

## Removal and Replacement of Absolute Encoder Resolvers

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Dusty Clark

### *Introductory Remarks*

The procedure documented here is fraught with peril; the absolute positioning of the MMT axes is utterly dependent on the output of the encoders, and the most-significant 9 bits of the ultimate 25-bit position value is output by the resolver(s). **Before doing any of this work, the reader should possess an intimate understanding of the encoder system operation, and be utterly certain the problem with the encoder is in fact the resolver unit itself. If either is not the case, STOP IMMEDIATELY, and get competent assistance!**

**Also, the procedure following depends on *certain knowledge* of the actual telescope position. Should this value be lost, or any question about the correct position value arises, STOP IMMEDIATELY! The position should be accurately determined before continuing to ensure the replacement resolver output position is correct.**

### **Determination of Resolver Fault**

First, it is *required* to check everything out as carefully as possible to find out if the resolver is for sure broken. The following describes what was done in the case of the recent failure. Should this sort of problem recur, more or less the same progression of checks should be followed.

The encoder position for the recent failure was reported by the mount software as being  $-110^\circ$ . This pointed to a failure in the encoder system's coarse position. The "standard fix" was applied of replacing the resolver's AD2S80 synchro-to-digital converter, which did not fix the problem. During inspection of the encoder signal outputs, it was noted that the resolver signals (SIN and COS) presented to the AD2S80 were of order 10mV for both signals. Their nominal maximum values are  $2V_{rms}$ , so this pointed to a problem with either the signal-processing hardware, some of which is within the encoder unit, or the encoder itself, not the conversion chip.

Checking the resolver excitation output from the system reference oscillator, the correct 10kHz excitation signal was observed. Probing signals within the encoder, the resolver preamplifier outputs were noted to be the same incorrect 10mV level. The resolver preamplifier was removed and a jumper board installed in its place to bring the raw resolver signals to the output terminals. The signals were again not the correct values, so at this point it was known that the oscillator, preamplifier, and associated wiring were not at fault.

Probing extensively for shorts to ground on the resolver output signals, still using the jumper board, it was found that application of gentle pressure on the resolver gear face made the sin/cos signals intermittently go into fault, and suddenly come back to a nominal high level of about  $1.4V_{rms}$ . The sin/cos output wiring was exhaustively checked for winding shorts and shorts to ground; they appeared correct. The next place to check was the resolver rotor winding, which has the 10kHz excitation signal from the oscillator on it. The signal wiring from the oscillator, through the connectors, and to the resolver itself all checked out, and none were shorted to ground. The rotor winding resistance, however, when measured at the encoder housing connector, was found to vary intermittently from  $20\Omega$  to several hundred ohms, to wide open when pressure was applied to the resolver gear face. Wiggling the wiring produced no change in the output, which removed the harness wiring as a cause of the problem.

**KEY ASSUMPTION:** The intermittent high level of the resolver, and the conversion electronics' subsequent output of 73.299816° were both correct.

Below begins the procedure for replacement of the faulty resolver:

Step 1: Since certain knowledge of the correct, or starting position is required, ensure that the drives cannot be started and all available brakes are set. Motion should not be attempted in any fashion until the repairs following are complete. Write down the raw and calculated position values from the mount computer, paying particular attention to the raw inductosyn and resolver raw 16-bit hex values.

Step 2: Power down the encoder electronics and remove the resolver AD2S80 conversion chip.

Step 3: Reapply power and measure with 6½-digit DMM and oscilloscope at the AD2S80 pins on the conversion board; make a note of all the values:

- A. REF signal amplitude. Expect a 2Vrms, 10kHz sinewave.
- B. SIN and COS signal amplitude. The nominal maximum amplitude is 2Vrms.
- C. Phase of SIN and COS with respect to REF signal.

Step 4: Power down and remove the large signal connector and cover from the encoder housing.

Step 5: Measure with a milli-ohmmeter the resolver winding resistance. Confirm that it changes intermittently with disturbances to the resolver shaft.

Step 6: Measure with milli-ohmmeter the wires from the signal connector to the resolver lugs and confirm the wires and ring lugs are low resistance.

Step 7: Assuming the wiring and cabling all measure out correct, the problem must be internal to the resolver unit. If not, correct the wiring and re-test the encoder outputs.

Step 8: Prepare to remove the resolver. This step is critically important. Done right, the situation is recoverable. Incorrectly done, it results in an inoperative encoder.

*Required materials:*

1. *Straight-edged reference block. Gauge blocks were used, but any precision machinist parallel or small square can be used.*
2. *Permanent marker or layout dye.*
3. *Scriber, preferably carbide- or diamond-tipped.*

A. Mark the resolver teeth and intermediate anti-backlash gear with marker or dye where they mesh. Mark an “up” arrow on the gear face also to make things unambiguous.

B. Using a square gauge block or machinist parallel against the inside flat on the housing between the resolver and shaft brackets, scribe a mark about 1/2” long across the tooth mesh. It should be clearly shiny and visible in the dye or marker. Avoid multiple marks! They should be unique and clearly visible for the least possible confusion.

C. Using a long parallel or block against the intermediate gear and resolver hub shafts, mark a line across the two gear faces.

D. Using a square block or machinist square against the mounting bracket flat for the resolver, mark a line orthogonal to the bracket flat across the resolver gear.

The first mark identifies the correct teeth that need to mesh, the second the relative angle between the

gears, and the third the resolver's absolute angle relative to the encoder housing. Using these three marks, the original resolver position can be recovered should it be found it wasn't broken after all.

Step 9: Two screws hold the resolver bracket in place inside the encoder. Remove the one furthest from the intermediate gear shaft first, then loosen the second screw while holding the gear face, and gently rotate the gear out of mesh with the intermediate gear.

