AO-5 Attitude Stabilisation System - “MASS”

Why did we include any attitude stabilisation system at all? Satellites with a serious purpose must have some such facility to maintain orientation of cameras, sensors or antennae for reliable observations or communications. AO5 didn’t have any such sophistication – no telescope to look at stars and so on - but paradoxically, it was the simplicity that demanded some attitude stabilisation.

AO5’s telemetry system to indicate temperatures, battery voltage and current plus horizon detectors to assess spin, was literally a basic form of music. The users being amateur radio operators, could not be expected to have any equipment specifically designed to interpret our signals, so we chose simple audible tone signalling, with a 6.5 second tone burst for each item. The frequency, that is, the musical “pitch” would convey the value of each quantity. Compared to any modern data encoding system, this was a slow process so the combination of:

- the 6.5 second switching sequence through successive channels,
- tone variation as the horizon sensors swept between earth and sky, and
- signal fading caused by the directional antennas of a spinning satellite

would reduce the telemetry to a useless warble.

On top of the necessity though, we were keen to experiment with a permanent magnet for stabilisation because it seemed to us that it ought to be simpler and more effective than other similar methods in common use. In the spirit of the times and our youth, we wanted “to give it a go”.

What did we do?

The Magnetic Attitude Stabilisation System (MASS) comprised:

- an array of lossy nickel-iron alloy wires to dissipate the satellites’s initial spin energy by magnetic hysteresis loss as they moved through the earth’s magnetic field. That’s just a complicated way of saying that they were to reduce the satellite spin by wasting its energy.
- A very strong bar magnet to follow the earth’s field.

That sounds very simple. Why had the method not been used before and why did even we agonise and argue about its operation? Perhaps we thought it would have been commonplace already if it was likely to work as well as we were expecting. On the other hand, there is a potential conflict between the rods and the magnet but we believed that aspect was manageable.

Little written information was available and even then, relevance to a small satellite like this was in question. The lossy rods had been used in earlier and much more elaborate satellites, such as in the first generation of military navigation satellites launched in 1960, but without a permanent magnet. Apart from school physics, two astrophysics text books in the Baillieu library were the total source of information. In case you don’t believe I really mean that, in 1966, there was no internet and no means of sending instant messages to possibly helpful experts across the world, even if one knew of any. We were on our own. One of the books gave the magnet a brief mention, but in almost hypothetical terms. The other text complicated the idea by implying that reducing spin energy would be of little help without something else to remove angular momentum and the methods suggested were much more complex than we could provide, such as mass ejection or “yo-yos”, thrust rockets or reaction wheels. I have been told to keep this simple, but angular momentum has to figure in the story. Watch high board divers, ballet dancers, gymnasts or spinning tops in action and you are seeing angular momentum at work. Fortunately our satellite was not expected to have much of it, but still it had to be reduced.

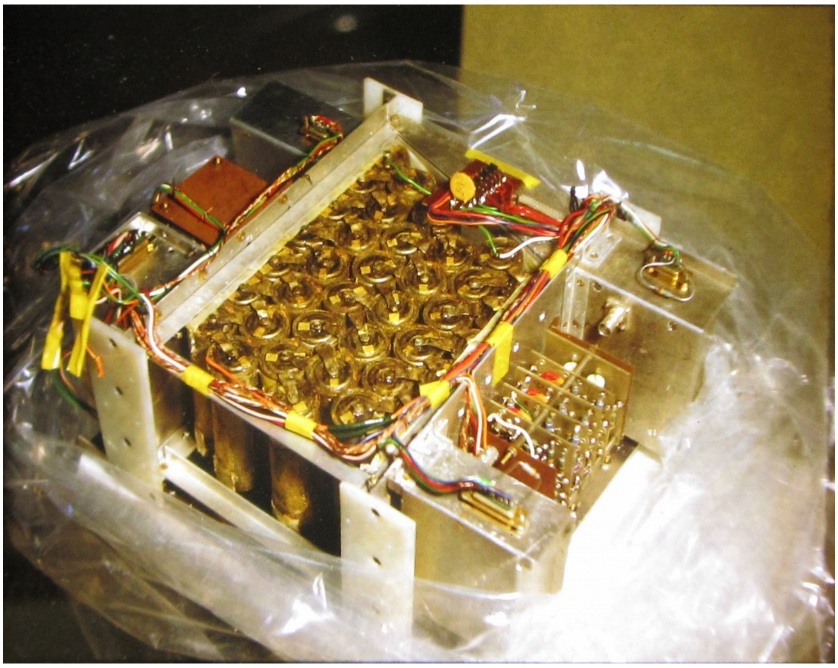
Was there any reason to expect that the task would be difficult? If a spinning ballet dancer moves from tips of toes to a flat foot stance, the spinning stops of course. By friction, or grip or traction if you prefer those words, most of the dancer's angular momentum is transferred to the earth, which does not notice a thing of course. We were being told that it's all different for satellites because "there is no friction in space ..."

