A RECORDING TORQUE METER

AUTHOR
STEW MEYERS

Looking Deeper at Winding a Rubber Motor

Recording Torque Meter History

For the last 30-odd years I have played around with making a Recording Torque Meter (RTM). My original effort was a crude RTM using discrete chips soldered to a perf board. There was no CPU. The entire operation was hard coded in TTL logic. A plastic optical disk was fastened to the torsion wire torque meter. This disk had a grey code pattern and photo diodes which registered the rotation to 15 degrees resolution. The readings were triggered by pulses from a reed switch on the crank end of a 15:1 winder. The angle of rotation was recorded as an eight bit word on 256 byte memory chip. The data was retrieved from memory by pressing a button to step through it and it was shown on a LED display. You then had to write it down and convert the digital word to an angle and thus, torque. I never got the unit to communicate with my single board Ohio Scientific computer, as was my intention. It had lousy precision and was labor intensive - not a success, but a step in the evolution of an RTM.

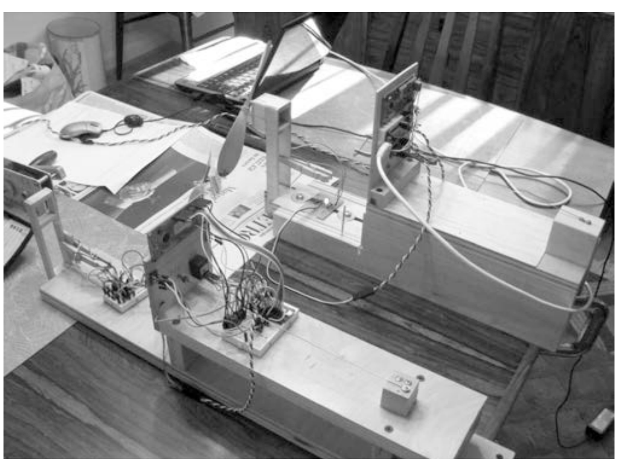

Fig. 1. Overview of RTM's MK1 & MK2, note the torsion wire. The MK2 has neater wiring and an adjustable hook length.

When op-amps became available on dip chips, I built a strain gauge bridge amplifier. Thus my next effort resulted in a strain gauge torque meter that worked quite well, displaying the torque on a LCD display to much better precision than can be gleaned from the dial on a torsion wire torque meter. It was fine for measuring the torque of a small motor, but when I tried using it for larger rubber motors, my original intent, the shock of the bursting motor bent the strain gauged beam, and ruined the strain gauge. I never did get around to porting the data to a recording device.

Well, now with micro controllers readily available, I have figured out how to use a non-contact rotary encoder to measure the angle of twist of a rugged torsion wire torque meter. I have integrated the parts into an engineering unit that communicates with a PC and am developing the procedures to accurately measure rubber motor parameters. See figure 1.

Description

The Recording Torque Meter (RTM) system consists of the test rig housing an Arduino micro controller, a LCD display, a few switches, and a Bourns EMS22A Non-Contacting Absolute Shaft Encoder geared one to one to measure the angle of twist of a rugged wire torque meter. There also is a nose block holder to allow unwinding of the motor by a prop and provision to vary the hook length of the motor. The rear hook has been replaced with a cross tube capable of holding a “wobble peg” to more faithfully emulate the actual installation of the motor in the model. See figures 2 and 3.

The Arduino is triggered by pulses from a winder or a prop. A hall-effect sensor on a Rees winder detects the passing of a magnet attached to the output shaft. This signal is in turn routed to a digital interrupt pin on the Arduino micro computer via Futaba servo extension cables. This pulse causes the Arduino to register a turn, get the time and read the position of the shaft encoder which is translated into in-oz of torque.

Fig 2. Front view of MK2 showing switches and rubber tube mount in lieu of a hook and meshing gears.

