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Mapping and Characterization of a Demonstrational Stirling Engine

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1. Abstract

This work demonstrates mapping and characterization of engines producing minute power outputs [mW], such as demonstartional Stirling engines. Measuring physical parameters (torque, power) is problematic when involving low rotational speeds, low torques and therefore low power outputs. Moreover, the use of commercial dynamometers for such purposes is problematic if even possible. An innovative method for measuring minimal power outputs of a rotating shaft in general, is proposed here. Experimental work based on external load measurment, and calibration with respect to known characteristics was performed. The work results in mapping a demonstrational Stirling engine showing a unique technique for such needs.

Keywords: Stirling engine, dynamometer, power, torque, engine mapping.

2. Introduction

Nowadays there is a deficit of cost-effective commercial methods of mapping small engine outputs. Stirling engines, which are characterized with low power to size ratio produce small outputs, in particular engines for laboratory and demonstrational uses. The work presents a simple and low cost, yet efficient technique for measuring such outputs. The scheme includes loading a demonstrational Stirling engine using a propeller mounted on the end of its axis. The propeller, thus the Stirling engine load is controlled with a fan placed in line with the engine, creating air flow in a manner that contradicts the air flow generated by the engine`s propeller itself, as shown in figure 2.1.

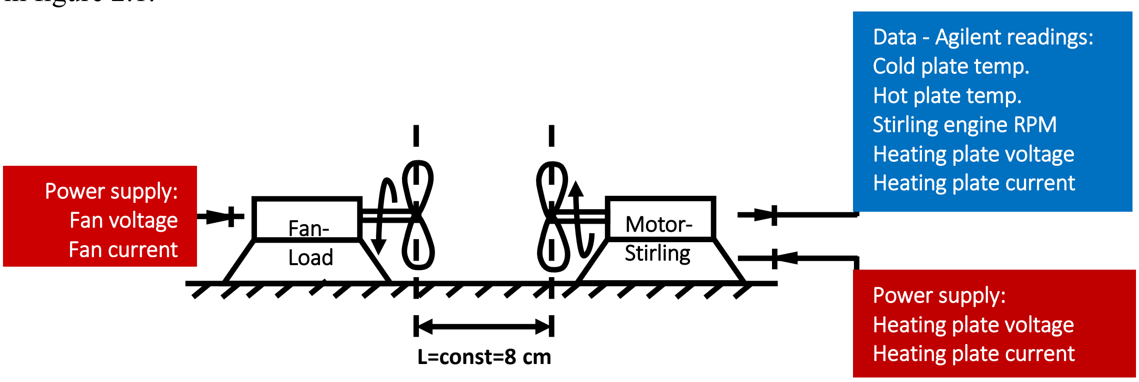

Figure 2.1. loading scheme of the Stiriling engine

The load and operational conditions such as fan speed i.e. airflow and engine speed were applied to a DC engine that replaced the Stirling engine, as shown in figure 2.2. At this stage the energy input to the DC engine was recorded.

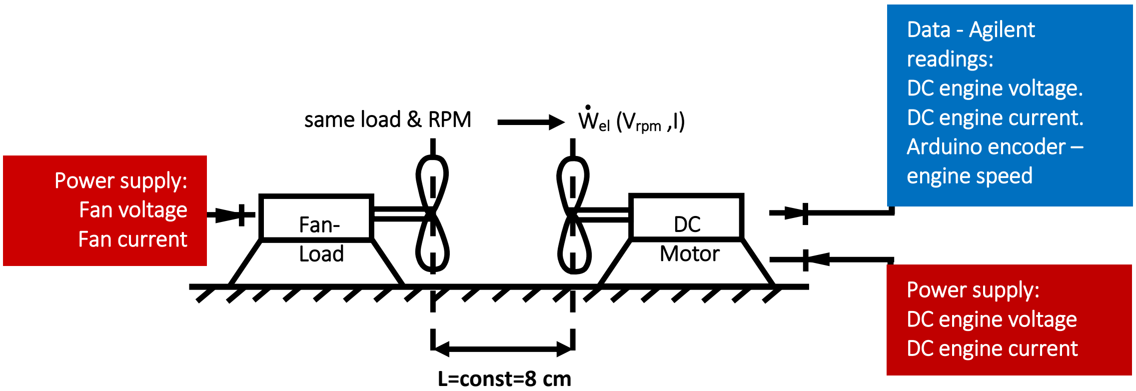

Figure 2.2. loading the DC engine with the same operational conditions

Later on, the DC engine's power output was measured by loading it with a set of weights, changing their height in specified time to receive the same loading conditions for the DC engine i.e. same energy input to it. This stage is conceptually shown in figure 2.3. The Stirling engine was powered by a controlled heating element forming heat generated inside the engine. Here, special design of heater housing was created allowing fine insulation from the surrounding environment. Temperature of the engine`s plates and surrounding environment were measured during all experiments.