The textbook that assured us that the satellite's angular momentum could not be removed easily explained the process in terms of the moments of inertia (propensity to spin) about each axis. Divers, ballet dancers and gymnasts regulate their speed of rotation very skilfully by changing moment of inertia –alternately straightening or bending the knees and extending or folding the arms,. A simple satellite has no equivalent of that but imagine the spin moving from one axis to another with greater moment of inertia. For the same TOTAL angular momentum, the spin rate can reduce but concentrate around the axis with greatest moment of inertia. That means a LOWER total spin energy for the same angular momentum. But can this keep happening as energy continues to be lost? Some energy loss can work this way but as the hysteresis rods keep wasting energy and the total energy heads towards zero, can the satellite keep spinning? Clearly there is something wrong with that explanation!

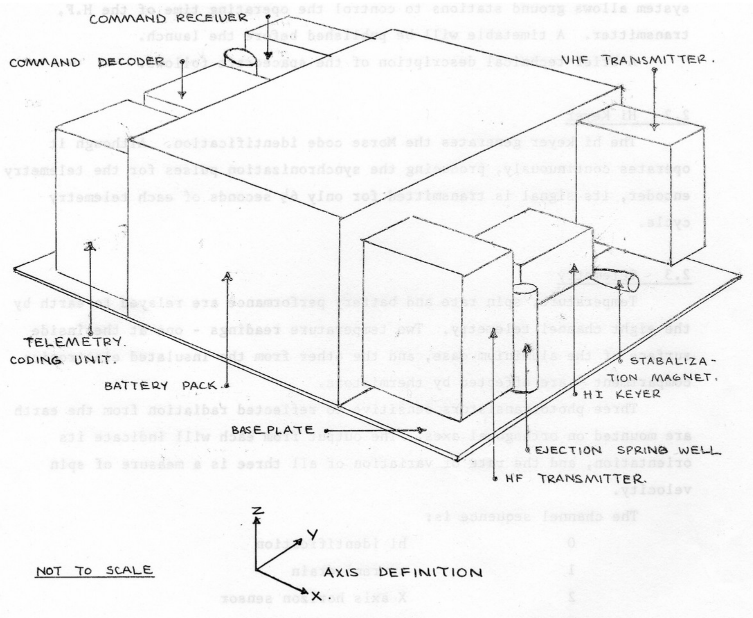
It's true that a satellite cannot work exactly the same way as feet on the ground, but is there any doubt that a similar momentum exchange can happen through the earth's magnetic field? Magnetic compasses have been used for thousands of years. Electric motors could not work without momentum transfer via a magnetic field. A newer and more dramatic example is the "maglev" train (patented more than 100 years ago incidentally). Clearly momentum transfer can occur via magnetic fields just as through mechanical friction. Therefore, both spin energy and angular momentum can be reduced steadily via the magnetic field interactions.

How did our "MASS" compare with the hysteresis rod system used in 1960 on the early US Navy navigation satellites? The lossy rods they used were quite effective and stabilised the satellite after about a month but we believed that with a powerful magnet as well, the result should be much better. Think of iron filings strewn around a magnet on a sheet of paper. Magnetic materials like that also become magnetised and tend to align with the field. A satellite with lossy magnetic rods can do the same, but a powerful permanent magnet can produce greater force and momentum exchange. We expected a battery life of just a couple of months so needed to reduce the satellite spin very early.

Here is a picture of Australis without the outer covers:



You can see the large battery pack in the centre, dictating the moments of inertia. The magnet was along the maximum dimension below the batteries and is not visible in this picture. Other metals were stainless steel and aluminium, and so did not interfere with the magnet's effect. Here's a diagram showing the placement of components:



Satellite "box" movement...

- magnet aligned with earth's field, and
- turning over 180 deg slowly as it passed near (10 deg away) the north and south poles
  Calculations predicted that the magnet would track the earth's field within 20 degrees.

If you think of the earth's field as if from a bar magnet, the bar is much shorter than the diameter of the earth. Magnetic field dip at Melbourne for instance is 68° from the surface of the earth, so the satellite only had to rotate gradually from horizontal (0°) at the equator through vertical (90°) close to the poles.

The permalloy wire had to be imported at significant expense. It needed heat treatment in a hydrogen atmosphere but that was done as a very valuable favour. We had to make up some apparatus to measure the loss in its "hysteresis loop" in order to estimate the energy loss per revolution of the box and its contribution to spin reduction. In contrast, the magnet was made for us in Noble Park by ROLA and cost us no more than driving out there to ask for a very strong one.

How well did it work?

As we had expected, the satellite spin in the early orbits made the telemetry decoding very difficult, though at about 15 seconds per revolution, the rate was less than we had feared. However after only about seven days, the spin had slowed down to almost 20 minutes per rotation. That was a very successful result.

Very similar arrangements have been used on many small satellites since, and detailed analyses are easy to find. A search for PMAS will find them – that's PASSIVE magnetic attitude stabilisation. I doubt any would mention us, but we did it a long time ago. Whether it was just our ignorance, consequent on lack of information of the state of the art then, or antipodean sentimentality enriched over time now, we believe it was the first of its kind and it worked.