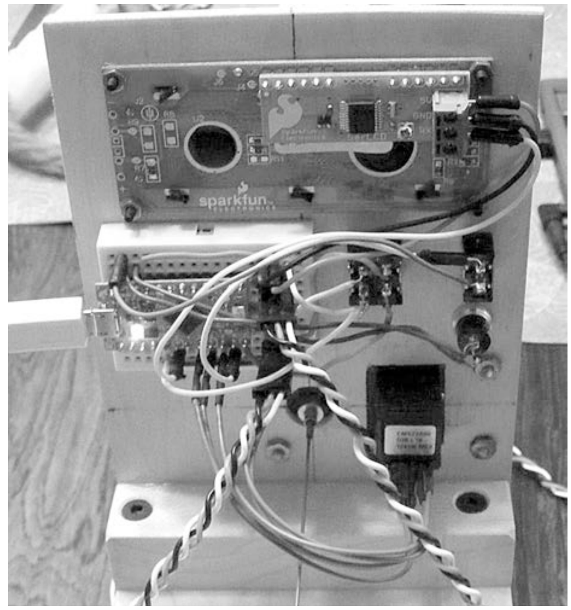

Fig 3. Rear view of MK2. The Bourns absolute shaft encoder is the square block. The braided Futaba cables go to the winder and IR sensor.

If the wind switch is in the WIND position, the turn is added to the total. If the switch is in the UNWIND position, the turn is subtracted from the total. There is another switch that changes the pulse input from the winder to an IR detector that senses prop blade passes. A Schmitt trigger and ‘D’ Flip-Flop is used to condition the IR pulse and divide the pulse count by four. Thus for a two-bladed prop, the torque is recorded after four passes or two revolutions of the prop. See figure 4.

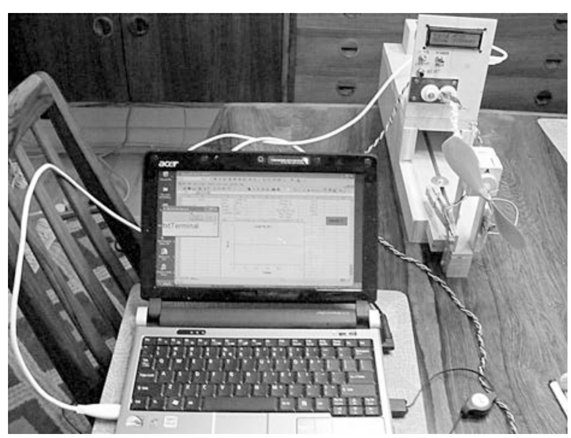

Fig 4. MK2 RTM connected to a laptop ready to go.

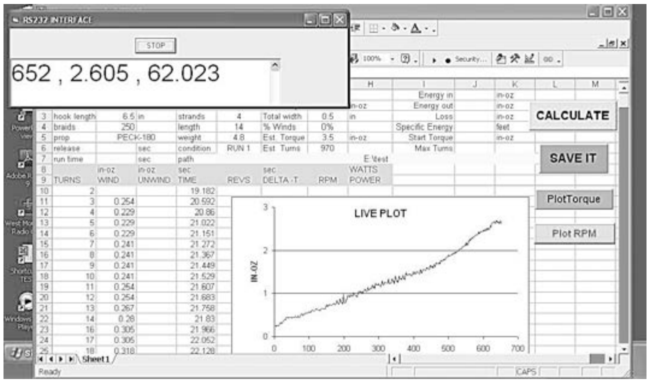

Fig 5. Screen dump from the laptop showing text window and real time plot on the spreadsheet.

Data Display and Recording

Turns and Torque are displayed on the LCD display and sent along with the time to the computer over a USB port as CSV (Comma Separated Variable) data. (This USB port powers the system.) A VB-6 terminal program on the P/C displays this data and stashes it on an Excel spreadsheet. The program senses the change from a monotonically increasing turns count to determine that the unwinding phase has started and displays a real time Torque-Turns graph. If the motor blows you have the last value recorded and the history prior to that saved on the computer. The wire torque meter and its attached gear are free to snap back and forth violently. The absolute shaft encoder on the meshed gear can follow these movements without damage as it's rated to 10,000 rpm and has double ball bearings. See figure 5.

