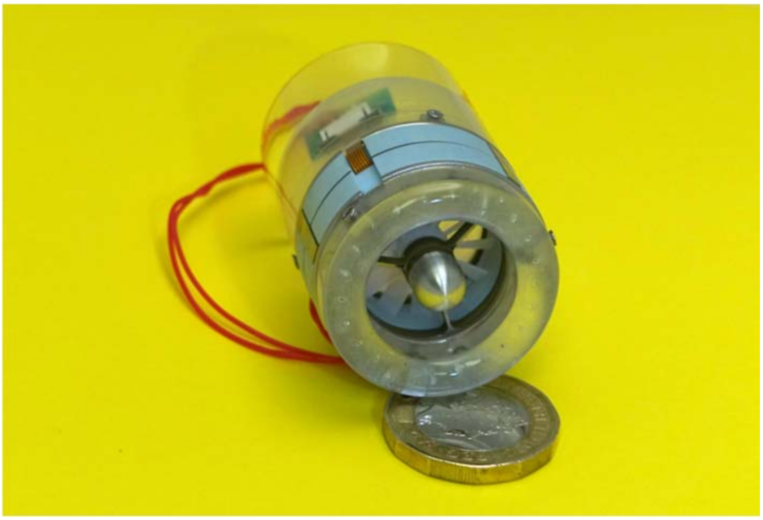
Micro Wind Turbines for Energy Harvesting
in support of
Self-Powered Wireless Sensor Nodes

Test data for first prototype MWT supplied to UC Berkeley



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15 August 2017

1. Introduction

This document contains preliminary wind tunnel test data for the prototype energy harvester supplied to UC Berkeley in respect of milestone M1.1 of the Seedling Project. A new rotor design and fabrication method were adopted for this device compared to the earlier MWT reported by Imperial College [1]. The stator and magnet configurations of the generator were also modified. Otherwise the design was similar to that of the earlier device.

The turbine was characterised under conditions of constant flow speed by applying a variable resistive load (R_L) and measuring or deriving the following quantities:

Vgen	V	RMS generator output voltage (i.e. terminal voltage *after* voltage drop due to stator resistance)
Igen	A	RMS current into load
f	Hz	electrical frequency of generator output
N	rpm	turbine rotation speed, calculated using the relation $N = (60/16)\times f = 3.75f$
P_L	W	average power into load, calculated as the time average of $Vgen \times Igen$

This test was repeated at different flow speeds in the range 3 to 7 m/s.

Testing was carried out in an 18” × 18” cross-section, low speed recirculating wind tunnel in the Aeronautics Department at Imperial College. The turbine was mounted at the centre of the test section, supported on an aerodynamic arm attached to one side of the tunnel. The tunnel flow speed was measured using a Pitot tube positioned ~20 cm upstream of the turbine and ~7 cm above the base of the tunnel. The Pitot tube was connected to a Furness Controls FC0510 micro-manometer.

NOTE: In all tests, the turbine rotation speed was not allowed to exceed 4,000 rpm as in earlier testing it had been found that rotor imbalance could lead to significant vibration at higher rotation speeds. For higher flow rates (≥6 m/s), a minimum electrical load was required to ensure the rotation speed did not exceed the 4,000 rpm limit.

2. Generator parameters

The generator is a 3-phase permanent magnet machine. However, for the experiments reported here, the three stator windings were connected in series (as A + B – C) to produce a single winding with twice the open-circuit voltage, and 3× the source resistance, of an individual phase winding.

The generator constant *Kgen* (RMS open-circuit voltage per unit rotation speed) and stator resistance R_S of the resulting single-phase generator were found to be:

$$Kgen = 0.27\ \text{mV/rpm} \quad ; \quad R_S = 21\ \Omega$$

The stator resistance is markedly lower than for the device reported in [1] because the coil configuration is different (fewer turns with wider conductors). The generator constant is higher than reported in [1] in spite of the lower number of turns because the present device has two magnet rings whereas the device in [1] had only one.

3. Performance curves

Figure 1 shows how the power delivered to the resistive load varies with load current.

