Structure Optimization of Grain Detecting Sensor Based on Vibration Modal Analysis*

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Abstract

In order to analyze the effect of sensor structure on the character of grain impulse response, 3-D models of grain detecting sensor were established and their vibration modal were simulated by using software SolidWorks. It was found that the dimension of the upper panel was an important factor which influenced the modal nature. With the increasing of upper panel width b, its natural frequency f monotonically increased, and its relative deformation ratio γ quickly decreased at first and then decreased to a constant value gradually. With the increasing of thickness h, monotonic increasing tendency of f and γ was received. Then, experiments were carried out by assembling the sensor on a support stand which fixed on the vibrating cleaning sieve, the results showed that the sensor can identify grain impact signal effectively from vibrating noise. The time band of grain impact signal acquired using sensor with b of 30 mm width was less than 2 ms which was much small than the signal acquired using sensor with b of 120 mm.

Key words Combine harvester, Grain detecting sensor, Modal analysis, Experiment

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Introduction

A combine harvester is a common and well-known machine for harvesting crop materials. It performs the basic functions of reaping crop materials from a crop field, separating the grain from the materials other than grain (MOG) and cleaning the grains. Grain loss is unavoidable for combine harvester during field operation, mainly including cleaning loss and separation loss [1~2]. Grain loss ratio is a key technical index for evaluating the operating performance and also is the basic design criteria of combine harvester. With the improvement of automation level, there is an urgent need to develop a grain loss monitor system [3~4]. The core problem is to research the corresponding detecting sensor, and many scholars are working hard on it in recent years [5~6].

The piezoelectric PVDF film as a new polymer piezoelectric material has a good sensitive to weak impact and acceleration. It became a research topic in recent years because of its advantages such as higher sensitivity, higher thermal, chemical stability, and flexible structures [7]. By using PVDF films, a floating raft structure sensor for grain loss detecting of combine harvester and constructed signal processing circuit will be developed [8~11]. In this paper, study will be carried out for optimization of the sensor structure.

1 Model Description of Sensor

The paper selected piezoelectric PVDF films of 50 μm thickness as the material which were adhered on the upper panels, and their piezoelectric constant was 25 pC/N [8]. To avoid the scratching of electrodes surface due to grain impact, two PET protective films (0.1 mm thickness) were adhered outside the electrodes. Upper panels were bolt connected with the bottom panel. The dimensions of the bottom panel were length of 150 mm, width of 120 mm, materials of upper panels and bottom panel were both stainless steel. In order to reduce the effect of combine harvester's vibration on monitoring accuracy, two 4 mm thickness damping sponges were adhered between the bottom

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panel and the parallel foundations. Because the selected PVDF film was flexible and lightweight, so its effects on the structural mechanical properties of the sensor could be neglected.

Based on the transverse vibration theory of thin plate, forced vibration differential equation of the panel was[12]

$$D\left(\frac{\partial^4 w}{\partial x^4}+2\frac{\partial^4 w}{\partial x^2\partial y^2}+\frac{\partial^4 w}{\partial y^4}\right)+\rho h\frac{\partial^2 w}{\partial t^2}=F(x,y,t) \quad (1)$$

$$D=\frac{Eh^3}{12(1-\mu^2)} \quad (2)$$

where, w—flexibility function

ρ—mass density, kg/m^3

D—bending rigidity, N/m

E—Young's modulus, GPa

μ—Poisson's ratio h—thickness, mm

F—excitation load, N

Considering the fact that impact signal of seed was slight, and its impact resonance frequency and deformation were greatly influenced by the dimension of the upper panels, in order to increase the response speed and sensitivity, upper panels with different size were used to construct an array structure, and each array unit had an individual signal process circuit which composed of a charge amplifier, band-pass filter, envelope detector, absolute value amplifier and square wave generator[8]. The upper panel dimensions were length a of 150 mm, width b of 25 ~ 120 mm, thickness h of 0.5 ~ 1.5 mm, the material properties used in the analysis were: Young's modulus E = 70 GPa, Poisson's ratio μ = 0.27, mass density ρ = 8 000 kg/m^3. Typical models of such sensors created using SolidWorks were presented in Fig. 1.

