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Optimization of the MFC – composite beam energy harvester

Abstract. *In the paper the piezoelectric Macro Fiber Composite actuator (M-8503-P1) connected to the composite cantilever beam is analyzed. The influence of different electrical conditions on the system response is observed by the beam amplitude – frequency characteristics. The main goal is the load resistance level optimization, during the system vibrates around the first or the second resonance region to maximize electrical power generated by the system.*

Streszczenie. *Praca przedstawia wpływ elementu piezoelektrycznego (M-8503-P1) na charakterystykę kompozytowej belki wspornikowej. Obserwowano zależność pomiędzy obciążeniem elektrycznym elementu aktywnego a odpowiedzią dynamiczną układu mechanicznego śledząc zmiany na wykresach amplitudowo-częstotliwościowych. Głównym celem badań jest optymalizacja poziomu obciążenia elementu piezoelektrycznego gdy belka drga w pobliżu pierwszej bądź drugiej częstości giętnej tak, aby odzyskać od układu jak największą moc elektryczną. (**Optymalizacja układu do pozyskiwania energii zbudowanej z belki kompozytowej MFC**).*

Keywords: Energy harvesting, Macro Fiber Composite actuator, resonance zone, load resistance.
Słowa kluczowe: Odzyskiwanie energii, element aktywny MFC, obszar rezonansowy, rezystancja obciążenia piezoelementu.

Introduction

A wide variety of self-powered microsystems entail efforts in field of energy harvesting investigation. In last decade the technique concerning the power scavenging is very attractive. There are many new challenges in projecting a unique power supply for modern systems as military monitoring devices, biomedical implants, watches, calculators or wireless sensors [1-3]. Moreover an ambient vibration offers a clean regenerative means of small devices powering [4, 5]. The blind spot of mechanical systems is their expecting energy harvesting efficiency around the damaging resonance zones. There are many papers where are reported a way of avoiding the harmful conditions by simultaneously broaden smooth a resonance response out [6, 7]. The crucial influence on the system behaviour has a mechanical system stiffness due to the electrical subsystem load. Such problems are considered in the papers [8, 9], where a piezo element play a role of controller's actuator for composite beam system. The efficiency of the energy harvesting strongly depends on the electrical and mechanical systems' parameters. The important parameter of an electrical subsystem is the load resistance, which has a significant influence on the dynamics of the mechanical system [6, 10].

In the present paper, the elasticity of the composite beam kept the system in save by damaging, during its vibrating in resonance zones. This permitted to focused the tests on searching the optimal load resistances for the sake of maximal output power.

Experiment

The laboratory experiments have been performed using electromagnetic shaker system TIRAvib 50101 presented in fig. 1, which reproduced environmental conditions over a required frequency band. The applied shaker was controlled by LMS TestLab software, which provided the sinusoidal input excitation signal of the analysed structure during vibration tests. The harmonic signal matched prescribed acceleration level at 1***g*** and swept through a defined range of frequencies, particularly around the resonance zones. The influence of different electrical conditions on the system response is observed by the beam amplitude – frequency characteristics. For energy harvesting acquisition data, the digital signal processing (*DSP*) module and conditioning system have been applied (Fig. 1). These devices measure the voltage *V* and current ***I*** as well as control the load tuning of vibrating the Macro Fiber Composite (*MFC*) actuator, which is connected to the composite cantilever beam. The applied beam consists of ten prepreg M12 layers with thickness 0,255mm oriented to the beam length in accordance with $[+45/-45/+45/-45-0]_S$.