Spreadsheet Processing

The Excel spreadsheet has embed macros to further process the data to compute energy in and out and the Specific Energy for the motor as well as Prop RPM and Power. Each row of the spreadsheet shows the number of turns, torque, and time for one measurement step. Since we now have the torque and turns data time stamped, it is easy to calculate the delta time for each step as well as the change in number of turns. RPM is simply the number of turns that occurred per step divided by the delta time for that step in minutes.

To compute energy or work, the area under the torque curve is integrated by the trapezoidal rule, the number of turns needs to be multiplied by two Pi since the revolutions need to be in radians. The area under the Unwind curve is the Energy Out. Divide the Energy Out by the weight of the motor and you get the Specific Energy the motor actually delivered to the prop.

To compute Power, the number of turns multiplied by two Pi and divided by time in seconds is multiplied by the torque for the step. Since our torque is expressed in in-oz the units are in-oz/sec. This is easy to convert to ft-lb/sec and watts. (If you divide ft-lb/sec by 550 to get hp, the values get really small. Milli-Hp seems a bit ridiculous.) I use watts to allow easy comparison to electric motors and a sanity check on the values I am getting. See figure 6.

Of course you can then take the data from the spread sheet and work it over with a better plot program like Dplot*. In addition to the Torque vs. Turns Plot that is usually presented, we can now plot RPM & Power vs. Time for the unwind phase. (It makes no sense to plot this

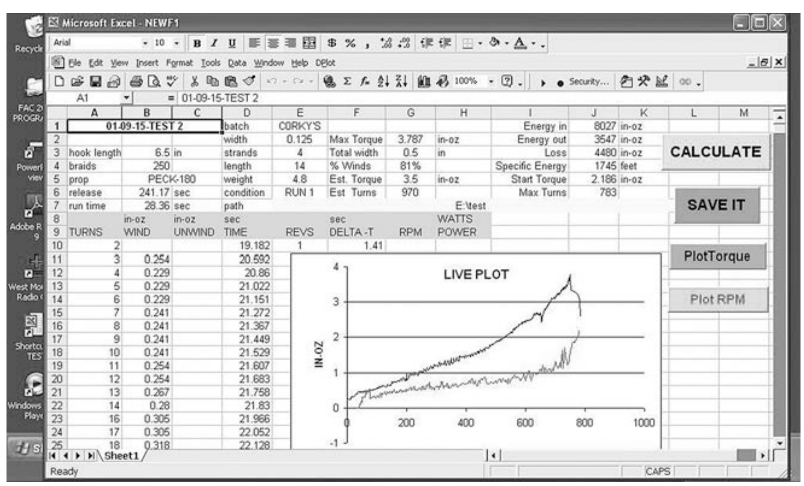

Fig 6. Screen dump at end of run, the Calculate button has clicked to process the data.

for the wind phase.) There are buttons on the spreadsheet to generate these graphs in Dplot automatically. The area under the Power - Time curve is equal to the Energy Out derived from the Unwind - Torque curve. Plotting RPM vs. Power allows one to characterize the performance of the prop used, at least under static conditions. See figures 7, 8, & 9.

Resolution

The prototype unit uses 9.5 inches of 0.032 music wire as the torque wire. This results in a deflection of 30 degrees per inch ounce with a 12 in-oz max torque. The encoder has a resolution of 1024 bits per revolution. That's 12/1024