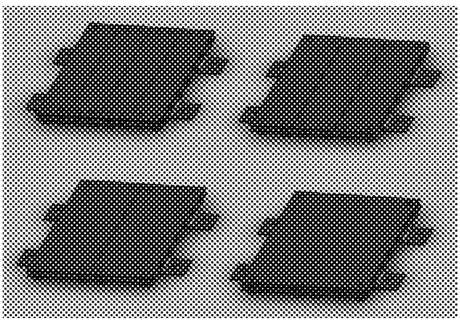

Fig. 1 Models of sensor

2 Modal Analysis and Discussion

2.1 Modal Analysis

LS-DYNA was used in this study for finite element modeling and computer simulations. Finite element results were obtained from a baseline FE model. Higher and lower mesh densities had also been used to check the convergence of the equilibrium path and the sensitivity of the onset of the secondary bifurcation. No significant difference was found. Fig. 2 gave the first mode shapes of the different upper panels.

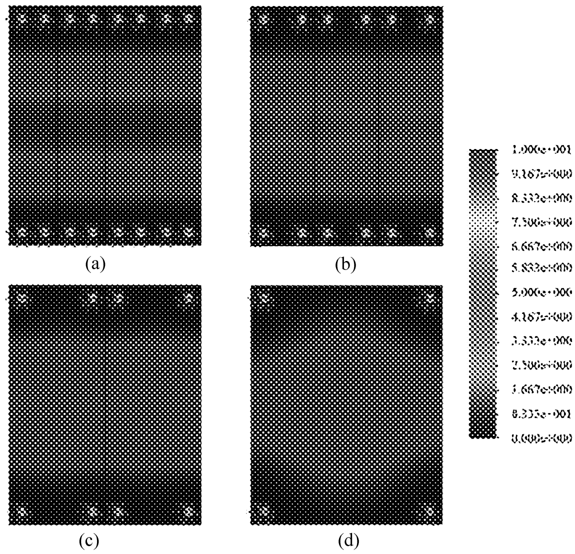

Fig. 2 Structural deformation graph of upper panels
(a) b = 30 mm (b) b = 40 mm
(c) b = 60 mm (d) b = 120 mm

It can be seen from Fig. 2 that structural deformation of the upper panel was non-uniform, the maximal deformation was generally appeared in the center of the panel, and it became smaller where near the bolted points. So PVDF films should be adhered in the center of upper panels to improve the grain impulse response. In order to describe the effects of width and thickness on panel deformation, a coefficient of relative deformation ratio γ was defined. It reflected the maximal deformation of panels with different dimension.

2.2 Model Geometry Effect on Modal Behavior

Fig. 3 was the variation surface of γ. With the increasing of width b, γ quickly decreased at first and then decreased to a constant value gradually. With the increasing of thickness h, a monotonic increasing tendency of γ was received.

Fig. 4 showed the effect of width b and thickness h on the first natural frequency f. It can be seen that f almost linearly increased with the increasing h, and monotonically increased with the increasing of b. When upper panel width b and thickness h were varied from 25 ~ 120 mm and 0.5 ~ 1.5 mm, modal analysis results showed that the first natural frequency f was in the range of 100 ~ 500 Hz. This value was close to the loss grain falling frequency and the upper panel can have a good response to grain impact.

