Options for Repair of Elevation Tape Encoder Scales
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The elevation tape scales have been damaged by an as-yet undiscovered source. Below, we have some pictures of the damage. It's a little hard to see, but the dark areas are places where the gold overlay has been knocked away. The West tape is pictured at the position where the tape encoder head reads at 23° elevation. The East side is out of focus and a bit harder to see, but the dark areas are visible if examined carefully:

Figure 1 West Tape at ~23 degree position

Figure 2 East Tape Area Below 5 Degrees

Careful examination with a surface-inspection 40X microscope shows that the scale graduations are still present, but the gold overlay is definitely scraped off. This makes the encoder read head output signals to drop below their specification level due to the lessened reflectance in those areas. I looked for any evidence that the ventilation hoses may be "walking" over and damaging the tapes but cannot say definitively they are at fault. I also have no good idea why the tape head alignment appears to have become so far out of spec.

I have spoken in detail with Tom Wyatt, Product Manager for Heidenhain USA's Automation Division about our tape problems and what might be done. Barbara recovered the original UA purchase order for the tapes (P259234) and the original length of 7640mm for a LIDA 105C tape, Heidenhain part number 310 565 81, from that PO is still valid.

I described the damage to both Tom Wyatt and the Heidenhain repair person and both agree that our acetone cleaning method should not damage the tape. They normally use isopropyl alcohol for cleaning, however.

They have no method of recoating the gold overlay on the tape and recommend new tape scales if ours are too damaged for continued use. It is unclear how much performance can be regained from the tape, although examination with the PWT alignment tool shows both tape heads to be out of alignment, and it is possible enough output signal overhead may be recovered that with careful alignment one or both tapes could be brought back into operation.

Recommended Short-term (< 3 months) Action

Prudence dictates that before spending large amounts of money on new tapes, we do our best to recover proper tape encoder operation. To that end, after consultation with JT, I recommend the following short-term action now that normal elevation movements can be performed using feedback from the absolute encoder:

1. Starting with only one tape, remove the head and mounting bracket.
2. Inspect the tape head face for damage to ensure it is not the source of the rub damage.
3. Mark the tape end mounting locations and remove the tape from the drive arc.
4. Clean all rust and grease from the tape mounting surface and side edge.
5. If feasible, phosphate-coat the unpainted steel tape mounting surface to prevent more rust from developing.
6. Inspect the tape scale carefully and note any damaged or worn/scratched areas.
7. Mark (via carbide scribe) an axial reference line to re-mount the tape against to ensure the tape is square to the plane of elevation motion and has low lateral variation.
8. Measure via our runout-measurement tool the axial and radial runouts of the tape surface to ensure proper alignment. This would be a good time to calculate the air-gap variation expected over temperature once the overall radial runout is known to ensure the air gap is set wide enough to tolerate warm-weather operation (could warm metal have cause the air gap to close and damage the tapes in "high spots"?).
9. Re-mount the tape against the newly scribed axial reference line. If desired, this could be deferred until after aluminization to preclude any new damage from handling the mirror cell vacuum closures.
10. Install the adjustable head mount and adjust the head location to align the tape as well as possible.
11. Check the tape output across all operation positions to ensure proper operation, or identify any areas where the tape is not working well. We would do well to ensure the elevation controller runs the position loop ONLY on the absolute encoder at low elevations (below 5°) to ensure that we don't again have problems safely closing the servo loops if the tapes aren't perfect.
12. Implement any additional safety covers or other methods that may be feasible to ensure the tape cannot be accidentally hit with ventilation hoses, cables, or other equipment and become (more) damaged.

It may be wise to remove both tapes before aluminization to prevent damage during handling of the mirror cell vacuum covers, in which case we could perform steps 1-8 ahead of time on both head surfaces.

Long-term Options (> 3 months)
For the long term, below are the options I see as possible:

A. **Do Nothing – "the 1968 Dodge Dart Option"**
   Assuming the 25-bit absolute encoder works well for pointing and tracking, *and* we can recover good feedback from one or both tape encoders for high-resolution velocity feedback, we could simply go on as before. Note that I say here absolute encoder → pointing performance, and velocity resolution → tracking performance, since the telescope servo performance depends on both aspects, and the higher the absolute encoder accuracy the better the pointing, while high velocity resolution gives better velocity control and disturbance rejection. This of course leaves us still vulnerable to tape encoder damage and problems as before.

B. **Do a Little More – "the 1980 Chrysler K-car Option"**
   If it turns out we cannot recover good tape operation, but still need high velocity resolution for acceptable tracking performance, it may be worthwhile to try installing one of the unused Heidenhain RON905 incremental encoders on the elevation axis, and implementing 1/T period counting on the velocity feedback. This has its own problems with getting hardware and software to work, but has the advantage of being possible to do relatively cheaply. I would estimate the cost at about $1-2K for mechanical mounting and another $1K to implement electronics to get the counting hardware integrated into the mount computer. This could pay off as I have long believed 1/T counting would need to be implemented for the azimuth servo upgrade anyway. I should mention here as well that the mount computer is out of available PCI slots, and buying new ATX motherboards with lots of PCI slots is getting more difficult by the day. It turns out, however, that we have surplus 14-slot 4U rackmount case, and could purchase a passive multi-slot PCI backplane ($125) and PCI CPU board ($500) and rebuild the mount computer to accept more hardware. Adding a new CPU and memory would add about $200 to the total. Naturally, we would have to ensure we could get this new hardware to run our existing mount code; I have no good way to assess this risk. Consultation with the CPU board vendor might clear this up.