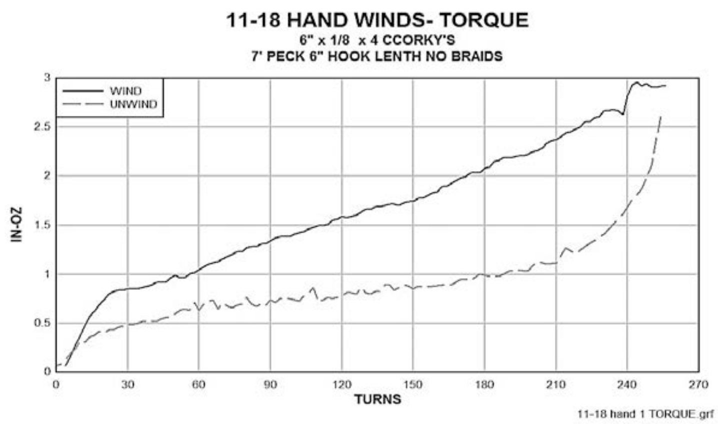

Fig 7. This is a quick dPlot Torque plot of some hand winds used to check power plots.

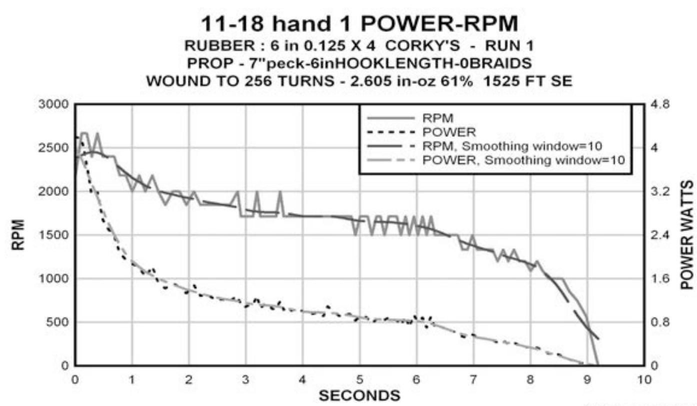

Fig 8. This is a quick dPlot Power plot of the hand wind test to check feasability of prop power plots. The curve have been smoothed so they can be cross plotted to create the Prop characteristic plot. RPM has and erro band of 500 .

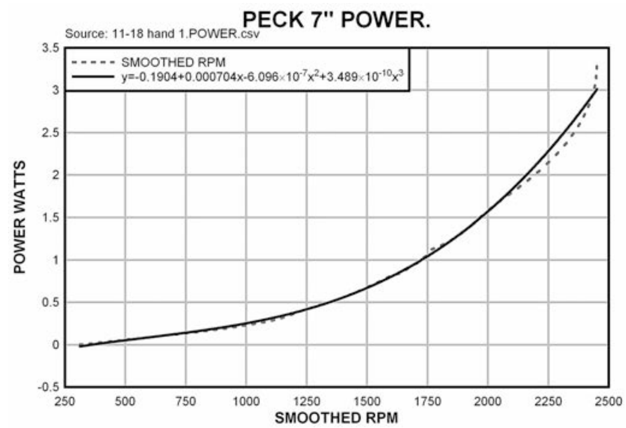

Fig 9. This is the test Prop characteristic plot for the 7" Peck prop used. It looks reasonable, but I would have to make many runs before I would use it.

or 0.012 in-oz resolution, plenty enough. The unit is easily calibrated with a lead sinker on a beam and the calibration factors can be programmed. Before each run the Arduino is reset and zero torque is established. Repeatability due to backlash is probably about a degree or 0.03 in-oz. Still an order of magnitude better than you can read a Wire Torque Meter dial. The particular Wire Torque Meter used in this version of the RTM is optimized for four to six stands of 1/8-inch rubber. Of course this could be changed to better suit other motors. Recording the data every turn on wind or every other if unloading with a prop produces more data points than are needed for any characterization of the motor system. See figure 10.

Procedure

The PC is turned on and connected to the RTM rig with a USB cable.

The rubber motor is attached to the rig on one end and the winder is engaged at the other. Make sure the winder is plugged into the rig.

The Terminal Program is run on the PC. Which brings up a Terminal form. When the NEWFILE button is clicked the program brings up a copy of the Excel spreadsheet and a form to modify it for the particular motor under test.

