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RESPONSE ANALYSIS OF THE DYNAMIC EXCITATION OF HEN EGGS

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Abstract

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Commercially produced hen eggs have been tested by means of dynamic excitation of the egg-shells with following analysis of their response. The falling steel ball have been chosen as a exciting instrument and the laser vibrometer have been used as a measuring device for the egg response. The reproductibility of the experiments has been relatively high and the surface velocity has been found to be significantly dependent on the position around the meridian. Analysed frequency spectrum has shown the peak frequency and frequency history. Proposed numerical model has demonstrated reasonable agreement with experimental results and can be used as an effective tool in modelling of analogous or similar experiments.

eggshell, impact, vibration, finite elemnt model

One of the accepted methods for determination of physical properties for quality evaluation of fresh products is dynamic excitation and response analysis. Many researchers have analysed acoustic impulse responses in various kinds of products (Armstrong et al., 1990; Chen et al, 1992; Duprat et al., 1997; Hazashi et al., 1995). Certainly, the method based on dynamic excitation and response analysis could be considered in application of the egg physical properties. Also the factors affecting the acoustic response of egg must be investigated to find out the optimal parameters for egg physical properties and the acoustic impulse response technique might be proposed to replace human egg sorting, including crack detecting. In this research, the eggs have been excited by the impact of the steel ball on the blunt side, and the response signals were detected by the laser vibrometers at the different points on the eggshell surface. The response wave signals were then transformed from time to frequency domain and the frequency spectrum was analysed. The specific objectives of the research were to:

1 – analyse the response time signals and frequency signals of eggs
2 – develop a finite element model of the egg in order to limit number of experiments.

MATERIALS AND METHODS

Eggs were collected from a commercial packing station. The main geometric properties of the eggs are presented in the Table I.

The measurement set-up is shown in Fig. 1. It has three major parts, namely the product support, the excitation device and the response-measuring device.

Product support – During the measurements the support of the egg must be such that the distortion of its natural motion caused by this support is minimal. The choice was made to support the egg with a teflon ring.

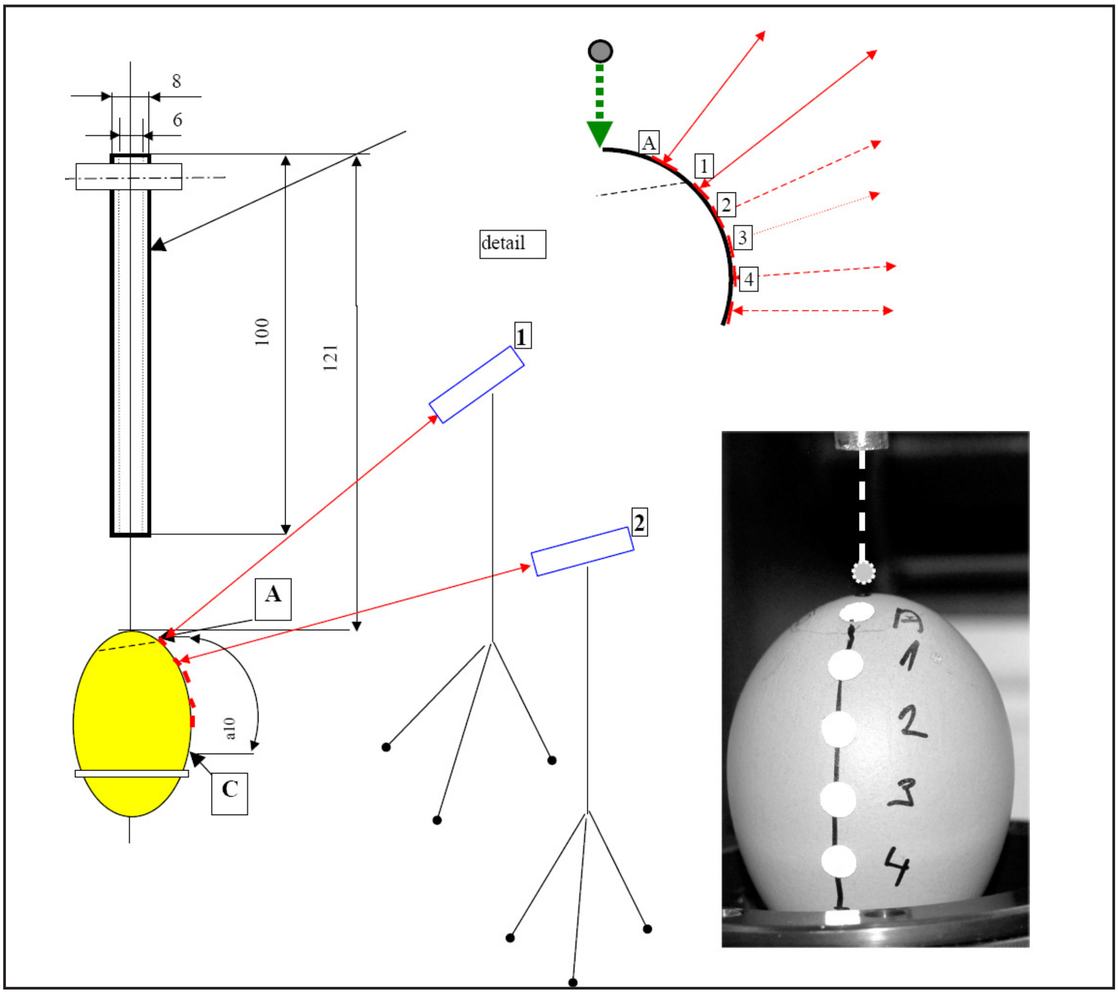
I: *Main characteristics of the used eggs*