Step 10: Re-tighten the remaining screw and power the encoder electronics up. With the oscilloscope connected to the appropriate pins at the AD2S80 socket (chip is still removed), measure the SIN/COS signals. Note their amplitude change with CW and CCW rotation. This information will help determine the correct output signal sign with the replacement unit. For the elevation unit that was removed, CW meant COS lowered in amplitude while SIN increased, and the opposite for CCW rotation.

Step 11: Power down the system and cut away any tie-wraps or harness tie-downs and flip the resolver assembly over to access the terminal nuts on the bottom.

Step 12: Carefully inspect all wires, wire lugs, and nuts for loose and corroded connections. Be especially on the watch for broken wires or shorts.

Step 13: Verify the housing marking (S1, S2, R1, R3, etc.) are the same as the replacement unit. If not, STOP! You must determine the correct winding connections before continuing.

Step 14: If the wires are without tags identifying their terminals, add them now.

Step 15: Once all terminals are disconnected, verify that no wire or lug is open. Check the resolver terminal resistances. If any open/shorted wire is found, correct the condition, and plan to test the encoder with the original resolver back in place (this is where all those marks will come in handy).

Step 16: Assuming we still find the resolver terminals show bad wiring internal to the unit, prepare to install the new resolver:

- A. Confirm the mounting bracket, spacer and screws are the same as the old unit. For the elevation unit, we had to use the original spacer; the replacement was considerably thicker.
- B. Confirm the driving gear on the resolver is the same.
- C. Carefully re-attach all wires to the correct terminals on the new resolver.

Step 17: With the resolver preamplifier installed and the new resolver out of mesh, power up the electronics and rotate the driving gear until the correct signal amplitudes and phase on the SIN and COS signals are observed. Mark an "up" arrow on the gear face to note the operational quadrant for the resolver.

Step 18: With the gear still out of mesh, rotate the resolver shaft and note the maximum RMS voltage of the SIN and COS signals; the AD2S80, when installed, expects the nominal signal range to max out at 2Vrms, so if the amplitudes are different, adjust the oscillator drive signal level until a 2Vrms maximum on the SIN and COS signals are observed.

Step 19: Using the previously-measured SIN and COS signal amplitudes, rotate the gear until those values are achieved, then attempt to bring the resolver gear into mesh with the intermediate anti-backlash gear. Ensure that the gear faces are flush in height and the gear teeth are not too deep in

engagement, then tighten the bracket screws.

Step 20: Power down the system and re-install the AD2S80 chip.

Step 21: Using the mount software, note the raw inductosyn and resolver hex values for the encoder, and compare them to those from before. If they are the same, the replacement is complete. The probability of this being the case is extremely small.

Step 22: Each gear tooth on the resolver is worth about  $2^\circ$  of position value, so assuming the position readout is off by more than this, we need to move 1 tooth closer to the correct value. Using a fine marker, mark the current gear tooth meshed with our previously scribed mark, and remove/loosen the bracket bolts enough to bring the gear out of mesh, then bring it back into mesh 1 tooth over from the original position.

Step 23: If the correct absolute position cannot be achieved using the gear teeth pitch, the resolver body needs to be adjusted on the mounting bracket. Start with the closest possible gear tooth position, and mark this position, since you will need to remove/replace the resolver again.

Step 24: Power down and remove the resolver and flip it around to access the servo-mount clamps on the other side of the bracket. While theoretically possible to do this without removing the bracket, it proves to be nearly impossible to satisfactorily engage the allen wrenches with the bracket installed. Loosen each of the 3 mounting screws no more than about  $\frac{1}{4}$  turn, just enough to be able to turn the resolver body.

Step 25: Re-mount the resolver and bring it back into mesh with the previously marked closest gear tooth.

Step 26: Power up the system and again check the raw encoder position against the correct one. If different, *slowly* turn the resolver body until the correct values from the mount computer are reported. It may be generally acceptable to get within about 1 arcminute of the correct value if fine enough adjustment proves too hard to achieve. Once the position value is correct (or as nearly as possible), reach around to the rear with an allen wrench and tighten the closest available mounting screw – it won't be possible to tighten all three, this will just ensure the resolver body won't be disturbed while the other two get tightened in the next step.

Step 27: Power down the system and again flip the encoder mount around so access to the resolver mounting screws is possible and tighten them all. Make sure not to over-tighten and break the small screws!

Step 28: Re-install the resolver, and paying close attention to the gear mesh, re-tighten the mounting bracket screws.

Step 29: Power up the system and confirm the correct values are read.

Step 30: Once correct values are reported, motion can again be attempted with the telescope. At this point, small slews can be tested to start with. *Avoid all operation near any limit or other position that might prove dangerous.*

Step 31: It is possible that motions larger than 42 arcminutes will fail. This is due to the fact that the mount servo code, when meshing the raw hex values from the coarse and fine parts of the encoder to form the full 25-bit value, calculates the fine parts of the position modulo 42 arcminutes, which happens to be the fundamental cycle of the inductosyn (fine position). If the meshing is not correct, 42-arcminute jumps in the position will be output from the encoder software, which will be caught by the safety checks in the elevation controller, shutting down motion.

If this is the case, the software value 'el\_coarse' needs to be adjusted. Use the command 'el\_coarse <n>' in the mount terminal to adjust this until proper motion is achieved. The allowed value is from -7 to +7; start with values  $\pm 1$  from the current one, do not use values that are *really* different without good reason.

Step 32: Now pointing on the sky should be checked; any pointing error in the axis under repair should be found at at least a couple of different positions. There will be a constant error the same as the positioning error when installing the new resolver, plus whatever cyclical error and flexure error in optical alignment (besides several other error terms) so use several positions to deconvolve the constant resolver clocking error from the other error sources.

The resolver replacement is now complete.