Things have to be done in the proper sequence. The switches have to be in the right position when data is transmitted to the P/C. The Ardui-

Fig 10. RTM calibration. A special calibration program is loaded on the Arduino which shows the torque every second. A lead sinker is attached to the torque bar and the rig rotated until the bar is horizontal. Comparing the known applied torque to the reading allows one to calibrate the rig.

no must be reset to clear the count and set zero torque before the START button is clicked on the P/C to open the USB port and start receiving data and the winder crank is turned which initiates the process of streaming data.

When the motor has been wound, it is removed from the winder and attached to the prop and the nose block is inserted in its holder.

For the prop unwind phase, in addition to putting the wind/unwind switch in the unwind position, the winder/prop switch must be in the prop position and no direct incandescent light may be flooding the IR detector before the prop is released.

When the run is over, clicking the STOP button on the terminal form closes the USB port and brings up the CALCULATE button on the spreadsheet. Clicking on this runs the macros to process the data. The SAVE button writes the Excel spreadsheet to memory and closes it. Clicking the Plot Torque or Plot RPM buttons creates Dplots of the Torque or RPM-Power.

Observations

Using the RTM was a real eye opener emphasizing the interplay of torque and tension. The ideal "S" shaped hysteresis loop of the typical rubber motor being wound and unwound like that shown in Fig. 11 from McCombs is hard to reproduce in the real world.

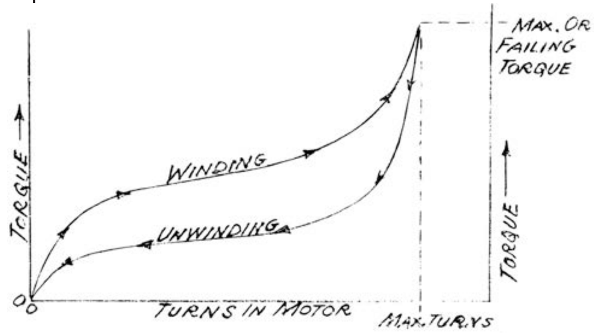

Fig 11 This is the ideal torque hysteresis plotfrom W.F. McCombs.

When you wind a rubber motor, it is constantly trying to redistribute the winds and knots into a minimum energy state. You can think of Hungorilla hanging in there to enforce this law of physics. There is a continual trade off going on between the basic twist and the knots. Tension plays a big role in this. When you stretch a motor and wind, you are usually just putting in pure twist. As you relax tension, knots form. That's the reason for stretching the motor as much a possible when winding. The release of energy during the unwind can be rather chaotic as the motor relaxes and tries to maintain a minimum energy condition while twisting the prop. Here Hungorilla is most active and may poke a hole through the side of your model with a knot.

"Using the RTM was a real eye opener emphasizing the interplay of torque and tension."

Watching the dial on a wire torque meter gives you some clues as to what is happening when you wind a motor. That slow, even rise is what you should be looking for. Tension is the other key variable. The preferred procedure seems to be stretch it out to five times the relaxed length and then try to wind at constant tension. With heavily braided motors you may notice a drop in tension as you start to wind. Extending the motor returns to the initial tension. I think this is the braiding turns rearranging themselves. At about 50% winds, start moving in while maintaining tension. You will notice a gradual increase in torque. Above 80% winds you may notice that more rapid increase in torque that warns you to stop before burst.

Watching the slope of the winding curve in real time on a P/C attached to the RTM gives one a much better feel as to what is going on than you can get from observing the dial on a torsion wire torque meter. That critical change in slope above 80% is much more distinct. The drop in torque as the winder is removed and the nose block is inserted into the rig is also readily apparent. The influence of tension on torque is profound and tension must be kept near constant to approximate the ideal curve. It would be desirable to record the tension as well as torque. What we actually see looks like Fig. 12.