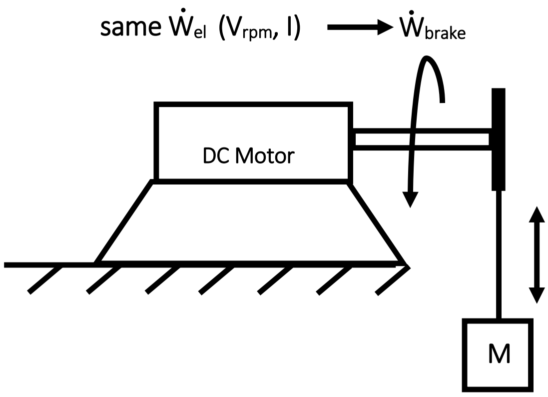

Figure 2.3. DC engine power output calibration

3. Contributions

Many systems include small engines working in a verity of purposes and in vast operational conditions. Some engines which are characterized with small power output and small rotational speed are of interest in this work, in particular the demonstrational Stirling engine. Due to engine size, some produce minute power that is difficult to quantify. The method herewith presented shows first and foremost the capability by applying the method discussed. The experiment conducted is a proof of concept and may constitute an accurate and cheap solution to the need of mapping such engines. The simplicity of carrying out the measurements in the conducted experiments implies that a universal platform for mapping engines can be made, making measurements much more approachable.

4. Results and Discussion

In the experimental procedure different readings were taken such as engine speed, power input of heating element to the engine, ambient temperature and pressure, engine's hot and cold plate temperature and isolation temperature. In addition electrical parameters of the loading fan and DC motor were also measured. Using the above complex of measured data, power output, torque and engine total efficiency were calculated. Altogether, 30 different and separate points of engine run were measured and reported. Figure 4.1 describes the engine output for different engine speed at five heat inputs to the engine.

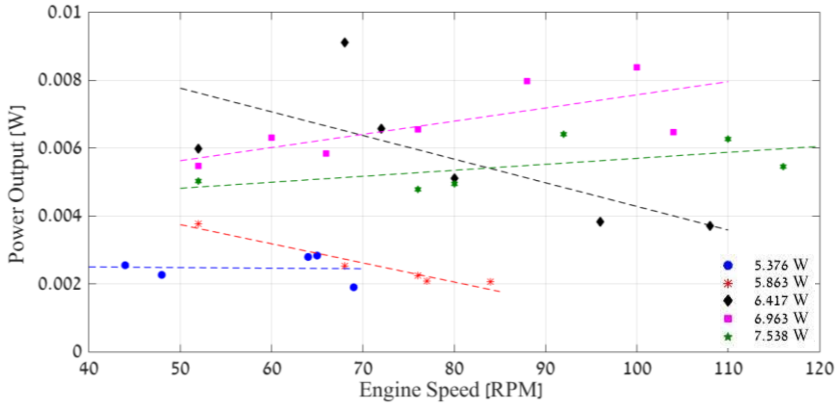

Figure 4.1. Stiriling engine power output with respect to engine speed at 5 different heating element inputs

It is shown that from the different points above described, the maximum power measured is 9 [mW] at 68 [RPM] when the heating element was set to 6.4 [W]. Also, at heat input of 5.3 [W] to the element, the power output was hardly affected by the change in engine speed. For heat input of 5.8 [W] and 6.4 [W] a positive trend can be seen, while the opposite is valid for heat input of 6.9 [W] and 7.5 [W] which have a negative trend. This implies that an optimal working zone can be achieved when the heating element is set to 6.4 [W] and the engine is undergoing a load that leads to an engine speed of 68 [RPM]. Figure 4.2 shows the calculated torque for the same operational modes as described in figure 4.1.