Fig.1. The equipment of measuring stand

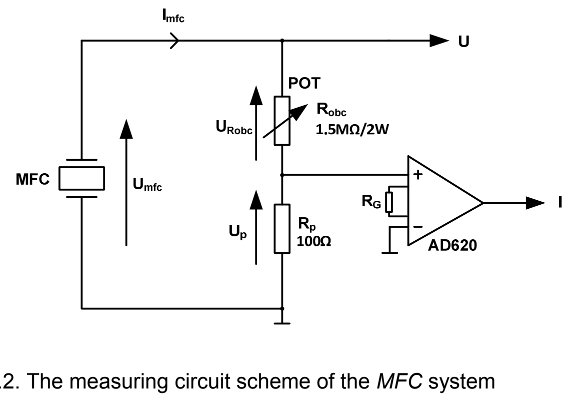

Fig.2. The measuring circuit scheme of the *MFC* system

The measuring circuit scheme of the *MFC* system is presented in fig. 2. The output current measurement of piezoelectric circuit was realized by voltage measuring on resistor R_P and amplified by Analog Device AD620. Finally signal was introduced to the acquisition card with *DSP* module.

Discussion

The characteristics describing behaviour of the composite beam around the first and the second resonance zone are presented in figs. 3 and 4, respectively. While system is excited at 1***g***, the free end of the beam reaches multiple values of excitation. Plots clearly report, the characteristic strongly depends on the state of piezo element. The piezoelectric load level creates a beam stiffness weaken or harden. In the experiment the load resistance was adopted in range of $R=0\Omega$ by shorted circuit up to $R=\infty$ by open circuit, including also three different finite values: $R_1=0.5M\Omega$, $R_2=1M\Omega$ and $R_3=1.4M\Omega$ in case of power measurements. It shows, the increased load resistance of the piezo element changes the natural frequency of the composite beam, moving the resonance point to the higher frequencies, in case of both analysed modes.

Note that at the second resonance zone, the system is more sensitive to the piezoelectric extreme load resistances ($R=0\Omega$ and $R=\infty$) moving the pick points of acceleration response around 10 Hz, while in fig. 3 the same difference is less than 2 Hz. However comparing these relative differences it is 1% and 0.8%, respectively

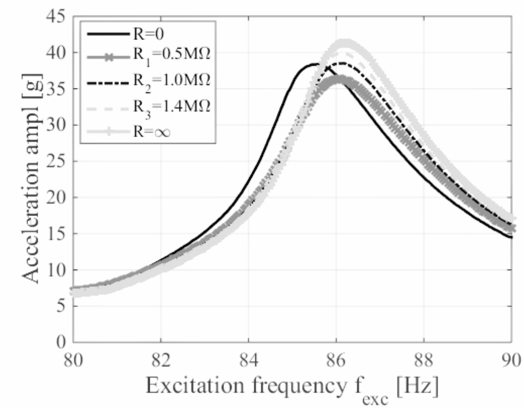

Fig.3. The response acceleration amplitude of the system via excitation frequency at the first cantilever beam resonance, by increased load resistance of piezoelectric element

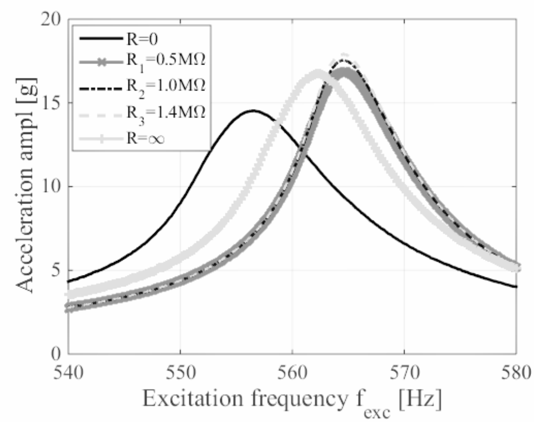

Fig.4. The response acceleration amplitude of the system via excitation frequency at the second cantilever beam resonance, by increased load resistance of piezoelectric element

Additionally the *RMS* of power (P_{RMS}) has been measured at changeable load resistance, to notice if the dependencies are confirmed. In figs. 5 and 6 the output powers are plotted via resistances R_1-R_2-R_3. One can see along with decreasing of resistance, the power increasing and the maxima P_{RMS} occurs around the same excitation frequency $f_{exc}=86.10Hz$ (fig. 4a), while in case of the second resonance, the excitation frequency slightly grows for consecutive maxima P_{RMS}.