Prop Unwinds

Allowing the prop to release the stored energy rather than using the winder is what makes the big difference between RTM results and most

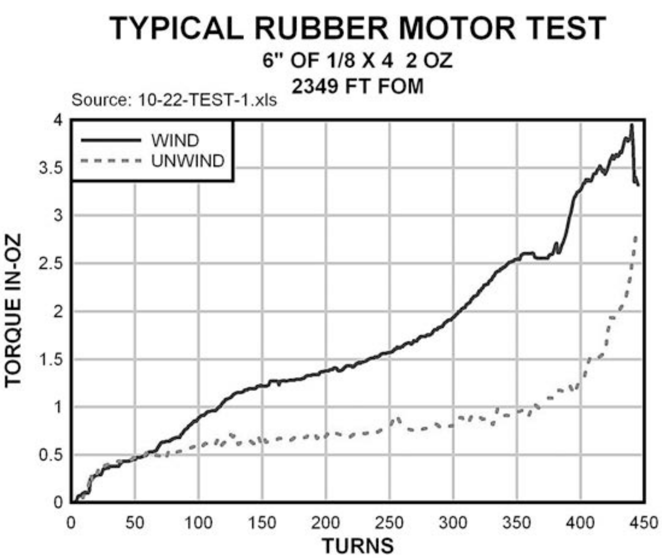

Fig 12. This is what we actually see when we plot the output of the RTM.

of the data I have seen. You can see the knots unwind and standing waves if they are present. The behavior of a rubber motor under test can be directly related to how it will behave in the model. See figure 13.

Since we are going to use the prop to unload the motor, some questions arise about how we treat transferring the rubber to the prop

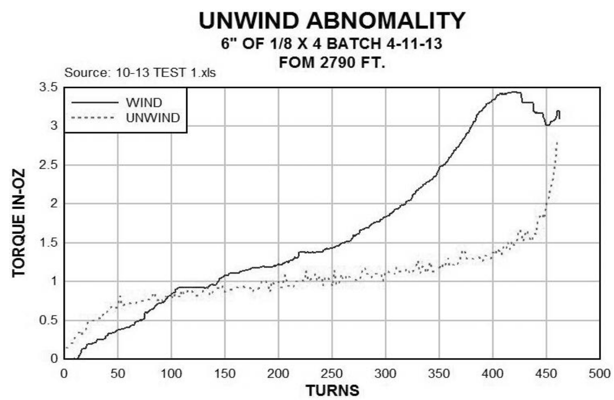

Fig 13. This plot duffers from the classical Torque Turns curve as below 100 turns the unwind curve is higher than the wind curve.

At first glance this seems to be impossible.

You can't always look at a given number of turns and assume the unwinding torque will be less then the winding torque at that point.

The rate at which the energy was put into the rubber motor is independent of the rate at which it is removed.

hook and inserting the nose block. This operation is the source of a large drop in tension and therefore torque. My initial thought was to minimize this loss to more closely emulate the ideal graph. To this end, I put a winding loop on the prop shaft and ran some tests using this approach. However since my intention for using the RTM is to characterize the motor I was using in a model, I went back to winding the rubber directly. Transferring the rubber from the winder to the prop hook can entail losing some winds as well as the loss of tension and therefor torque, if a Crocket hook or "O" ring is not used. These lost turns can be compensated for in the data processing. See figure 14.

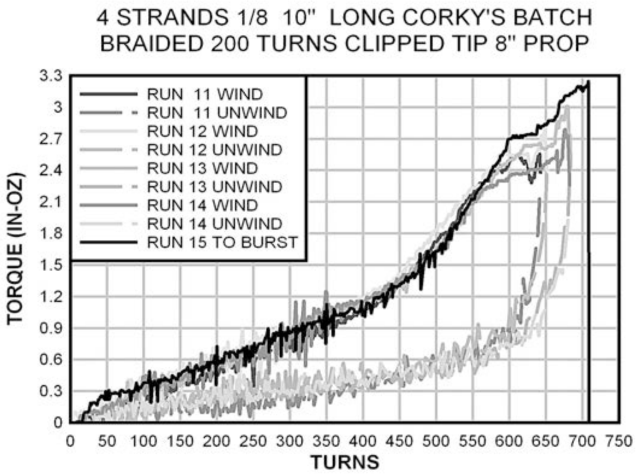

Fig. 14. Superposition of several runs of a well used motor shows consistency except in the last few winds as the motor is walked in.