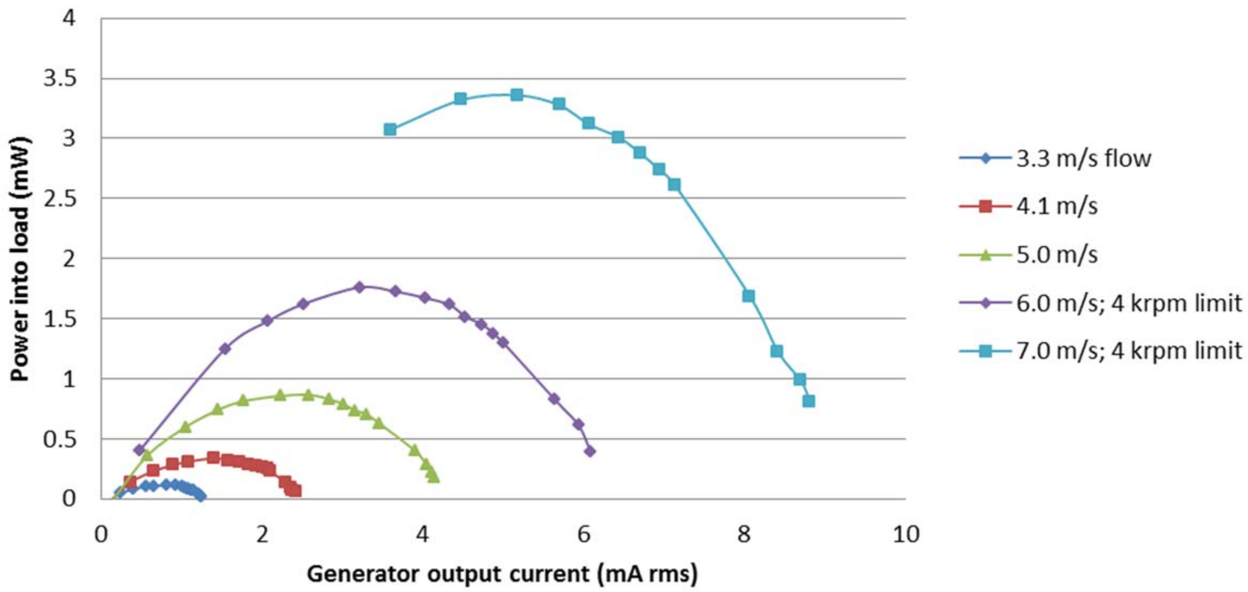

Figure 1: Load power vs load current.

Points to note from Figure 1:

- The load power passes through a single maximum when the load is "matched". This kind of behaviour is typical both for an electrical source with a finite source resistance and for a turbine. Actually in this case the overall characteristic is dominated by the turbine, which slows down (leading to a reduction in generator output) as the electrical loading becomes heavier.
- The curves for 6.0 and 7.0 m/s do not extend to zero current because a minimum level of electrical loading was required to maintain the rotation speed ≤4,000 rpm.

Figures 2 and 3 below show the corresponding variations of RMS generator output voltage and electrical frequency with load current.

Points to note from Figure 2:

- The I-V plots are approximately straight lines suggesting that, for the purposes of steady state power estimation, the turbine/generator combination can be represented as an AC voltage source with an effective source resistance.
- If straight lines are fitted then effective source resistances in the range 160 to 225 Ω are obtained. This confirms that the I-V characteristics of the device are dominated by the turbine, since the stator resistance is only 21 Ω.

