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Conclusion (quick look on how useful the reviewed articles can be for your research work)

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Пример оформления библиографической ссылки:
Feldman, J., Hanrahan, B. M., Misra, S., Fan, X. Z., Waits, C. M., Mitcheson, P. D., & Ghodssi, R. (2015). Vibration-based diagnostics for rotary MEMS. *Journal of Microelectromechanical Systems*, *24*(2), 289–299 **(40 000 characters)**

Glossary (20 - 50 терминов – English-Russian, в алфавитном порядке)

Plan for a critical review
(for each article)

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ПРИМЕР АНАЛИТИЧЕСКОГО ОБЗОРА ПО СТАТЬЕ ПО ЗАДАННОМУ ПЛАНУ

1. **Vibration-based diagnostics for rotary MEMS**

General information about the article

This paper was written by a scientific team from USA and UK and was published in the Journal of Microelectromechanical systems on the 2 of April, 2015. This manuscript is indexed in Scopus. The article consists of seven sections: Abstract, Introduction, Experimental Set-Up, Results, Conclusion, Acknowledgment, References.

Importance of research

The importance of research is explained by the existing of rotary bearings inside each electromechanical system. Vibration characteristics affect reliability and operation lifetime of electromechanical systems: "*Vibration is a characteristic of all machines and has long been known to be a product of all mechanical rotary systems due to imperfections in design or manufacturing. In macroscale machinery, rotary machines use rolling element bearings to provide low friction and wear contacts for two surfaces with relative velocity while under load. The stiffness and geometric accuracy of the rolling element bearings contribute to the vibration characteristics of rotary machines, and therefore, vibration monitoring provides insight into the mechanical state of the bearings, Microscale rotary machinery also uses different kinds of bearings and will have a set of state-specific vibration signals.*" In this regard, it is necessary to investigate this field of science.

Literature review

The literature review in this research includes a very extensive list and consists of *fundamental literature*, for example, V.Wowk "Machinery Vibration: Measurement and Analysis" New York, 1991, and *modern sources*, for example, F.Cong "Vibration model of rolling element bearings in a rotor-bearing system for fault diagnosis", 2013. *The oldest literature source* in this paper was written in 1962. Two main threads of vibration analysis were highlighted in several literature sources: "*Vibration-based diagnostics consist of a vibration-to-signal transduction followed by computational analysis, allowing for diagnosis and prognosis of faulty operation or failure prevention. There are two main threads of vibration analysis: the first dealing with whole body motion and the second with pressure waves that propagate through a body*". *The authors investigate* both time and frequency domain methods reviewing literature sources. Shock pulse method, observation of periodic time domain peaks, measuring the overall root-mean-square level and crest factor and other were considered to understand the difference between time and frequency domain methods. "*The observation of periodic time domain peaks has been shown to successfully detect local defects caused by interactions between mating elements that occur at a single point in the raceway and repeat every revolution. In the frequency domain, the occurrence of system resonances appearing as peaks in the fast Fourier transform over a selectively filtered dynamic range and causing excitation of natural frequencies can be successfully correlated with assumed defect modes. Additionally, it is notable that periodic* *peaks in the time domain are more effectively detected in the frequency domain as a peak in the fast Fourier transform, with specific peaks in some cases consistently acting as a marker or specific defects*". The considered literature sources laid foundation for this research work.

Research gap

There is some research on vibration characteristics of macroscale rotary machines but the vibration characteristics for microscale machines are understudied. "*Automated detection has clear advantages and os required for integrated diagnostic schemes. Although these characteristics and techniques have been explored in great detail in macroscale machinery, very little has been done translate these benefits to rotary micro electromechanical systems. A set of operational characteristics from macroscale dynamics of rotary machines was expected on the microscale, but as of yet has not been demonstrated in a practical system*".

Aim

The aim of this article is to receive practical confirmation of the theory about similarity of vibration characteristics for both macroscale and microscale systems. "*In this paper, techniques are presented to aid in the understanding of microscale tribology by translating successful macroscale vibration diagnostic techniques to their microscale counterparts realizing benefits such as improved microsystem reliability, predictability, longer lifetimes, and overall improved performance with the term "high performance" defined as higher rotational speed per unit input power*".

Methods

The methods used in this investigation are clearly described. This section is named "Experimental Set-UP". It contains detailed information about rotary micro electromechanical system device used by authors for the experiment: "*The rotary micro electromechanical system device used in this study platform is a silicon micro electromechanical system micro-turbine supported on micro-ball bearings of 285 μm diameter. The rotary micro electromechanical system device is fabricated using a 45-five step, 14 photolithography mask microfabrication process*". Also the authors report about measurement units bonded to construction. It is worth to mention that these measurement units are parts of the construction: "*The rotor-stator assembly has two micro electromechanical system accelerometers bonded directly to the stator. The first accelerometer is used for high-sensitivity measurements with a sensitivity of 174 mV/g, a range of ±5g, and a bandwidth of 0.5-1600 Hz. The second accelerometer extends the range of the vibration study at the expense of sensitivity. The sensitivity, range and bandwidth of this device is 16 mV/g, ±70g, and 0.5-22000 Hz, respectively*".

After that, this section contains the description of installation sensor suite. Turbine pressure sensor is used to measure the pressure at the turbine inlet. Also two optical displacement sensors were used in this study. The mass flow controller is used to monitor and control the gas flow rate: "*The turbine pressure sensor is used to measure the pressure drop across the turbine assuming outlet is at ambient pressure. The first optical displacement sensor measures the distance to a surface* *on the rotor and is positioned above the rotor petals measuring a pulse every time a petal passes underneath the sensor to obtain rotor speed. The second optical displacement sensor is used to measure the out of plane displacement at a single point above the rotor to extract wobble in the rotor. The mass flow controller is used to monitor and control the flow rate of the turbine actuation gas, thus controlling the rotational speed*".