C. **Replace the Tapes – "the 1975 GMC Jimmy Option"**
   Again assuming the tapes don't work well, we have the option to buy new tape scales, for one (or both) sides. Heidenhain quotes a price of $3932.35 for each, with a 12-week lead time (this price is with a 15% discount). I believe this choice, should it be taken, should be done with the surface-preparation mentioned above, and any possible steps to prevent future damage would be well to implement (e.g. covers, careful air-gap management, cable tray/cable control, etc.) At this point, I am unsure why the tape heads should be out of alignment, and cannot guarantee this would not happen in the future, let alone any accidents during normal operations that result in more tape-surface damage.

D. **Purchase a New Absolute Encoder – "the 1985 Ferrari 308GT Option"**
   Assuming the tapes don't work well, *and* we find pointing and tracking to be less than desired, Heidenhain offers an absolute encoder that may well meet our needs. This is the RCN829, a rotary absolute encoder with 29-bit resolution. This encoder has an available hollow shaft of 100mm diameter and appears to be feasible to mount using an (estimated) $1-2K worth of mechanical hardware. It also offers a separate 32768-line incremental encoder channel that would be available for implementation of 1/T counting. It would require use of an IK220 PCI interface board to read the absolute encoder data, since it is formatted in Heidenhain's EnDat serial interface. I have confirmed with Tom Wyatt that the EnDat output can be read at 1kHz and the unit would operate at our temperature range and altitude. We currently own 3 IK220 boards. This gets us back to the requirement for more PCI slots in the mount computer, and would need implementation within our mount-control software. The RCN829 offers the advantages of guaranteed 1" accuracy over the full 360° of rotation, and careful mounting and use of the supplied calibration chart from Heidenhain, while using only ¼ of the encoder rotation we could potentially get the accuracy down to 0.2" or less. This is better than our known cyclical error (~0.25" error that repeats every 21' and 42') and offsets from the existing Inductosyn encoder that gives us ~0.25" RMS all-sky accuracy, so I would expect pointing to be improved. Cyclical errors from the RCN829 are fixed and could well be mapped and corrected via a LUT (look-up table). The incremental-counting line accuracy is quoted at 1% line-to-line, so the issue of velocity jitter from counting-mark variation becomes more tractable to deal with since signal head alignment is no longer a factor. And of course a big advantage is that we are no longer vulnerable to tape encoder damage (although if we got them working or replaced they could be considered redundant encoders for use as back-up/sanity-checks). Heidenhain quotes a single-unit price of $7816.66 each (with 15% discount) and 2-4 week lead time.

Recommended Long-term Action

Given that the mount computer now and in the foreseeable future is in need of more i/o hardware, I recommend first that the mount computer hardware be upgraded to provide more PCI slots to accommodate any future additions to the mount control system. This gives us the freedom to add IK220 PCI boards, 1/T counting i/o boards, and the like without having constraints that preclude their implementation. We should consider purchase of a spare for development and emergency replacement purposes, as well.

I think continued use of the tape scales on the elevation axis will remain problematic due to their vulnerable location and exposure to accidental damage. Although we may well be able to regain good operation and perhaps install some sort of cover, they will forever be open to people stepping on the head mounting brackets, equipment scratching the tape scales, alignment drift, and other problems. Given the nearly equal price of two tapes ($7864.70) and the RCN829 ($7816.66), even with the costs and effort of mounting the encoder, it has the advantage of being far less susceptible to damage. The much shorter lead time is also compelling. That said, I am awaiting additional answers to questions about the RCN829 to Heidenhain regarding its low-level output error performance before recommending the unit 100%. I present this recommendation in anticipation that the answers will be satisfactory in the interest of time.

I would relegate the existing tapes, once they have had a "best effort" alignment, to backup status and take advantage of the higher resolution (29- versus 25-bit), guaranteed accuracy and stability, and go forward with 1/T velocity feedback. I recommend also consideration of purchase of a second RCN829 for use as an azimuth encoder with similar feedback hardware.

Here is a breakdown of the costs with the recommended approach:

Mount Computer	Price, $
Chassis (est.)	250
Power Supply (est.)	100
Motherboard	500
CPU, DDR2 memory	200
Passive PCI backplane	125
Total, 1 unit	825
Add 1 spare	1125
Both units	1950

The mount computer costs do not include any new or spare i/o boards that might be needed to clone the existing mount computer hardware.

Encoder System	Price, $	Notes
RCN829 Encoder	7816	each, with 15% discount
Mounting hardware (est.)	1500	
Cables (est.)	100	
Dry air regulator/filter (est.)	200	Recommended for contamination control inside unit
IK220 PCI interface board	0	
1/T counting electronics (est.)	1000	
Total, 1 unit	9616	
Add azimuth axis	19032	regulator/filter can be used for both
Add 1/T counting	20032	additional counting channels have trivial cost

Here is a summary of the options explored earlier:

Option	Cost, $	Notes
A, Do Nothing	0	Potentially accepts compromised elevation performance, limited mount computer hardware for future support
B, Do a little	4450	New mount computer + spare, mounting hardware for RON905, and 1/T counting electronics
C, Replace tapes	7864	2 new tapes with 12 week(!) lead time, resulting in comparable performance to the existing system, and the same vulnerabilities/problems

We should remember that replacing the tapes, or trying to add some sort of cover, will have some unknown dollar cost that should be taken into account. Although the recommended path is expensive and involves a lot of mechanical, electrical, and software work it is in my opinion the best long-term solution. I invite your comments on the above.