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To: VLBA/MKIV Recorder Configuration
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Re: Reel Servo/Driver Configuration and Margin Analysis, Recommendations for More Reliable Operation at 320 ips Maximum

Background

Several years ago Honeywell [now Metrum] changed the design of the reel servo in order to improve its notoriously low MTBF; short-circuit failure of one of the 5 parallel output transistors on each side of a reel motor driver had been a common occurence. The worst-case consequences of these changes for operation at a highest speed of 320 ips have only just become clear in the effort to understand the loop-dropping and tape breakage sometimes experienced on VLBA drives.

Even earlier [in the early 80's] we were independently driven to improve MTBF in VLBI operations [with the old design].

This was done in part by introducing gain-switched operation of the reel servo in which the so-called '1/4" tape' mode is used when the tape is not accelerating. The 1/4" mode reduces gain to 25% of normal and, as was only recently realized, also reduces the motor-current-limiting effect of the clipping diodes in the loop-position error-signal amplification path from about +/- 10 to +/- 5 amps. This is cause of the loop-dropping reported.

More importantly, the optical position sensors were unambiguously isolated from deck plate [chassis ground] to prevent catastrophic rail-to-rail oscillations of the motor current.

Also, sporadic loop-dropping at turn-around was traced to loose and/or corroded power connections [terminal board screws, 'fast-ons']. It was found nececessary to strap the return side of the reel-motor current-sense resistor to the local analog ground in order to insure that the return resistance, seen by servo amplifier is much less than 0.1 ohms. If this is not done, a return resistance of 0.1 ohms is enough to halve the current-limit [and, less importantly, halve the gain], which is then insufficient to accelerate the reel. The importance of the return-strapped configuration, and of tight, very low resistance power connections between motor, servo, and unregulated supplies can't be overstressed. Loop-dropping during acceleration to speeds much lower than 320 ips is almost always caused by poor connections which directly or indirectly keep the motor from getting enough current.

It is now clear that the unintentionally reduced current-limit which accompanies gain-switching leaves a too-thin power margin for worst case transitions between ramping [standard gain and current limit] and running [1/4 gain, 1/2 current limit].

Furthermore, because the hard point plates are now angled [2mils/inch] so that loop-position and a transverse [tracking] error are more strongly coupled, the sloppy [1/4 gain] servo in running mode degrades tracking performance, especially at high speeds [270 - 320 ips] when the supplying reel is nearly empty [when rpm and hence the servo bandwidth requirement is highest]. Even at full gain there is typically a dominant reel-once-around error signal under these conditions.

Primary Conclusion

We therefore now recommend abandoning the use of gain-and-current-limit switching.

In addition a more careful study of the reel servo bandwidth and damping requirements for 320 ips recording and processing seems indicated.

Old and New Servos and Drivers

Honeywell's changes involve both the Dual Reel Servo circuit card: 16778850 old, 16813450 new; and the Driver/Heatsink subassemblies [one for each reel]: 16776995 old, 16813453 new.

The primary change in the latter is that the resistor in series with each of the 5 parallel output transistors was changed from 0.25 to 4 ohms. At 10 amp rated load the resistive voltage drop is only .5 volts for the old but 8 volts for the new driver.

In the dual reel servo card the new version omits an extra error signal inverter on the takeup side and inverts the sense of the motor connection. The effect of this simple change is to invert the relative use of the positive and negative "33 volt" unregulated supplies.

Both driver and servo changes affect the voltage margin available for highest rpm [empty reel at 320 ips] operation at which the highest voltage is applied to the motor. The voltage constant [volts/Krpm] of the motor [16776163, never changed] can be checked with a scope or voltmeter by accelerating to a known speed from the load point [typically 24 volts at 320 ips and 4.6" pack diameter].

The primary effect of the servo card change is opposite and comparable to that of the increased driver resistance: During acceleration, in the new design only, opposite polarity supplies are used for the two reels. The reduction in supply droop is comparable to the increased driver voltage loss because the current required to accelerate the full reel is comparable to the empty one [which undergoes 3 times the angular acceleration] and the supply impedance is roughly the same as the impedance of the new version of the driver [0.8 ohms, five 4-ohm resistors in parallel].

