Microscale Turbine/generator Unit for Energy Harvesting in Fluidic Mechatronic Systems

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Abstract

Up to now, the fluidics-specific operation of micro-mechatronic fluidic systems has required two parallel forms of energy (fluidic and electronic share of work and output). This incurs costs for wire routing and energy provision. The self-sufficient fluidic systems known so far work with batteries or accumulators, which also incurs high costs for maintenance and disposal. The overall increase in decentralisation and flexibilisation moves the focus more towards the aspect of installation space:

- Limited installation space requires functions to be integrated in the smallest possible space
- The integration of functions requires the use of micro system components

The powerFLUID project aims at converting the fluid-inherent mechanical energy into electric energy, herewith supplying microtechnical function modules by using suitable conversion systems [1]. As an initial step, this article describes a general approach to selecting suitable conversion systems and to applying adequate consumer loads, like actuators and sensors. The approach is based on the precise balancing of electrical and fluid-mechanical parameters of the active system components. As a representative mechatronic system an automatic water tap with an integrated microscale turbine/generator unit is introduced. The overall system design and design parameters of the used microscale turbine/generator unit as well as the other system components like the bistable microvalve, the capacitive self-sufficient sensor and control electronics are explained. The operation of all participated micro systems in the water tap is described. Monitored long-term operations of the automatic water tap under real-live conditions are presented, pointing out the stability of the system in this harsh environment. Furthermore, investigations on the behaviour of the prototype of a microscale turbine/generator unit in fluids with a different kinematic viscosity than

water show the influence on the power/conversion rate. A different design of the fluidic part of the microscale turbine/generator unit is deduced for fluids with relatively high kinematic viscosities. The article concludes by giving suggestions for further applicable micro products that may have an advantageous operational behaviour if designed as a micro energy harvesting system. These could be systems for water regulation in horticulture and agriculture as well as active fluidic systems in machine tools.

1 Motivation and project targets

In the field of fluid technology, it is common for stored potential and kinetic energy to be dissipated to the environment without being exploited or to be converted into heat. This means that a large share of the costs and time that go into the provision of energy is ineffective. One example is the outlet air of pneumatic cylinders used in production systems, which is generally released into the environment without being exploited. For extensive systems with decentralised energy supplies it makes sense to pick up the hitherto unused energy and make it available again to the production systems. The energy must be provided in an appropriate form. Therefore, it is converted into electric energy using suitable micro generators. This allows sensors and actuators to have a local and self-sufficient electric energy supply for actuation. The powerFLUID project, funded by the German Federal Ministry of Education and Research (BMBF), aims to develop and implement self-sufficient, decentralised energy supply systems for micro system components. Electromagnetic, piezoelectric and thermal converter principles are examined to see how the energy contained in a fluid can be converted into electric energy. The results are then integrated into simple converter modules that are easy to retrofit. One of the target systems is a self-sufficient, automatic water tap.

2 Design process for energy-sufficient fluidic systems

If individual subsystems of an energy-sufficient system are to be adapted and integrated into a global system, the limit values for the fluidic working range of the individual components must be identified. They can be obtained from the descriptions of the respective subsystems. The fluidic components have limits for the minimum and maximum operating pressures, and for the minimum and maximum flow rates. Therefore, if several fluidic subsystems are integrated into a global system, there is an overlap of several fluidic working ranges (see Figure 1).

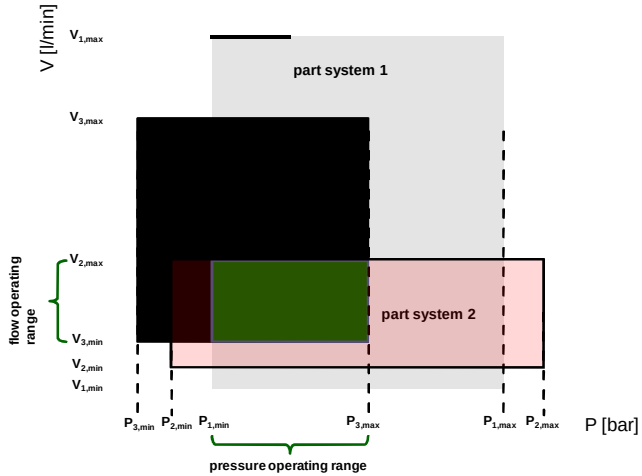


Figure 1: Design process

The overlapping working ranges of the different subsystems defines the constraints and minimum technical requirements of the pressure operating range and flow operating range of the complete energy sufficient system.

