The wheels, pivoting block, and parallelogram linkage are the only moving parts in the readhead assembly, none of which require machining to any precise tolerance. Since this assembly is small and inexpensive, it is feasible to make a spare unit. Cost estimates for the spare are $150 in parts and one man-week to machine and install it. Even if the more traditional approach of coupling a rotary encoder to the dome were used, a similar assembly would be required to keep the mechanical pick-off for that encoder in contact with an out-of-round dome. Thus, the cost of this assembly should not be viewed as an added cost of using the hybrid encoder.

Another advantage of the hybrid encoder is that a gear reduction is not required, as is the case when an absolute rotary encoder is coupled to the dome. A gear reduction is expensive, and is also a significant source of error. If the gearing does not produce the exact reduction required, the rotary encoder will incur a small incremental error on each rotation. If the dome is rotated repeatedly in the same direction, this incremental error will accumulate and could grow unacceptably large. Additional errors result from mechanical backlash in the gears.

Fault detection and fault tolerance

Faults in dome positioning are often not noticed until they become sufficiently severe to occult the telescope. Based on past experience with both the 1-meter and 3-meter telescopes, even misalignments of the dome in which the mirror was 30 percent occulted often went undetected by observers who relied solely on the television guider image. These misalignments were usually detected only by visual inspection from the dome floor, and were often not suspected until significant observing time had been wasted. Without some redundancy of information, there is no way to automatically detect when there are problems with a system or to isolate where they are.

The hybrid encoder solves this major problem because the incremental and the absolute parts provide redundant information, thus allowing the system to be self-diagnosing. When the system is first turned on, it uses the absolute position tags on the data track to establish the initial dome position. From then on, these tags serve as a cross-check against the changes in relative position indicated by the incremental encoder on the timing track. A loss of an incremental tick will be detected, reported, and corrected as soon as the next valid absolute position tag is read. The absolute tags are encoded with parity checking and checked by the software for adjacency (i.e., a tag is considered to be in error if it is not encountered in the expected sequence) to insure that a corrupted absolute position tag does not corrupt the dome position. Any errors are reported so that corrective action (such as replacing a damaged piece of the mylar strips) can be taken.

Since the absolute position tags are coded in serial form and read into software defined shift registers, as many bits as desired may be allocated for parity bits or error correction codes. However, in using more bits for error checking, each tag becomes longer, and fewer tags can fit into the same circumference. Note that the number of data bits needed for each tag is a function of the number of tags, and not the number of incremental ticks. The tags are used to index a look-up table, which translates the tag number into the corresponding absolute position. Adjacent tags are assigned distinctive bit patterns so that a corrupted tag which passes the parity test will have the highest likelihood of failing the adjacency test.

Resolution and dome size

In the system at the 1-meter telescope, each tag consists of 7 data bits and 1 parity bit, and is framed by a start bit on each side. In addition, each tag is separated by an equivalent amount (10 bits) of blank space (which is used for synchronization) so that there is one absolute tag for every 20 bits, or every 20 incremental ticks. Using 1/2-inch-wide incremental ticks, absolute position tags occur every 10 inches. The dome is 23 feet in diameter, and there are 1771 1/2-inch incremental ticks and 88 absolute position tags. This corresponds to an incremental angular resolution of about 0.2 degrees, and an absolute angular resolution of about 4 degrees.

If the incremental tick size were kept at 1/2 inch, scaling up to a larger dome would yield increased resolution. For a 100-foot-diameter dome, a width of 1/2 inch per tick would yield 6280 ticks, for an incremental angular resolution of 0.06 degree. If absolute position tags were spaced every 10 inches, two additional data bits would be required to represent the number of tags (314) that would fit into the larger circumference. This number of tags yields an absolute angular resolution of 1.15 degrees. The widths of the ticks could be made wider if less resolution were adequate.

However, there is a limit to how narrow the ticks can be made for a given dome size and rotational speed. A problem could arise if the dome were so large or the ticks so narrow that the linear speed of the ticks past the read head exceeded the capacity of the micro-