slew concept: BETA change (Pitch slew) points satellite X axis (Roll) on target star cone about the sun. Then a SUNLINE slew moves IUE around cone to the target.

SUNLINE slews are a combination of a basic YAW movement plus small ROLL corrections to maintain BETA fixed. SUNLINES take place along small circles of the celestial sphere. There no longer exist pure yaw slews except when the sunline takes place at Beta=90 degrees, where roll corrections are not needed.

$$\text{SUNLINE} = \text{YAW} / \sin(\text{BETA}) \qquad (5)$$

The amount of Roll correction done is:

$$\text{ROLL} = (-1/\tan(\text{BETA})) * \text{YAW} \qquad (6)$$

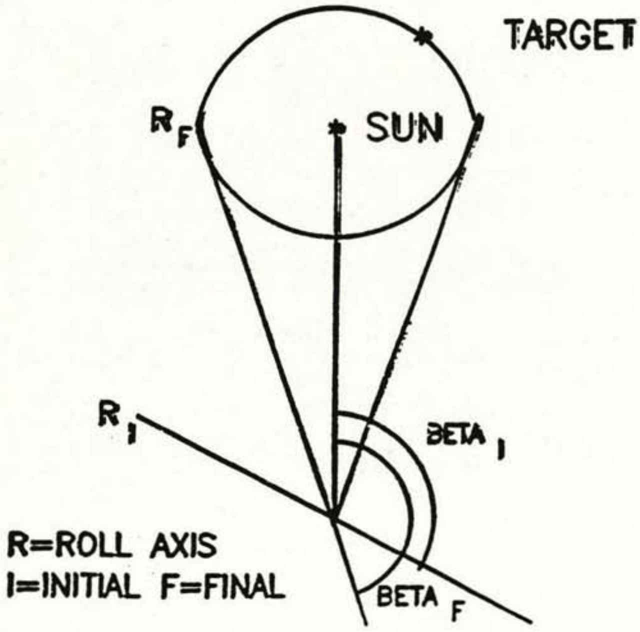

Figure 6. IUE NEW SLEW CONCEPT

Gyroscopes arranged in a 2*3 cosine matrix sense the basic movements in Pitch and Yaw, (there are no longer Roll slew legs). During Pitch slews the FSS measures the Beta change and controls that the sun is always in the X,+Z hemiplane with zero Roll deviation. While in Yaw (SUNLINE) slews, the FSS holds Roll deviation at zero for the desired Beta angle and Pitch fixed at the same Beta.

The Manoeuvre Generator calculates now 3 only possible combinations to move IUE in the sky.

a) Pitch slew + Sunline slew (2 legs)
b) Sunline slew + Pitch slew (2 legs)
c) Pitch + Sunline at Beta 90 + Pitch (only remaining 3 legs manoeuvre).

Worker 0 has been rewriten in extenso, with good results, to allow this type of manoeuvering. Long manoeuvres, that may go up to almost 200 degrees of arc, are now more accurate than with 3 gyroscopes.

2.4 <u>The Hold Modes</u>

With 3 Gyros, holding attitude (tracking) during long exposures was achieved by the OBC using FES information (light photons and x and y telescope mirror position) of a star, other than the target, but in the same field of view.

The OBC employed the FES given x and y position and displacements of the guide star to correct for gyroscopes inertial drift, trimming them with a bias voltage. So that the target was held into the selected mirror aperture under which one of the four UV cameras was exposing.

Tracking has 2 basic options now with the 2GYRO-FSS system.

Option 1. - Pitch and Yaw on Gyros + FES; Roll on FSS.
MA=1; ML=3; MB(P)=MB(Y)=0; MB(R)=2
MC(P)=MC(Y)=3
This has the disadvantage that Roll axis will follow the apparent sun motion. Worst case is when tracking near the ecliptic poles (maximum apparent sun motion could pull the target out of the aperture for a very long exposure).

Option 2. - Pitch and Yaw on FES, Roll on gyroscopes.
MA=1; ML=3; MB(P)=MB(Y)=MB(R)=0
MC(P)=MC(Y)=2; MC(R)=1
With the advantage that Roll axis is inertially held.

To perform the small movements in Pitch and Yaw (less than 16 arc minutes) needed to introduce the target into the selected aperture the configuration used is:

Pitch and Yaw on gyroscopes, Roll on FSS.

At the present time IUE is able to track on celestial objects with good accuracy. However other different combinations could be used in the future, given the MODE BITS versatility.

3. THE ROLL CONTROL

Roll rate can not be determined directly with 2 Gyroscopes (mainly used for Pitch and Yaw body angles and rates) and one FSS (for Roll position only).
To solve for 3 body rates, along with the direction cosines of the 2 remaining Gyros (Eq. 2 & Eq. 3), the constraint equation (Eq. 4) that <u>assumes</u> the sun held in the Yaw-Roll hemiplane at zero deviation, is needed.

It is the Roll Control Law which makes the assumption in Eq. 4 true, by holding the sun fixed at zero Roll:

$$NRER = 2*(NRBIAS - NB) - 1 \quad (7)$$

NRER = New Roll Error
NB = Digital Output Readout of the FSS
NRBIAS (NEW ROLL BIAS) = The NB value that corresponds to zero Roll deviation at a given BETA angle.

The FSS currently uses System#1, head#2, for Betas less than 75 degrees. And System#2, head#1, for Betas equal or greater than 75 degrees.

The output of each head is a digital value called NB. Heads are calibrated so that the NB value corresponding to zero Roll deviation at each Beta is well known.

The law tries to maintain NRER to 0 or -1 values. This is called tight control. When (NRBIAS-NB) reaches 100 counts a motor voltage command is applied to the Roll inertial wheel with opposite polarity to that of the error, correcting for the deviation.

Since average FSS resolution is 15 arc sec., the maximum deviation allowed is:

100*15arc sec. =1500arc sec. = .4 deg

The Roll Control Law has been revised making smaller the amount of voltage correction applied to the roll wheel, since at low Betas voltage commands overcorrected for the errors and oscillations developed frecuently. This problem has now disappeared.

4. CONCLUSION

A 1 Gyroscope System is being tested at the present time to have it as backup and ready in case another gyroscope fails. Still needs to be seen how accurate long manoeuvres and how tight 3 axes control will be.

However, maintaining 3 axes stabilization with 2 gyroscopes and hopefully with one in the future, represents an interesting challenge.

5. REFERENCES

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