EGGSHELL CRACK DETECTION USING DYNAMIC FREQUENCY ANALYSIS

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ABSTRACT

The experimental method of the eggshell impact loading has been used for the dynamic loading of eggs. This experimental arrangement enables to obtain the impact force and eggshell response. The work studied the influence of cracks on the dynamical frequency response of eggshells. Five excitation resonant frequency characteristic of signals were extracted based on the difference of frequency domain response signals. These parameters enable to distinguish between intacted and cracked eggs.

Key words: eggshell, impact loading, frequency analysis, cracks

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INTRODUCTION

Egg as a well-popular and nutritious food in the daily human diet is considered to be a cheap source of quality protein. Cracks on eggshell are commonly produced during packing and/or transportation. Cracked eggs are more vulnerable to *Salmonella spp.* and other bacterial infections leading to health hazards. Therefore, the detection and removal of cracked eggs continue to be very important for quality assurance in the production and marketing of eggs (Hunton, 1995; De Ketelaere *et al.*, 2004).

Vibration-based response analysis and machine vision inspection are the two main methods employed for eggshell crack detection (De Ketelaere *et al.*, 2004). Many studies have shown that the vibration-based response analysis is a more effective detection method than the machine vision inspection method, especially for the detection of hairline cracks and invisible cracks (Cho and Kwon, 1996; Cho *et al.*, 2000). Regardless of this effort many problems connected with the use of this technique remain unsolved.

In the given paper the main attention has been focused on the use of method of the eggshell impact. First of all the conditions of the crack origin have been studied. Effort was further focused on the eggshell response to impact. The response has been evaluated both in the time domain and in the frequency domain.

MATERIAL AND METHODS

The experimental device described e.g. by Nedomova *et al.* (2009) has been used schematic of this device is shown in the Fig. 1.

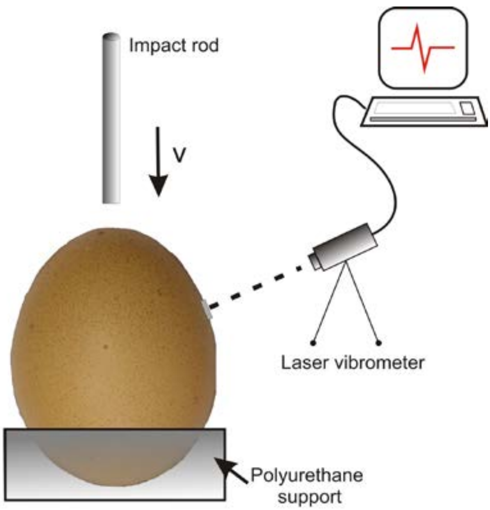

Fig. 1 Schema of the impact loading of the egg

This experimental arrangement enables to study the egg behaviour under impact by the different bodies accelerated to different velocities.

It consists of three major components: they are the egg support, the loading device and the response-measuring device.

1) The egg support is a cube made of soft polyurethane foam. The stiffness of this foam is significantly lower than the eggshell stiffness; therefore there is very little influence of this foam on the dynamic behaviour of the egg.

2) A slender bar of the circular cross-section with miniature semiconductor strain gauges (3 mm in length) is used as a loading device. The bar is made from aluminum alloy, its length is 200 mm, and diameter is 6 mm. The bar is allowed to fall freely from a pre-selected height *h*. The instrumentation of the bar by the strain gauges enables to record (time) history of the force at the area of bar-eggshell contact. The value of striking velocity *v*, of the bar can be estimated from well-known equation:

$$v = \sqrt{2gh}.$$

The verification of this equation is part of this study.

3) The response of the egg to the impact loading, described above, has been measured using the double channel laser vibrometer CLV 2000 (POLYTEC). This device enables to obtain the time history of the eggshell surface displacement.

Eggshell response is measured in terms of the eggshell surface displacement. In this paper impactors in form of flat cylinders and ball have been used. The use of the cylindrical impactor enables to record the time history of the impact force. The effects of excitation point and impact intensity on the shell crack origin as well as on the response signals were investigated.

Eggs (*Hisex Brown* strain) were collected from a commercial packing station. Their physical and geometrical characteristics have been evaluated using of the procedure well described by Severa *et al.* (2013). Eggs were excited by the impact of projectile at three different positions: on the sharp end, on the blunt end and on the equator.

RESULT AND DISCUSSION

In the Fig. 2 an example of the loading force on the eggshell is displayed. One can see that the eggshell damage is connected with a significant change in the time history of the loading force. The response of the eggshell can be also described in the frequency domain. This procedure is based on the Fourier transform technique.

For a continuous function of one variable *f (t)*, the Fourier Transform *F (f)* is defined as:

$$F(\omega) = \int_{-\infty}^{+\infty} f(t) e^{-i\omega t} dt.$$

And the inverse transform as:

$$f(t) = \int_{-\infty}^{+\infty} F(\omega) e^{i\omega t} d\omega,$$

where *F* is the spectral function and ω is the angular frequency. In the Fig. 4 an example of the frequency dependence of the amplitude of the spectral function (force) is shown.

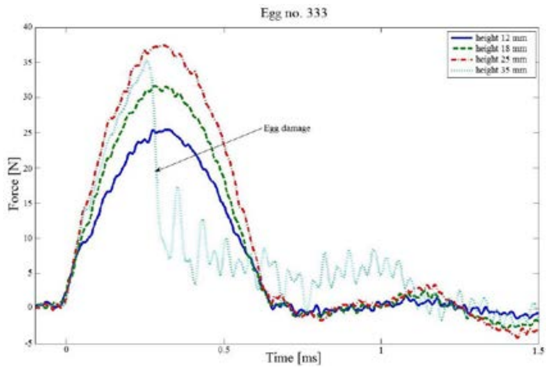

Fig. 2 Experimental records of the force at the point of the bar impact (sharp end)

The eggshell damage has also a significant effect on the eggshell response which is given by the eggshell displacement time history – see Fig. 3.