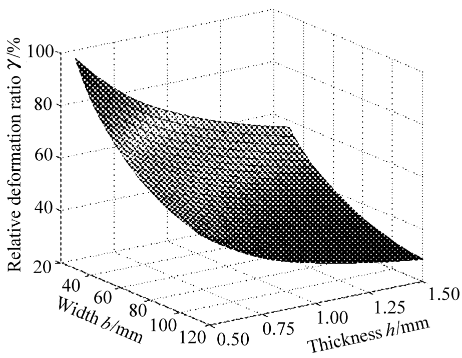

Fig. 3　Effect of width and thickness on the relative deformation ratio

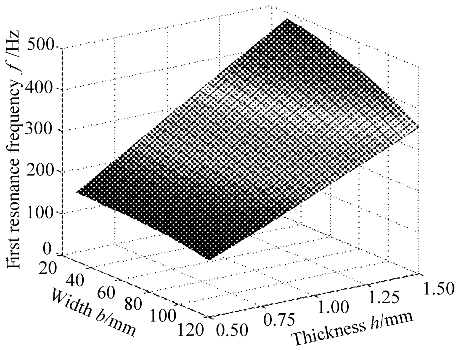

Fig. 4　Effect of width and thickness on the first natural frequency

Detecting frequency and sensitivity were the most two important targets of a sensor. The higher resonance frequency can improve the response speed of grain impact and the sensor detecting frequency. The greater deformation can improve the sensor detecting sensitivity. So, taking the effects of γ and f into a comprehensive analysis, four 30 mm × 150 mm panels with thickness of 1 mm were used to construct an array structure sensor.

3　Experimental Results

The sensor was mounted at the rear of vibrating cleaning sieve for the grain cleaning loss measurement of combine harvester (shown as Fig. 5).

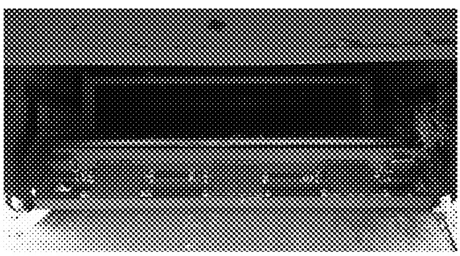

Fig. 5　Installation position of the sensor

When combine harvester operated with working parameters, the sensor vibrated at a same frequency with the cleaning sieve. Grain ejected from the rear of cleaning sieve and impacted on the upper panel, an electric charge and voltage was generated on the electrodes of PVDF films. After signal processing, grain impact signal was recorded by digital oscilloscope with sampling frequency 15 kHz. The results were shown in Fig. 6. Signal amplitude of high frequency vibration interference can be suppressed below 1.0 V and signal voltage amplitudes of grain were mainly in the range of 2.0 ~ 4.0 V, the time bands of grain signals were generally less than 2 ms, therefore threshold voltage of comparator was set to 1.5 V and grain impact signal can be clearly identified.

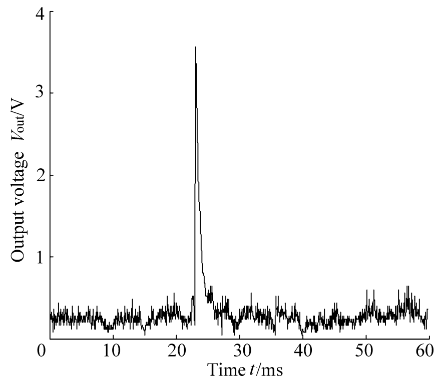

Fig. 6　Output signals with b = 30 mm

Similarity, experiments were carried out using the another sensor with upper panel width b of 120 mm and thickness h of 1 mm. Grain impact signal were shown in Fig. 7. Because the natural frequency was higher, it leads to a longer resonant time. Comparing with Fig. 6 and Fig. 7, it can be found that under the same voltage amplitude, the signal time band can exceed 10 ms, which will reduce the measurement velocity of sensor.

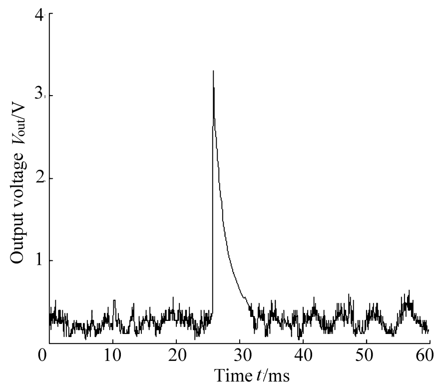

Fig. 7　Output signals with b = 120 mm

4　Conclusions

(1) In this study, PVDF films were applied for developing grain detecting sensor for combine harvester. Based on the vibration modal analysis of 3-D sensor models, the width b and thickness h of the upper panel effect on grain impact resonance has been

received which can be summarized as: with the increasing of width b, natural frequency f monotonically increased, relative deformation ratio γ quickly decreased at first and then decreased to a constant value gradually. With the increasing of thickness h, f and γ both presented an increasing trend.