Finally in figs. 7 and 8 the influence of load level resistor on the maxima of output power P_{RMS} is reported. In both resonance zones, it is observed decreasing tendency of power, while the load resistance increasing. Moreover, the efficiency of the system is significantly better around the first resonance excitation. It is due to effecting a larger bending moment on the piezo element while the beam takes the first vibration mode.

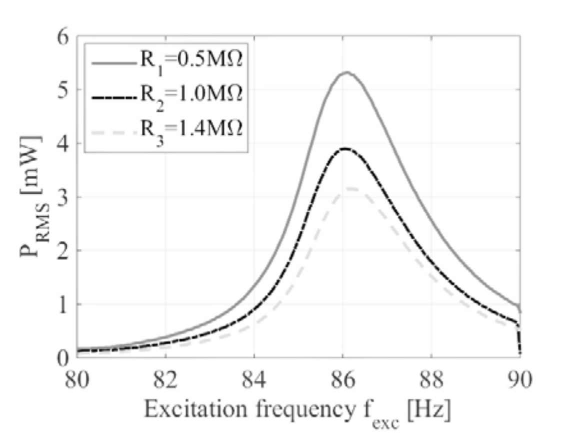

Fig.5. The root mean square of measured power of the piezoelectric element via excitation frequency at the first cantilever beam resonance, by increased load resistance

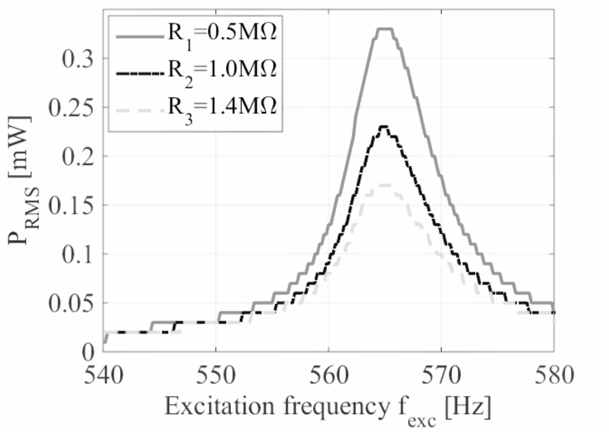

Fig.6. The root mean square of measured power of the piezoelectric element via excitation frequency at the second cantilever beam resonance, by increased load resistance

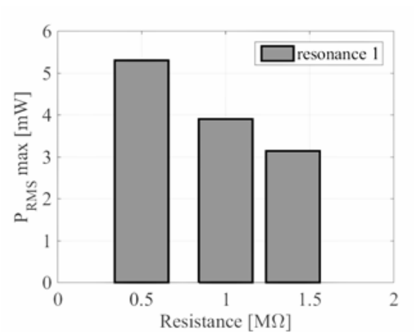

Fig.7. The maximum of the measured power at different load resistances at the first resonance zones

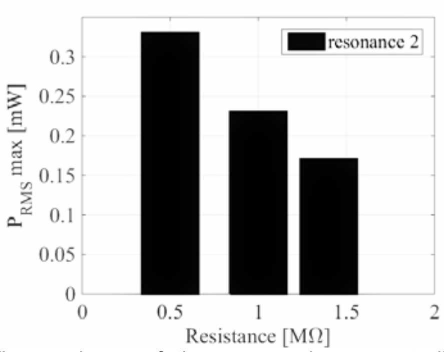

Fig.8. The maximum of the measured power at different load resistances at the second resonance zones

Conclusions

In the paper was presented the influence of the load resistance to the beam stiffness as well as to generated the electrical power P_{RMS}. The performed tests result that the loaded piezo element at growing resistance, causes the increasing stiffness of composite beam. This is especially visible at first resonance zone. The energy harvesting efficiency takes opposite behaviours. The output power reaches the highest values at lowest of assumed load resistances. Analysing results, for final conclusions it requires providing additional measurements within resistance range $R=(0\text{-}0.5)M\Omega$, to find the optimal value of R for the most power output P_{RMS}.

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