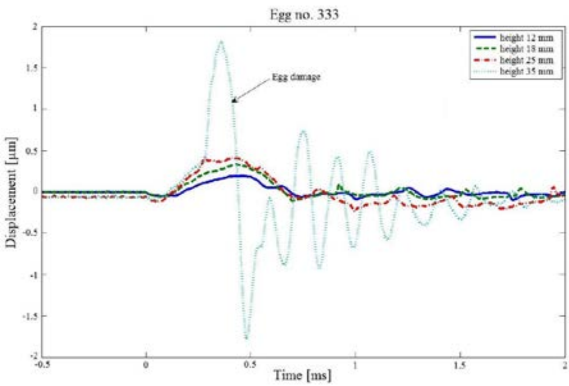

Fig. 3 Experimental records of the surface displacements measured on the equator

The frequency response function is characterized by many peaks. The amplitude exhibits a maximum. The corresponding frequency is denoted as the dominant frequency. This frequency plays dominant role at the evaluation of the mechanical stiffness of many fruits and eggshell. Its value depends on the excitation intensity (i.e. on the height of the bar fall).

In addition, the differences among the first peak (f1), second peak (f2), and third peak (f3) were remarkable (f1, f2, f3) mean of the first, second and third maximal magnitude value of frequency domain signal, respectively. In contrast, eggs with cracks have heterogeneous frequency response signals and their peak frequencies were disperse and not prominent. Differences among the first peak f1, second peak f2, and third peak f3 were much smaller than that of intact eggs. It could be explained by the difference of stiffness of the intact and cracked eggs. Differences in response signals between intact and cracked eggs were remarkable when the distance of impacting location and crack was less than about 30 degrees. Very similar results have been reached by Sun *et al.* (2013) where five frequency characteristics were suggested. They were; mean of the amplitude values (X_1), value of first peak frequency (X_2), index of first peak frequency (X_3), mean of magnitude values from top three peak frequency (X_4) and standard of magnitude values from top three peak frequencies respectively (X_5). All these parameters can be used for the evaluation of cracks of the eggshells.

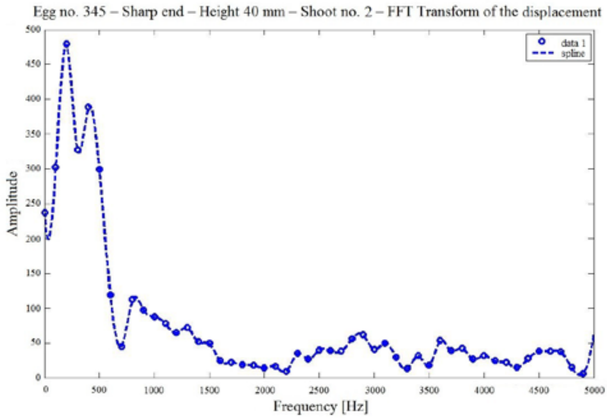

Fig. 4 Amplitude spectrum of the surface displacement – time record

Values of these parameters are given in the Tab. 1. These data represents collection of more than 200 eggs.

Tab. 1 Parameters of the frequency spectrum

Parameter	Intact egg	Cracked egg
X_1	120 - 165	140 - 190
X_2	260 - 320	200 - 280
X_3	420 - 650	480 - 760
X_4	370 - 420	410 - 460
X_5	58 - 135	42 - 95

The next analysis of the obtained results led to the conclusion that the resonance frequency domain and the dominant frequency were dependent on the relative position of the excitation point towards the location of the crack on the shell. This is illustrated at the Fig. 5.

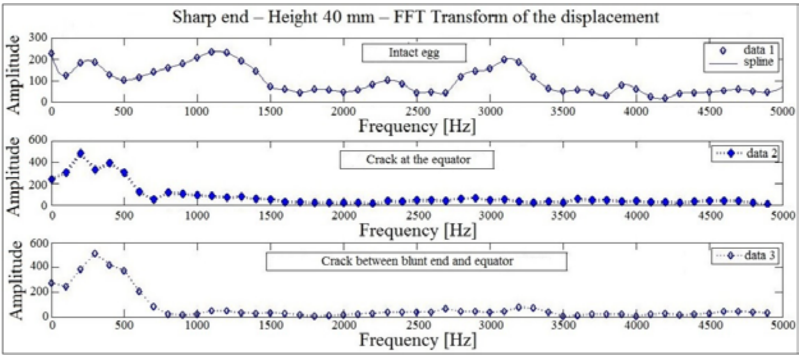

Fig. 5 The effect of the crack position on the eggshell frequency response, egg loaded at the sharp end

CONCLUSIONS

This work studied the possibility of the detection of eggshell crack based on eggshell impulse response. A system was developed for the detection. The knowledge of the cracks effect on the eggshell has been obtained using of the signal frequency analysis. The work showed that the proposed method is suitable for the crack detection. The main factors affecting the detection reliability were identified. The work shows that cracked eggs can be effectively detected by impact measurement system coupled with a fast signal processing. The excitation resonance frequency characteristic of the cracked egg and intact egg can be identical in the situations when the detection point is far from the position of the crack.

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