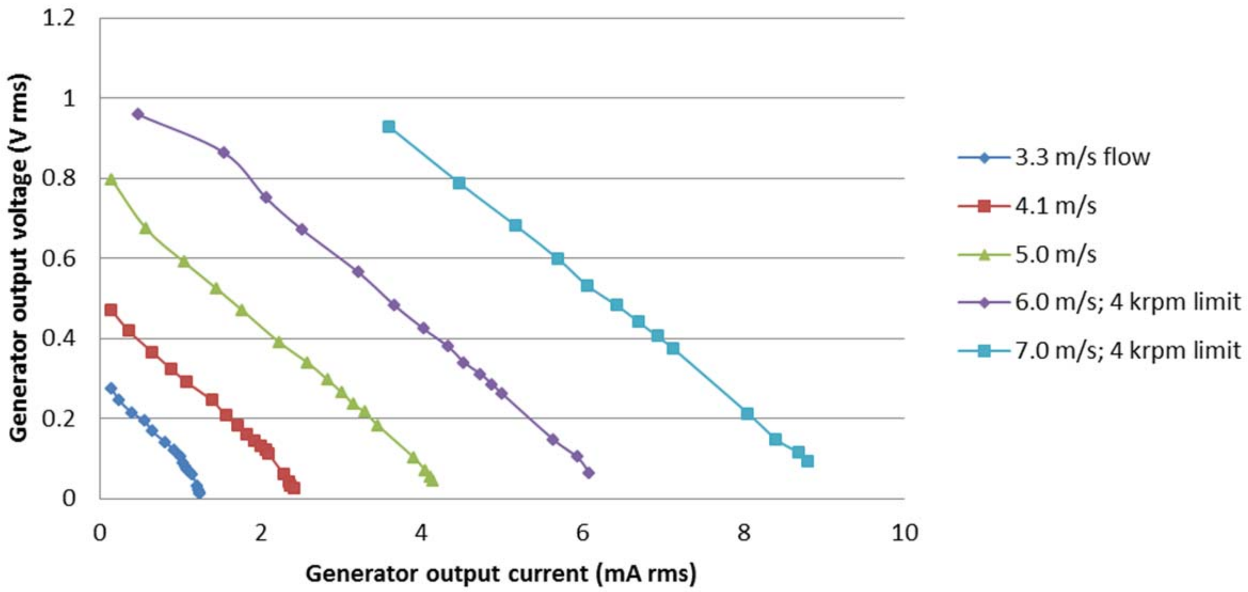

Figure 2: Generator output voltage (= load voltage) vs load current.

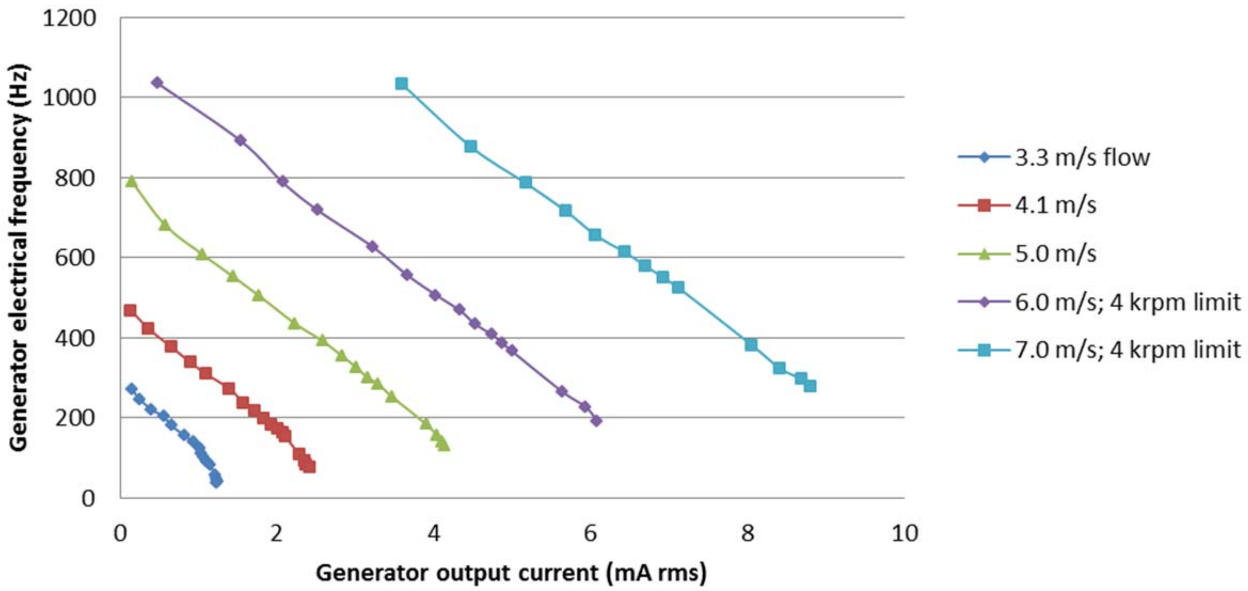

Figure 3: Generator electrical frequency vs load current.

4. Maximum electrical power levels

Table I below summarises some of the key numerical data, including the maximum measured electrical power delivered to the load at each flow speed (col 2), the load resistance for which this maximum occurred (col 3), and the corresponding generator electrical frequency (col 4) and turbine rotation speed (col 5). The right-most column shows the maximum allowable load resistance, above which the turbine speed would rise above 4,000 rpm.

The load resistance at maximum power is expected to decrease monotonically with increasing flow speed. The values in Table I do not reflect this because they are calculated as V/I ratios at actual measurement points which may not correspond to the true maxima; also, the measured V-I characteristics are not perfect straight lines as can be seen from Figure 2.

Table I: Summary of key numerical data.

Flow speed m/s	**max P_L mW**	**R_L at max P_L Ω**	***f* at max P_L Hz**	***N* at max P_L rpm**	**max R_L Ω**
3.3	0.11	172	156	585	∞
4.1	0.34	174	271	1018	∞
5.0	0.87	131	391	1467	∞
6.0	1.76	176	627	2353	~2000
7.0	3.36	131	785	2944	~260

References

1. Howey D.A., Bansal A., Holmes A.S., "Design and performance of a cm-scale shrouded wind turbine for energy harvesting", *Smart Materials and Structures*, 20, (2011), paper 085021 (12pp).