No	Mass (g)	Width (mm)	Length (mm)	Shape index [%]	Air bubble [mm]
1	60.39	44.71	54.16	82.55	2
2	60.75	45.28	53.50	84.64	1
3	66.50	43.99	61.10	72.00	2
4	65.17	45.21	56.32	80.27	1
5	61.73	44.74	55.50	80.61	1
6	64.17	44.60	57.33	77.80	2
7	65.79	45.20	57.21	79.01	2
8	63.95	44.21	57.36	77.07	2
9	68.66	46.03	57.18	80.50	2
10	64.30	45.99	54.03	85.12	2
11	67.51	45.69	57.52	79.43	1
12	66.67	45.45	57.63	78.87	2
13	65.30	45.02	57.70	78.02	1
14	60.39	43.51	58.23	74.72	2
15	63.86	44.33	58.73	75.48	2
16	63.25	44.62	55.93	79.78	2
17	60.84	43.91	56.26	78.05	2
18	62.17	45.06	54.86	82.14	2
19	62.54	43.78	58.51	74.82	2
20	63.13	44.20	58.53	75.52	2
21	62.92	44.51	56.37	78.96	2
22	64.26	45.62	54.72	83.37	2
23	65.54	44.90	58.03	77.37	2
24	67.79	46.20	56.89	81.21	2
25	61.48	44.29	55.28	80.12	1
26	66.77	45.56	56.93	80.03	2
27	63.43	44.43	56.48	78.67	2
28	68.54	45.81	57.91	79.11	2
29	64.37	44.41	58.05	76.50	2
30	66.44	45.19	57.94	77.99	2

The impact excitation method was chosen for this test because of its fast and simple nature. The egg is excited at top of the blunt part of the egg by the impact of the steel ball. The ball falls from the heigth of 121 mm.

The egg response measurement. A laser vibrometer was used to measure the egg response to the impact. This contactless sensor adds no extra mass to the structure and does not disturb the free vibration of the egg. The laser-vibrometer measures the velocity of the vibration at a certain point in the direction of the laser beam. In the test, the laser beam is focused normally to the eggshell surface at a selected node on the meridian of the egg. The laser vibrometer is isolated from the egg supporting structure so no disturbing vibrations are introduced when performing the measurements.

Data acquisition and analysis. When eggs were excited, the response acceleration signals in time domain were detected, and MATLAB computer program was used to transform the response from time to frequency domain, by means of FFT. The dynamic response curves in the time and frequency domain of all eggs were gained. The experiments were conducted five times.

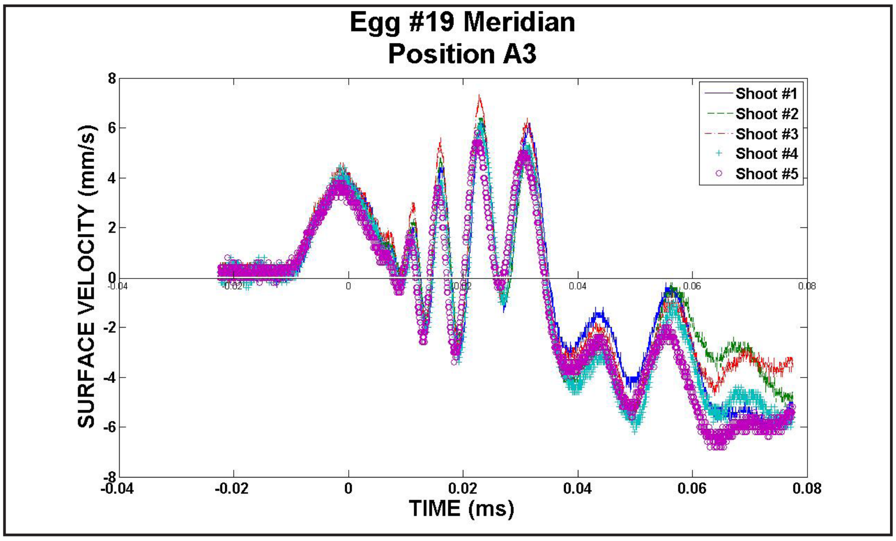


1: *Experimental set up. Positions A, 1, 2, 3, 4 are denoted as A0, A1, A2, A3, A4*