3 Micro turbine with claw pole generator

For this project, a micro turbine with a claw pole generator was used to convert the kinetic energy into electric energy. Figure 2 shows the general design of the energy converter as a CAD sectional view.

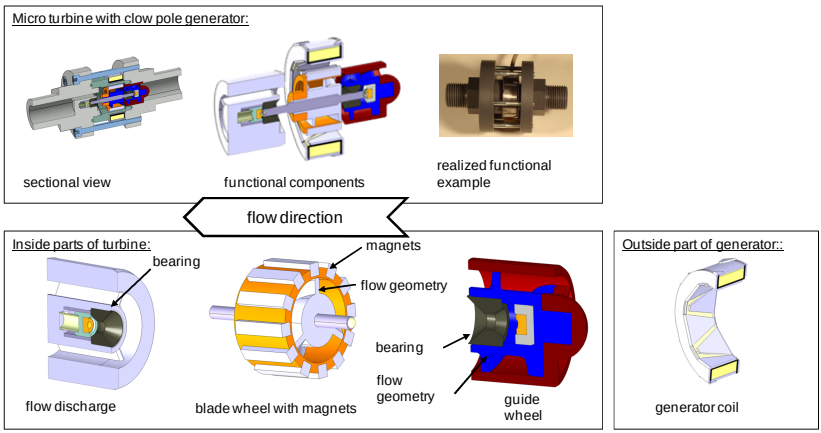
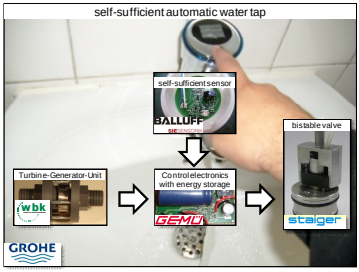


Figure 2: Micro turbine

The turbine is designed as an axial unit. The fluidic design is determined on the basis of the process outlined in [2]. The turbine is coupled with the electromechanic parameters of the generator by means of an iterative process based on the two coupling parameters torque and rpm.

4 Project results

For the project, a sample system in the form of an energy-sufficient, automatic water tap was set up for the operation of the micro turbine. The micro turbine had to be designed to operate as the energy source of the system, and the electrical consumers had to be optimised and adapted to the requirements of the system. Figure 3 shows the performance specifications for the individual components.



Turbine-Generator-Unit	self-sufficient sensor	Control electronics with energy storage	bistable valve
Axial machine with clow pole generator (12 poles)	capacitive sensor, self-sufficient by solar cells	8-bit µC, SuperCaps, cascaded	Pilot valve with add. mechanical activation
P_{el} = 0,39 W (4,7 V) @ 3,8 bar, 7 l/min	power input 1,5µA @ 3V	$U_{operating}$ = 1,2 .. 6,3 V	$U_{operating}$ = 5,5 ... 8 I_{Load} = 200 mA @ 6 V
Δp = 0,1 bar @ 7 l/min	Puls:Pause 1:833	$I_{Standby}$ = 1,5 µA	Impulse time 7 ms
η = 0,2	Open Collector output	Storage with 3,345 F	-
n = 3100 1/min @ 3,8 bar, 7 l/min	energy storage with 0,33 F	Storage current I_{max} = 50 mA	-

Figure 3: Self-sufficient water tap

A total of 15 water taps were used to collect operating data by means of field tests. These data were evaluated in order to verify the stability of the system.

5 Future steps

Hydraulic systems and cooling lubricants were examined to see whether the energy converter can also be used for other fluidic fields of production engineering. The basic turbine design parameters for these fluids were identified by means of experiments and simulations. The article discusses and describes the results of these investigations in detail.

References

[1] powerFLUID: Entwicklung und Umsetzung energieautarker Funktionsmodule in der Fluidtechnik, BMBF-gefördertes Verbundforschungsprojekt, Projektträger: VDE/VDI-IT Berlin 2007, http://www.power-fluid.de

[2] Sigloch, Herbert: Strömungsmaschinen: Grundlagen und Anwendungen. 3. Auflage, Hanser, München, Wien 2006, ISBN 3-446-40288-8.