(2) Grain detecting experiments were carried out by mounting the sensor to the cleaning sieve of combine harvest and the results showed that the sensor can identify grain impact signal effectively from vibrating noise, and the time band of grain impact signal acquired using sensor with b of 30 mm width was less than 2 ms which was much small than the signal acquired using sensor with b of 120 mm.

Reference

1 Miu P I, Kutzbachb H D. Modeling and simulation of grain threshing and separation in threshing units—part Ⅰ [J]. Computers and Electronics in Agriculture, 2008, 60(1): 96 ~ 104.

2 Ebrahimi M A, Khademolhosseini N, Abbaspour-Fard M H, et al. Optimum utilisation of low-capacity combine harvesters in high-yielding wheat farms using multi-criteria decision making [J]. Biosystems Engineering, 2009, 103(3): 382 ~ 388.

3 Mahmoud O, Majid L, Hossein M, et al. Design of fuzzy logic control system incorporating human expert knowledge for combine harvester [J]. Expert Systems with Applications, 2010, 37(10): 7 080 ~ 7 085.

4 Geert C, Josse B, Bart M, et al. Fuzzy control of the cleaning process on a combine harvester [J]. Biosystems Engineering, 2010, 106(2): 103 ~ 111.

5 Maertens K, Ramon H, Baerdemaeker J D. An on-the-go monitoring algorithm for separation processes in combine harvesters [J]. Computers and Electronics in Agriculture, 2004, 43(3): 197 ~ 207.

6 Mao H P, Ni J. Finite element analysis and measurement for array piezocrystals grain losses sensor[J]. Transactions of the Chinese Society for Agricultural Machinery, 2008, 39(12): 123 ~ 126. (in Chinese)

7 Shirinov A V, Schomburg W K. Pressure sensor from a PVDF film[J]. Sensors and Actuators A, 2008, 142(1): 48 ~ 55.

8 Zhao Z, Zhou J. Study on grain loss detecting sensor of combine harvester [C] // 2011 International Conference on New Technology of Agricultural Engineering, 2011: 109 ~ 112.

9 Li Y M, Chen Y. Monitoring method and device of attachment loss in combine harvester [J]. International Agricultural Engineering Journal, 2011, 20(2): 14 ~ 19.

10 Santos F M, Temarel P, Soares C G. Modal analysis of a fast patrol boat made of composite material [J]. Ocean Engineering, 2009, 36(2): 179 ~ 192.

11 Liu Y C, Gary G. Effects of wall thickness and geometric shape on thin-walled parts structural performance [J]. Thin-Walled Structures, 2011, 49(1): 223 ~ 231.

12 Li Y Y, Cai R X. Some concise exact analytical solutions of rectangular plate bending [J]. Chinese Journal of Mechanical Engineering, 2008, 44(10): 72 ~ 76. (in Chinese)

基于振动模态分析的籽粒检测传感器结构优化设计

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【摘要】 为了分析传感器结构对籽粒冲击响应信号的影响,建立了籽粒检测传感器的三维结构模型,利用SolidWorks分析了传感器的振动模态。结果表明:传感器的上层面板的结构尺寸是影响传感器振动特性的主要因素,随着面板宽度 b 的增加,相对变形率 γ 首先迅速减小;随着 b 的进一步增加,γ 逐渐减小至恒定值,固有频率 f 则单调增大;增加面板厚度 h,固有频率 f 和相对变形率 γ 均呈单调增加趋势。将传感器安装到联合收获机振动筛尾部支架上进行清选损失检测试验。结果表明,传感器能够在振动干扰中识别籽粒冲击信号,当 $b=30$ mm 时,籽粒冲击响应时间小于 2 ms,远小于 $b=120$ mm 时的籽粒冲击响应时间。

关键词: 联合收获机 谷物检测传感器 模态分析 试验

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