Scientific report

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Thanks to the research networking program Exploring the Physics of Small Devices (project number 6383), I visited Prof. Christian Van den Broeck and his Phd student Tim Willaert at Hasselt university from the 6th January to the 17th January 2014. This visit has been really productive and has significantly accelerated my researches on a timely topic: The question of the fluctuations of efficiency has been risen several times in the recent conferences I have attended.

Purpose of the visit

The aim of this visit was to share and summarize common work on the fluctuations of efficiency of small thermal engine. This project started six months ago by the study of a specific model, namely a modulated two-level system. This study was carried out by T. Willaert on the basis of previous work realized in collaboration with C. Van den Broeck [2]. On my side, I have worked during this period on the general meaning of a fluctuating efficiency at the large deviation level and interact by mail and phone many times with T. Willaert. During the visit, we gathered our works on these topics and started to write a letter.

In addition, I have worked in the last year on a mean field theory for non equilibrium one dimensional systems and on the statistics of dissipation in such systems. This work concerns at the moment a toy model proposed by C. Van den Broeck and called the Brownian Donkey [1]. My interest for this model comes from the possibility to extend it to more general systems, like chemical networks. This visit was for me a good occasion to benefit from C. Van den Broeck expertise in this field.

Description of the work carried out during the visit

During this visit, I shared my time between the two projects shortly described above. The work carried out on the fluctuation of efficiency in small thermal engines was 1) to agree on the precise topics to address in the letter, 2) to agree on the notations to use, 3) to check the validity of the results we obtained separately (including the numerical results), 4) to produce the figures which illustrate well our results, 5) to understand the physical interpretation of our numerical results. All this work has provided the materials needed to realize the letter: One week after my visit, a first version of the letter exists but still needs improvements and reorganization.

On another side, I have worked on the Brownian donkey thanks to several useful discussions with C. Van den Broeck. These discussions lead to the conclusion that I have to study a simplified version of the model (without interaction) to illustrate the theoretical tools I am proposing in the field. Our discussions concerned the physical interpretation of the results obtained on the Brownian Donkey. These results, obtained with two independent methods, agree with each other but the physical understanding is still not clear for us. This explains why we are considering to study a simpler model than the Brownian donkey, i.e. without phase transitions.

Description of the main results obtained

During this visits, we obtained the first quantitative statement on the fluctuations of efficiency in small thermal engine. We have been able to argue that the fluctuations of efficiency decay exponentially with time and that the most probable efficiency (remaining at long time) coincides with the usual definition of thermodynamics efficiency.

We have also obtained a geometrical interpretation of the shape of the large deviation function of efficiency of a thermal engine. Such a function is obtained from a contraction of the large deviation function of work and heat which can be seen as a geometrical operation. The maximum value or the plateau value of this function are easily understood from this geometrical interpretation.

On another side, I understood from the discussions with T. Willaert that it was a difficult task to obtain the exact large deviation function of efficiency in the close to equilibrium limit for the modulated two-level system. In this limit, I have shown that the large deviation function of efficiency can be obtained knowing the first and second work and heat cumulants. The second cumulant of heat is rather difficult to obtain even for our simple model. Using the fluctuation theorem, valid in our model, I have been able to show that all these cumulants are related to each other. This allows to avoid the computation of the second cumulant of heat simplifying the calculations.

Future collaboration with host institution

I plan to continue my collaboration with C. Van den Broeck and T. Willaert on the two project described in this report. Our work on the fluctuations of efficiency may require additional investigations: the two-level system we have studied is very rich and the full description of this model goes beyond the scope of the letter we are writing. Similarly, our work on the fluctuation of entropy production in mean field models goes beyond the Brownian donkey. I expect to continue my collaboration on this topic with C. Van den Broeck.

Projected publications

In addition to the publication of a letter on the fluctuation of efficiency in small thermal engine, we plan to publish an article on the fluctuation of entropy production in systems with a phase transition, with an application to the Brownian donkey model and to a model of independent spins without interaction.

References

[1] B Cleuren and C Van den Broeck. Ising model for brownian donkey. *Europhys. Lett.*, 54(1):1–6, APR 2001.

[2] G. Verley, C. Van den Broeck, and M. Esposito. Modulated two-level system: Exact work statistics. *Phys. Rev. E*, 88:032137, 2013.