At the end of this section a software suite was described: "*LabVIEW software manages the platform by controlling the simultaneous sampling DAQ, controlling the ,ass flow controller and actuation gas shutoff valve, which actuates the micro turbine. MATLAB was used for later stage analysis and visualization on datasets exceeding the memory capabilities of LavVIEW*".

Results

The results section includes experimental data and explanations for more interesting results. This section is divided into two directions: time and frequency domain analysis. For time domain technique, authors explain rotor wobble, turbine instability and ball impact events. For frequency domain techniques, the authors explain rotor imbalance, rotor resonance and micro-ball whirl: "*Once the actuated load exceeds gravitational load, the rotor settles to a 1.2 μm peak-to-peak operation. The steady-state wobble is due to the fabrication dependent non-uniformity of the raceway and is expected to improve for smaller radius devices. When the balls interact with the sidewalls, the device tends toward instability, indicated by the measured root-mean-square radial vibration showing radial vibration scaling with decreasing rotor normal force for different rotational speeds. The impulses will be referred to herein as a "ball impact" and are characterized as a sudden spile in the accelerometer signal, caused by either a ball-to-ball interaction, or a ball-to rotor and raceway or another interaction in-between, with an example of one such ball impact. The imbalance is observed by taking the fast Fourier transformation of the accelerometer data to obtain the frequency spectrum and measure the magnitude of the fundamental vibration magnitude. A single 440C stainless steel ball from the device weighed 95 μg, and with a 75% reduction roughly in line with this mass change calculated from the model, supporting the theory. Whirl can be detected well before damage or performance degradation occurring at 1.902 seconds and leading up to performance reduction at 2.562 seconds, giving a full 660-seconds window for the system to react to this detection of whirl*".

Discussion

The discussion section is absent in this paper. The authors explain the results in section "Results". The non-uniformity of the raceway results in the steady-state wobble, and the authors think that its wobble will be decresed with smaller radius devices: "*The steady-state wobble is due to the fabrication dependent non-uniformity of the raceway and is expected to improve for smaller radius devices*". The authors obtain the parabolic stability curve by tuning rotor, due to monitoring, as the Results section presents: "*By tuning the rotor normal load leads to an ideal operating mode and tracks the parabolic stability curve*". "*This result highlights the prognostic capability of monitoring ball impact events versus other data*". The results of the experiment show that sometimes vibration of the device increases, and the authors link this phenomenon to mechanical resonance properties: "*When rotational frequencies match the mechanical resonance properties of the bearings, vibration amplitudes will exceed normal levels*". "*The 1/2X detection is not common, but does lead to accelerate device degradation and may potentially add to resonance inducing excitation, adding to damage caused by the 1/2X peak and its resonance vibration*".

Conclusion

The conclusion section contains:

– brief information about the field of this research: "*Rolling element bearing technology is well known and widely used in macroscale machines*"

– explanation of the research relevance: "*As micro electromechanical rotary systems mature and become more prevalent in commercial systems design, a full understanding of characteristics in rotary micro electromechanical systems, as well as methods to monitor these systems to guarantee reliable lifetime and performance, will be needed*"

– current problem in this field: "*As form factors scale from the macro- to microscale, the operationa; dynamics and performance regimes are not well known, with macroscale characteristics often not scaling in the same way as their microscale counterparts*",

– brief description of the proposed research methods: "*This paper demonstrates the use of vibration analysis using integrated accelerometers to perform in-situ monitoring software suite was designed to interface with sensing transducers at the platform level allowing for monitoring, auromation, and data collection*"

– brief information about applied methods: "*The accelerometer is shown to provide high sensitivity, and wide bandwidth measurement of the forces generated in the rotating micro-turbine. A dual accelerometer configuration is used to record vibrations at two different sensitivities ranges, when both are bonded to the micro-turbine stator and analyzed in parallel*"

– main results of investigation: "*The sensor suite has been used to characterize the rotor instability for rotor speeds from 10-20 krpm, diagnose imbalance acceleration with sensitivity down to 0.0001g, determine rotor wobble with an accuracy of <500nm, and monitor system resonances through the speed range of 5-30 krpm*"

– positive value of the investigation results: "*The data provided by the system have applications on rotary microsystems for the early detection of failure, fault diagnosis, and integrated diagnostic systems for feedback-based optimization to increase device performance, reliability, and operational lifetimes*"

This positive value of the investigation can be considered as the main author's conclusion.

Relevance to my research work

This article is relevant to my research work because a high-speed electromechanical system is investigated in this paper. A high-speed rotary electrical generator is considered in my research work as well, and it is very useful for me to know any specific features of high-speed rotary electromechanical systems. In addition, the authors propose interesting diagnostics methods for an early detection of failure, fault diagnostics, and integrated diagnostics systems for feedback-based optimization to increase device performance, reliability, and operational lifetimes. It may be useful as modern high-power density micro gas turbine installations are considered in my research work. Besides, the question of choosing bearing technologies is very difficult. Owing to this investigation, it is absolutely evident that a rolling element bearing technology is not the best choice for high-speed micro electromechanical systems. Nowadays, air gas dynamic bearing technology is used in a micro gas turbine installation. But the air gas dynamic bearing technology in a micro gas turbine plants has some well-known shortcomings. This research paper describes the shortcomings of a rolling element-bearing technology. Due to this investigation a magnetic bearing technology is chosen for my axial flux-style permanent magnet synchronous machine developed for modern micro gas turbine plants.