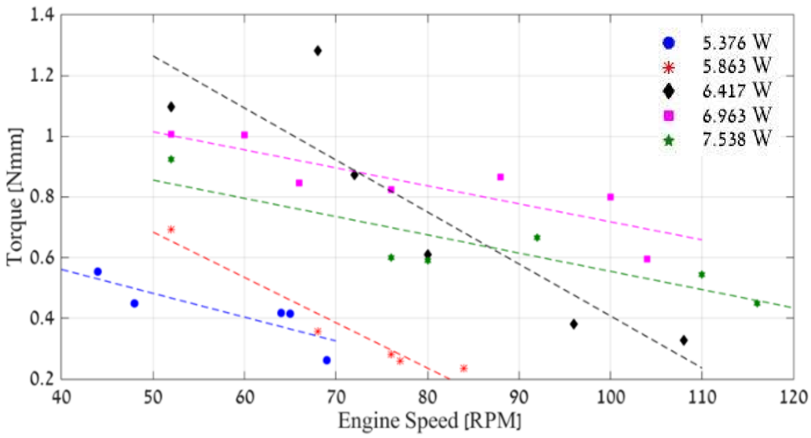

Figure 4.2. Stiriling engine torque output as with respect to engine speed at 5 different power inputs to the heating element

Here it is shown that as the load increases, engine speed is reduced. This behavior is typical and predicted as a result of the load. The optimal working area of the engine can be seen again at 68 [RPM] in the figure above, producing a torque of 1.3 [Nmm] in magnitude. Figure 4.3 below shows the actual efficiency of the Stirling engine with respect to Carnot-efficiency calculated on the basis of the measured temperatures of the heater plate and the surrounding environment.

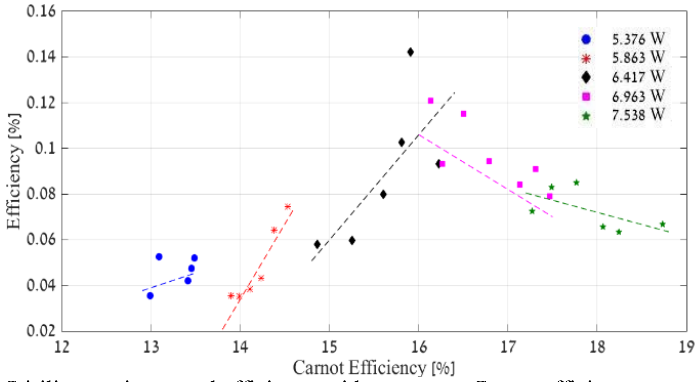

Figure 4.3. Stiriling engine actual efficiency with respect to Carnot efficiency at each point for 5 different power inputs to the heating element

Here, on one hand positive trends can be observed for heating element inputs up to 6.4 [W], while on the other hand, negative trends are shown when the element's power increases up to 7.5 [W]. It is implied that there is an optimal working zone, as above stated. Figure 4.4 shows an approximated surface, fitted to the measured operational modes.

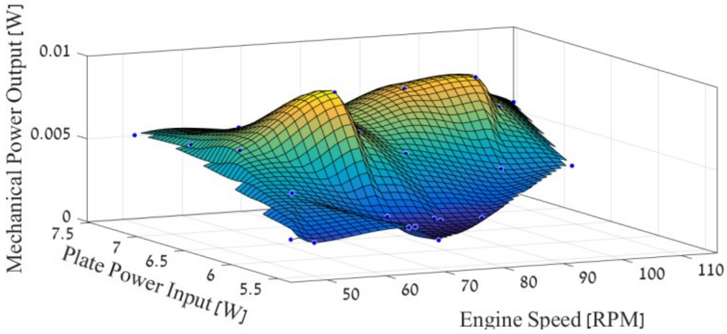

Figure 4.4. approximated surface for modes that were not measured explicitly.

Here, general operational regimes can be derived, which may be suited to given conditions, as power input or speed, other than had been measured in practice.

5. Conclusions

The conducted work concludes that the method proposed and developed is capable of measuring minute power outputs of engines. Involving the demonstrational Stirling engine that was studied in this work, it is shown that:

1. The engine's output ranges between: power of 1–9 [mW] producing shaft torque between 0.2–1.3 [Nmm] for rotational speeds varying from 44-116 [RPM].
2. An optimal operational regime is clearly derived from the conducted experiments as described in the characterization maps shown above.
3. The optimal point is at an engine speed of 68 RPM and power input of 6.4 [W]. At this point the engine produces 9 [mW], 1.3 [Nmm] of torque and has 0.14 % efficiency.
4. The results come in agreement with estimated approximations and preliminary experimental work, previously conducted.

6. References

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