Avoid the Bad Combo: Old Servo - New Driver

The moral of this story is that there is a bad combination of old servo board and new driver module that must be avoided for operation above 300 ips. This bad combination was discovered inadvertantly installed in drive #3, when it failed to accelerate to 320 ips in a 105 volt low line margin test.

Note however that all VLBA recorders are of recent enough vintage that they should not have either of the old parts.

The most likely place for an inadvertant bad combination is at one of the processors with a mixture of many old and a few relatively new machines under the same roof.

Best Combo: New Servo - Old Driver

A significant increase in high-speed and/or low AC voltage margin can be obtained by combination new servo and old driver designs.

While the thermal layout of the new driver appears to be a genuine reliability improvement, the resistor increase in the name of better current-sharing is grossly overdone and unnecessary.

New drivers can be easily converted to have the low voltage drop advantage of the old version by strapping a 0.3 ohm 3 watt resistor in parallel with each 4 ohm resistor.

A pair of such modified new driver modules passed an extreme conditions test in which the AC was set at the high drive specification limit of 130 volts and a full 16" reel of thin Sony tape was shuttled at 360 ips for 3 days with vacuum set at 20" of water. The drive was run at standard full gain but without the standard +/- 10 amp reel servo current limit. Holding current for the full reel was 5 amps and 12 amps total [7 amps for acceleration] was required to accelerate the full reel against the vacuum at the VLBI standard rate of 67.5 ips/s. During deceleration of the empty reel the peak load on 5 parallel output transistors was 70 volts at 8 amps, which approaches the 80 volt at 2 amp SOA spec of the individual MJ15024 transistor. Operation at 105 volt low line, with all other extreme conditions the same, is also troublefree. The pair of experimentally modified new drivers continues now to be used on one of the VLBA drives on the Haystack processor to spot check for some other [unanticipated] failure mode.

Key Specifications for Margin Analysis

AC voltage spec: 105 to 130 volts for the model 96 drive.

Note, the brushless vacuum motor [used only in VLBI recorders] was observed to fail to regulate [starts to hunt] at and below 100 volts. Thus operation below 105 volts is precluded both by drive specification and the characteristics of the vacuum motor.

The VLBA uses UPSs which are specified at +/- 3%, 114 to 121 volts as I understand it, and produce an alarm if the output drops to 109 volts.

Reel motor voltage constant spec: 18.6 +/- 10% volts/Krpm.

Implies at most 28 volts will be needed to drive the reel at 1360 rpm [22.7 rps], the rate required to run a 4.5" diameter hub at a tangential speed of 320 ips.

Observed on one recorder and assumed typical [the 2 motors behaved identically] was 24 volts at end of ramp to 320 ips from load [at a pack diameter about 2.5% greater than the bare hub] and implies that a typical motor is 13% better than worst case or equivalently buys a 3.3 volt margin w/r worst case.

Note that the maximum voltage that must be capable of being supplied to motor somewhat exceeds that required for open loop operation; closed-loop operation of the servo appears to require at least 2 volts of headroom. Up to 2-volt or 4-amp excursions about mean values are observed in standard-gain ramping and running modes. Peak current up to 8 amps can be drawn by an accelerating empty 14" reel.

Unregulated "+and-33volt" supplies spec: +and- 40 volts, +/- 20% over 105-130v line and 0-10 amp load variations.

Implies 32 volts minimum at low line and rated load.

Unloaded output at low line is observed to be 40 volts and supply impedance was measured to be .8 ohms at the reel servo input. Thus the measured supply, thought to be typical, just meets its spec and will deliver 33.6 volts at 8 amps with a 105v [low] line.

New-combo Worst-Case Analysis

With the new servo-and-driver combination the peak voltage drop through the takeup driver and current sense resistor during empty reel acceleration is then 7.2 volts [.9 ohms at 8 amps] plus 1-2 diode drops [1.4 volts max] on the negative supply side of the driver, so that the worst case voltage available to the motor is -25 volts. This is not enough to reliably accelerate an empty reel to 320 ips.

However, at 114 volts AC minimum [defined here as the VLBA low line condition], with all other things as before, the motor will be able to get -28.4 volts. This is enough for the 'typical' motor with about 2.4 volts or 10% to spare, but not enough for the worst case motor spec'd.

