MWT model – parameters for prototype MWT supplied to UC Berkeley
ASH, 04.01.18, updated 07.01.18

Parameters have been extracted for the prototype MWT assuming the reduced model shown below. In this model the bearing torque is not shown explicitly; rather it is combined with the shaft torque. The source T_{op} at the left of the model represents the available shaft torque after the bearing torque has been subtracted off.

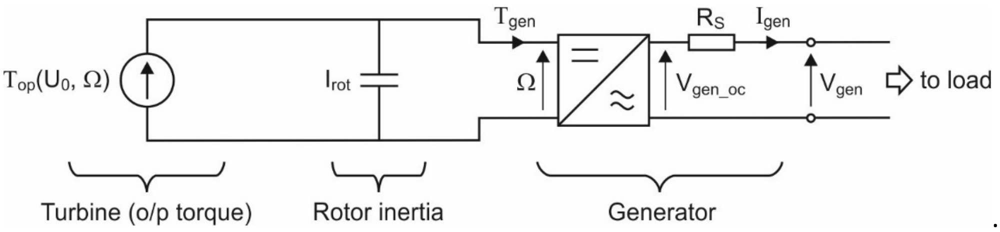

Figure 1: Simplified MWT model.

The variations of T_{op} with flow speed U_0 and rotation speed Ω were estimated from the wind tunnel data obtained in August 2017. In the wind tunnel tests the turbine was characterised at several different flow speeds using a variable resistive load. For each flow speed and load setting, the electrical frequency (and hence the rotation speed), the AC load voltage V_{gen} and load current I_{gen} were recorded once the turbine had reached steady state. Using these measured values, the turbine output torque in steady state was estimated using:

$$T_{op} = \langle T_{gen} \rangle = \{\langle V_{gen} I_{gen} \rangle + \langle I_{gen}^2 \rangle R_s\}/\Omega \qquad (1)$$

where $\langle\ \rangle$ denotes time average. Equation (1) assumes that any non-resistive losses in the generator (e.g. eddy current losses) are negligible. Figure 2 shows the observed variations of T_{op} with rotation speed for 5 flow speeds in the range 3.3 to 7.0 m/s.

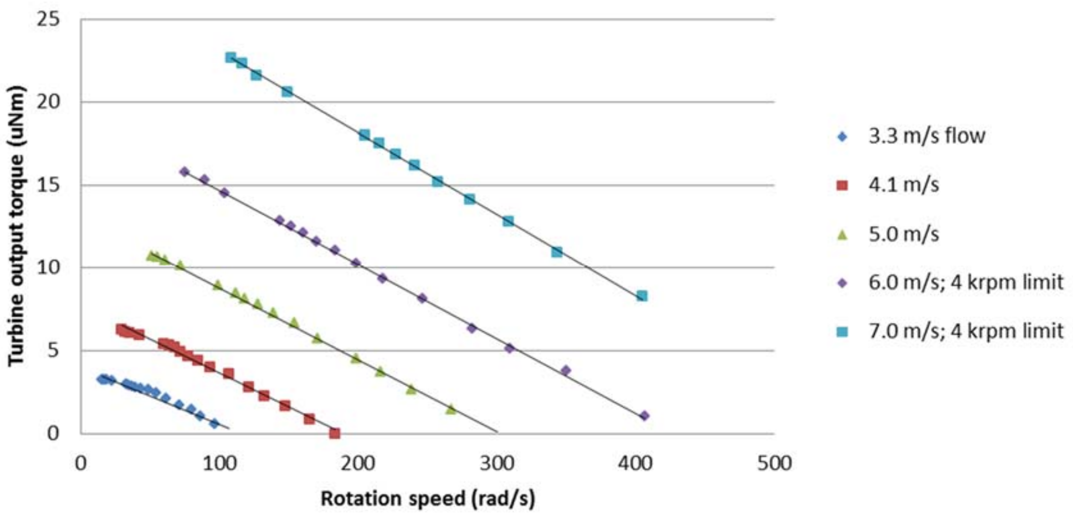

Figure 2: Variations of T_{op} with Ω at different flow speeds, derived from wind tunnel data using Equation (1).

Figure 2 also shows linear best fits to the data in which the torque variation is approximated as:

$$T_{op} = T_{op0} + T_{op1}\Omega \tag{2}$$

The coefficients T_{op0} and T_{op1} corresponding to the best-fit lines in Figure 2 are shown in Table 1.

Table 1: Coefficients for best-fit lines in Figure 2.

U_0 (m/s)	T_{op0} (μNm)	T_{op1} (μNms/rad)
3.3	3.98	-0.034
4.08	7.7	-0.041
5.03	13	-0.043
5.95	19.1	-0.045
7.02	27.9	-0.049

Figure 3 shows the variations of T_{op0} and T_{op1} with flow speed, together with suggested trendlines. The T_{op0} data fits well to a quadratic curve. A linear fit has been used for T_{op1}; this is not great but there is no reason to use a higher order polynomial.

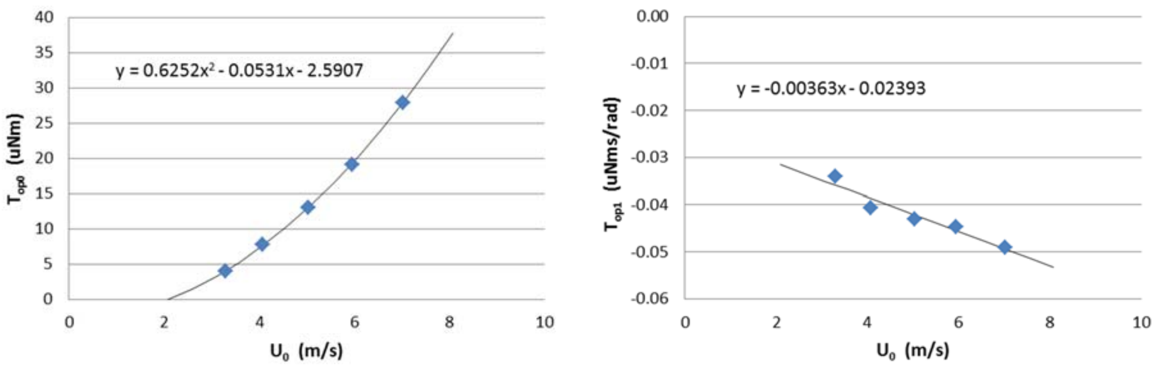

Figure 3: Variations of T_{op0} and T_{op1} with flow speed, with suggested quadratic and linear fits.

Using the above forms for T_{op0} and T_{op1}, Equation (2) becomes:

$$T_{op} = a_2U_0^2 + a_1U_0 + a_0 + (b_1U_0 + b_0)\Omega \tag{3}$$

where the coefficients a_i and b_i are the polynomial coefficients in Figure 3.

It should be noted that, while it can be expected to work well for flow speeds within the range covered by the wind tunnel tests, the approximate form in (3) cannot be relied on to give accurate predictions outside this range. For example, at the lower end, it predicts a start-up speed of ~2.1 m/s which is known to be lower than the actual start-up speed of ~3 m/s. This is because the linear fit for T_{op} in Figure 2 breaks down at low rotation speeds. At the upper end it can probably be used with reasonable confidence for flow speeds up to ~10 m/s.

The other parameters required for the model in Figure 1 are the rotor moment of inertia, the generator source resistance, the generator constant and the number of pole pairs. The values for the prototype MWT are $I_{rot} = 408\ \mathrm{g.mm^2}$, $R_s = 21.3\ \Omega$, $K_{gen} = 2.58\ mVs/rad$ and $N_p = 16$.