I finally got tired and just wound to burst.

Recording Standing Waves

A Mobius ActionCam** can be set up to record the rundown of the motor and any standing waves that may develop. By including the LCD display or P/C screen in the background, the behavior can be correlated to the recorded data on the spread sheet. It's interesting to note how the knots unwinding are reflected in the data even when the evil standing waves are not present. See figure 15, 16 & 17.

Tension Measurement

To investigate the relationship of torque to tension, I got a #84707 Digital Pull Meter from Micro Mark. See figure 18. Unfortunately this meter does not read continuously, but goes into a hold mode if it thinks the pull has stabilized. So it essentially reads the max pull. It also turns off after 90 seconds. If you hit the off-on button before the 90 seconds is up, you can get out of the hold mode and get new readings. A little awkward while winding; you need a third hand. That being said, I did determine that 4 strands of 1/8 goes hard at about 40 ounces of tension. It is also obvious that the Torque-Tension relationship is not a linear. This Pull Meter would be better used to check out tension vs. extension for different batches of rubber. However, I would be leery of using this meter to pull

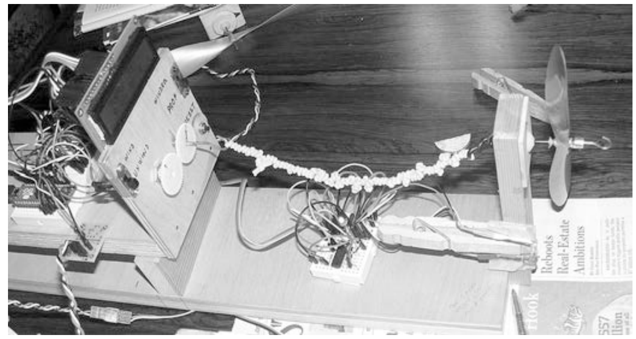

Fig. 15. This is a stop action photo of a rather large standing wave. On some runs it was large enough to knock some of the wires out of the IR conditioning circuit in the plug board under it on the MK1 RTM stopping the recording of data.

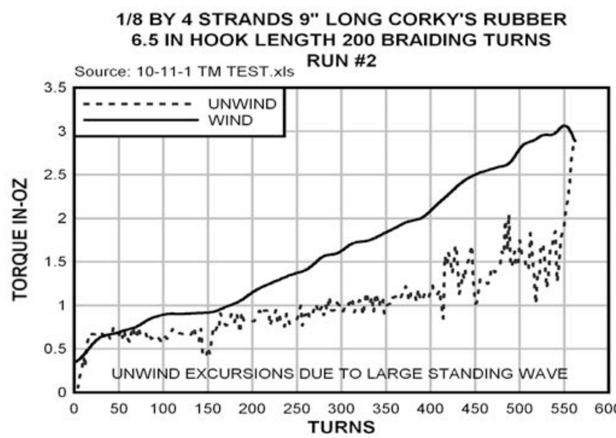

Fig. 16. Here is what a standing wave does to the torque plot.

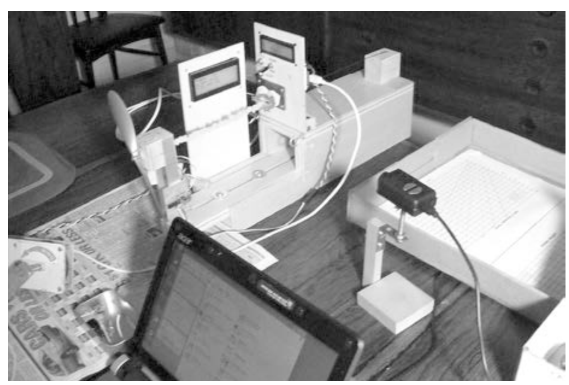

Fig. 17. A Moebus Cam is set up to record the rundown.