Recommendations For VLBA

Thus for VLBA 320 ips maximum speed operation, the simplest immediate recommendation is not to change the hardware, but to disable the low gain-and-current-limit mode in software.

In addition, if the UPS setpoint can be adjusted from 117.5 to 121.5 [118v min at -3%] the worst case motor spec could be accomodated.

Otherwise, it should be verified that the average voltage across a reel motor that has just finished ramping an empty reel up to 320 ips does not exceed 26 volts and that the power supply meets its spec.

The simplest overall check that there is at least a 12.5% voltage margin at 320 ips is to observe no loop-dropping or squawking when test-ramping the empty reel to 360 ips [which TDC allows you to do].

Recommendations For MkIV

For non-UPS-backed MkIIIA/MkIV operation at 320 ips maximum, the 105-volt low-line spec should be supported.

This can be done with either the old or the probably-more-reliable 'retromodified' new driver modules.

The voltage drop in driver and current sense resistor is at most 2.6 volts at 8 amps peak so that at least -31 volts can be applied to the motor [provided the opposite positive supply is driving the full reel during acceleration, as is the case only when the new servo board design is used].

This substantial margin [which guarantees 320 ips operation with the worst case spec motor and provides more than 21% overspeed margin for the typical motor even at low line] seems important enough so that I would recommend implementing the simplest modification of old servo boards to make them work like the new ones. The easiest way, which can be done in place, is to clip open the output of the unnecessary inverter [pin 6 of U7] and interchange the power leads from the takeup motor [the 5th and 6th wire counting from the red edge of the ribbon and going normally to TB1-19 and -20 respectively].

If this is not done and the old servo board continues to be used as it has been, the positive supply will be used simultaneously to accelerate both the empty takeup reel against the vacuum and the full supply reel aided by the vacuum. The extra power supply droop due to having to accelerate the supply reel is roughly 3 volts max for 10" vacuum; in addition the positive side of the servo amplifier has 3 more diode drops than the negative side. Taken together, these two effects reduce the voltage available to the motor in the worst case from 31 to about 26 volts, which is only slightly better than the VLBA new-servo-and-driver combination and only marginally good enough for the particular reel motors tested. In order to tolerate the worst case spec motor in this configuration, at least 114 volts AC must be guaranteed.

To disable low gain/current-limit mode in MKIIIA processor drives only a small software change is needed as is the case for VLBA drives. For data acquisition drives the hardware control must be changed: on the Honeywell control board the jumper from U3504 to U5012 should be unsoldered at the U35 end and connected to ground at U3507.

Addendum:

I concluded that reducing the acceleration from 67.5 to 50 ips/s does not buy much high speed margin: Roger Capallo installed experimental firmware which allowed different accelerations and speeds greater than 360 ips to be tried. With 14" reels, 10" vacuum, 109 volt line, and the new-new reel servo configuration locked in standard gain/current-limit mode, the loop dropped consistently when the empty reel was accelerated at [VLBI standard] 67.5 ips/s and trying to lock up at 390 ips but did not drop the loop or squawk when locking up to 380 ips; at 50 ips/s loop-dropping occurred at 400 ips, a speed margin gain of only 2.5% for a 25% acceleration reduction.

This is largely because dynamic or transient current requirements of the closed-loop reel servo can easily dominate the total maximum current budget. For example, when an empty 14" reel is accelerated at 67.5 ips/s it draws on average 4 amps, of which only 0.5 amps is needed to offset the torque due to tape tension at 7" H2O vacuum. At 5" vac the variation of motor current [not oscillation] was observed to be +/- 4 amps peak about the average during acceleration and subsequent 330 ips running. The peak current requirement in running mode is hardly diminished.

It is interesting to note that the motor-current wiggle-room requirement appears to decrease as tension is increased so that at 10" about +/-2.5 amps and at 20" only +/- 1 amp of wiggle is observed. I don't fully understand this effect or all of its consequences.

By measuring the forward-reverse difference in average motor current during acceleration the effective moment of inertia of reel+motor+pack can be obtained. The accelerating component of motor current for an empty 15" reel was found to be 4.5 amps which is to be compared with 3.5 amps for a 14" reel, as expected within the measurement error. A full 15" reel requires a peak motor current of 10 amps which a properly configured drive should be able to supply.