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Novel non-resonant vibration transducer for energy harvesting

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Abstract

This paper presents a new non-resonant vibration-to-electrical power generator which can scavenge energy for a wide frequency spectrum. The working range of the micro-generator is thereby not limited to a narrow frequency band. Analytical and numerical simulations are verified on measurements of an inductive generator prototype. With a total volume of 1,3cm³ the generator is capable of producing up to 11mW for vibration frequencies ranging from 60-140Hz with 200µm vibration amplitude.

Keywords: micro generator, energy harvesting, non-resonant, vibration, electromagnetic.

1 Introduction

The development of distributed wireless sensor systems for automotive, medical or monitoring applications is one of the great efforts for MEMS technology. The required power can be provided by batteries, micro fuel cells or by energy harvesting. Mechanical vibration is a potential energy source. The aim of this publication is to present a novel alternative conversion mechanism which works without a spring and does therefore not have a classical resonant frequency. The generation of electrical energy is not limited to a narrow frequency band. Another benefit is the chaotic behaviour of a MEMS device. Power will also be generated for non-harmonic vibrations. Analysis and simulations were accomplished for both fine-mechanical and MEMS power generator. Experimental results of a fine-mechanical inductive generator prototype were used to verify the simulations.

2 Generator principle

The idea is to convert linear vibration into a rotary motion (Fig. 1). Dependent on the geometry and initial conditions the mechanical excitation of the generator housing leads to a rotation of the pendulum. The embedded magnets cause a change of magnetic flux in the stator coils and induce therefore an output voltage according to Faradays law. The current in turn causes a magnetic field, which damps the motion of the pendulum. The energy dissipated by the electromagnetic damping equals the generated electrical power. In the following analysis this effect is considered to be proportional to the angular rate.

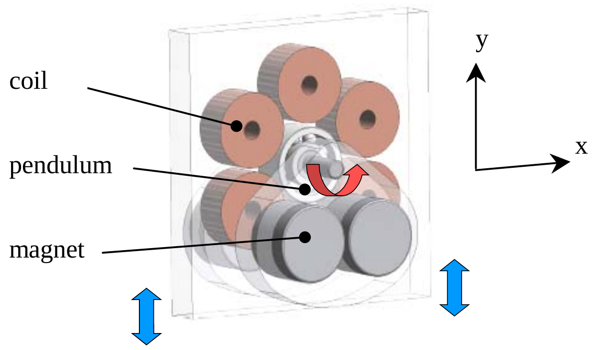

Figure 1: Under certain conditions linear vibration causes a rotational movement of the pendulum

3 Modeling and Simulation

The generator can be considered as a rotating unbalance. To predict the performance of the system it is modelled as a damped mathematical pendulum. Vertical vibration of the suspension point in y-direction leads furthermore to a driving force. For this case one will find the equation of motion of a damped and driven pendulum[1]:

$$d^2\varphi/dt^2 + \gamma\, d\varphi/dt + \omega_0^{\,2}\sin\varphi = -a\cos(2\pi f t)\sin\varphi$$

with:

$$\omega_0^{\,2} = \sqrt{g/l} \quad \text{and} \quad a = (2\pi f)^2 A/l$$

where A is the amplitude, f the frequency of input vibration and l the pendulum length. Solving this differential equation for different parameters shows the properties and the feasibility to transform linear vibration into a rotational motion.

One will get very similar results for the movement in x-direction. The system has two degrees of freedom in the xy-plane for energy conversion. The overall system has been modelled in MATLAB.

3.1 Fine-mechanical generator

A) Without initial angular rate

For a fine-mechanical generator the vibration amplitude will always be much smaller than the pendulum length. In this case the deflected pendulum performs a damped motion which is not influenced by the vibration (Fig 2). This case is irrelevant for the generation of power because there is no rotation.

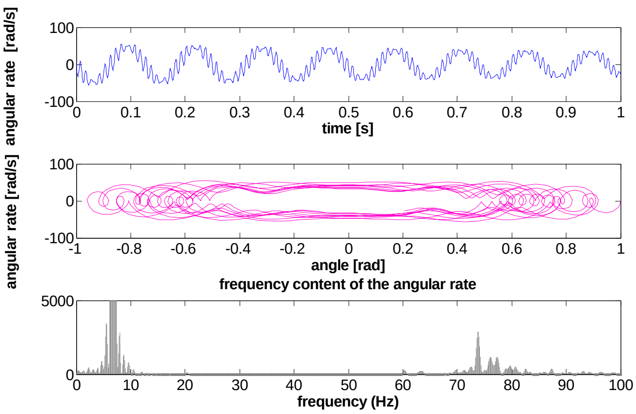

Figure 2: Damped pendulum motion for a fine-mechanical generator with initial angular rate equals zero

B) with initial angular rate

For the case that the initial angular rate is in the range of the vibration frequency the pendulum performs a rotation.