An auxiliary display has been added to appear in the background.

The action of the rubber motor can therefor be tied to the data.

You can see the effects of knots unwinding or the evil standing wave on the data.

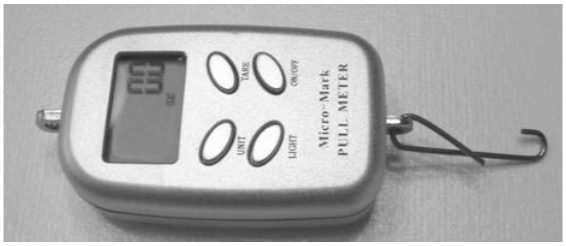

Fig 18. The pull meter used for tension tests.

rubber to burst because shock might damage it. Perhaps comparing the batches at an extension ratio of five would be conservative enough.

I am currently working schemes to measure Tension by a strain gauge while simultaneously measuring torque and input it to the Arduino where it can join the data stream going to the P/C spreadsheet.

Sag Tests

Another use for the RTM is SAG testing. A question came up during a FAC mass launch about how much energy is lost by waiting around with a wound motor. If you wind a motor hooked to a wire torque meter and hook the other end to establish a fixed length, you can barely see the meter dial move over time. It was a trivial matter to reprogram the Arduino on

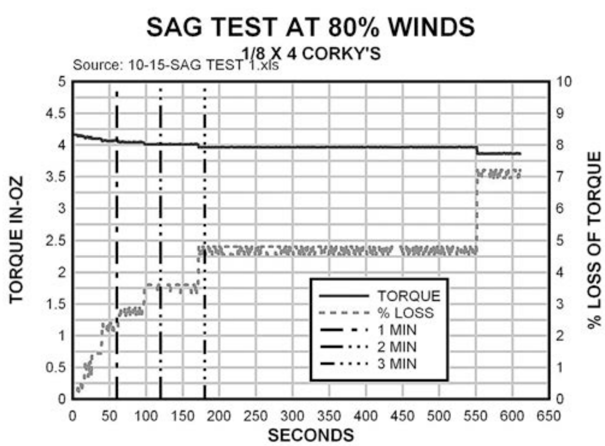

Fig 19. The results of a SAG test. Note less than 1% loss in the first minute.

one of my recording torque meters to ignore the winder and simply output the torque every second. A mere 600 data points covers 10 minutes. More than enough time to establish what is going on. Not surprisingly, the sag loss is dependent on the percent of max torque the motor is wound to. At 50% there was no appreciable drop over ten minutes. For the particular 1/8" rubber I was using at 60% (not unreasonable for the first sortie in a mass launch event), the loss was less than 1% for the first minute, 1.5% at two minutes, and 4% at three. After ten minutes the drop was 7.5%. These are smoothed curves. The "bumps" are due to changes in torque when a knot is relaxed and the winds redistribute. See figure 19.

The Three "Ts"

The RTM, can measure Turns, Torque, and Time for a rubber motor and record them on a spreadsheet for data analysis. By using a small video recorder we can also observe the behavior of knots and standing waves if they are present. It's early and I am still developing the RTM and associated data analysis techniques. Hopefully, I can add a fourth T, Tension to the recorded data. I intend to run a series of tests to see what I can learn about specific motors used in some of my FAC ships and extrapolate the information to rubber motor behavior in general.

RTM Drawings, Schematics and Code.

I certainly don't have the time to perform all the tests that are brought to mind by the looking at the plots generated. Therefore, I am happy to supply the drawings, parts list, schematics, and code to build your own Recording Torque Meter. Be forewarned these are in a state of flux as I further develop the system. This article is not the place for this information so contact me if you are interested.

dPlot is available from www.dplot.com.