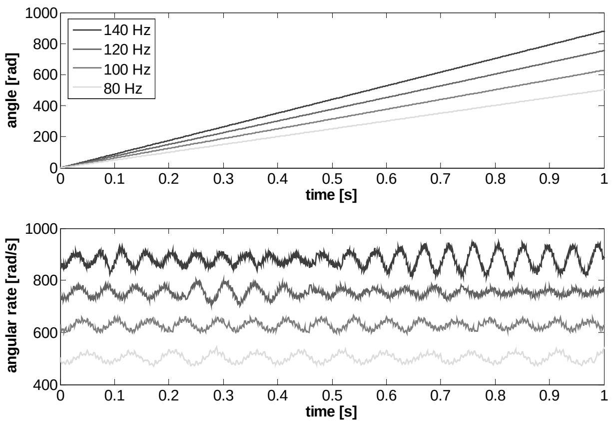

Figure 3:With initial angular rate the pendulum rotates for any vibration frequency

The angle goes therefore to infinity. The generator shows this behaviour for any vibration frequency. Changing the frequency over time does not affect the continuous rotation.

3.2 MEMS generator

The behaviour of a MEMS power generator is completely different. In this case the vibration amplitude has approximately the same size as the pendulum length. The system gets chaotic (Fig 4). For any vibration shape and frequency the pendulum will rotate. Compared to the fine-mechanical system the maximum angular rate is higher for the chaotic system. Because of the proportionality of the damping to the angular rate the chaotic system delivers a relatively higher output voltage.

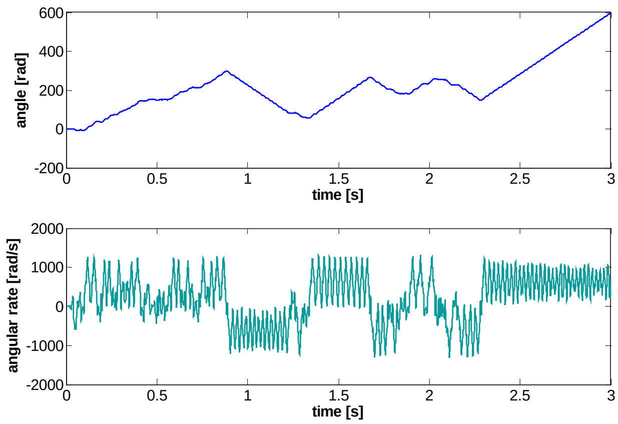

Figure 4: The MEMS generator is a chaotic system and rotates without initial condition (100rad $\hat{\approx}$ 16rev.)

4 Prototype testing and results

An inductive prototype is used to investigate the performance of the new conversion principle. The generator with a total volume of $\approx$ 1,3cm³ is shown in Fig. 5. With the given pendulum length of around 4mm and the excitation amplitude of 200µm the system needs an initial angular rate. For a frequency sweep from 60-140Hz the RMS output power is shown in Fig 6. Contrary to a resonant system, the output power always increases with the input power.

Figure 5: Prototype of an inductive non-resonant vibration transducer

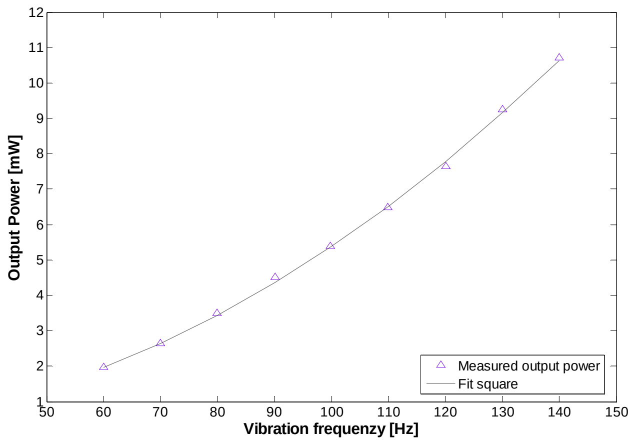

Figure 6: Measured RMS output power vs. vibration frequency for 200µm amplitude

5 Scaling considerations

By determining the total magnetic flux linkage Λ for all coils and assuming a harmonic time function, which is approximately true, some important proportionalities can be deduced [2]:

$$V_{rms} \propto L^2 \omega \qquad P \propto L^5 \omega^2$$

where L is a characteristic linear dimension and ω is the angular rate of the rotor. The ω^2 dependence of the output power is obviously visible in Fig. 6. According this rules the downscaling by a factor of 4 (1mm pendulum length) will reduce the output power to 10µW.

6 Conclusion

This paper presented an innovative principle for the non-resonant conversion of vibration into electrical power with two degrees of freedom. Analytical and numerical simulations with MATLAB were performed to predict the performance of both a fine-mechanical and a MEMS power generator. For a fine-mechanical prototype it was demonstrated that the electromagnetic generation of power within the range of 11mW is possible for a total volume of 1,3cm³. The development of a MEMS power generator is under process.

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