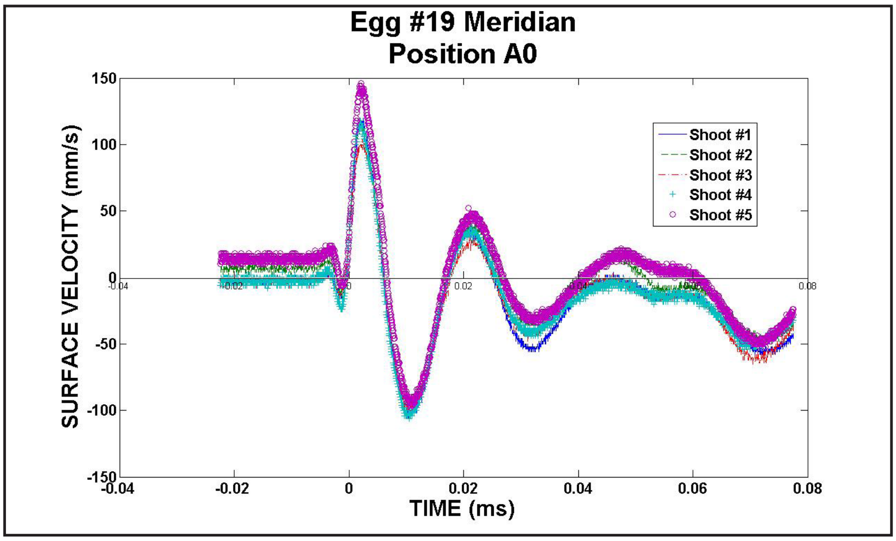
RESULTS AND DISCUSSION

Time domain

Examples of the surface velocity of the egg surface are given in Figs. 2 and 3.

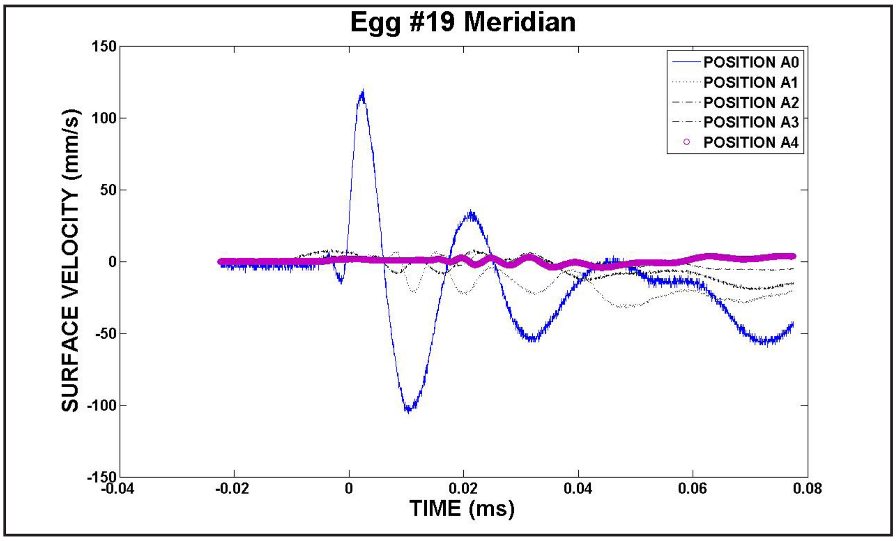


2: *Time history of the surface velocities at the ipoint A3*



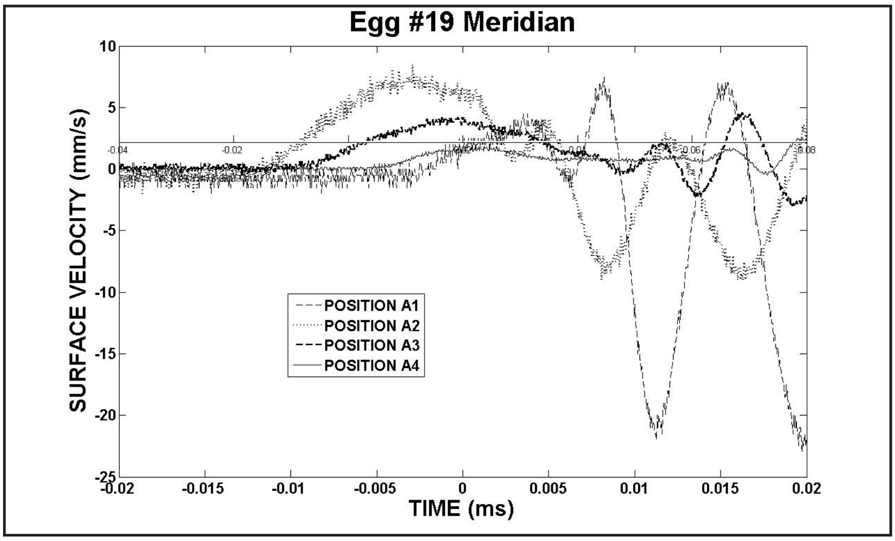
3: *Time history of the surface velocities at the ipoint A3*

It can be seen that the reproducibility of the experiments is relatively very high. The surface velocity is significantly dependent on the position around the meridian – see Fig. 4.



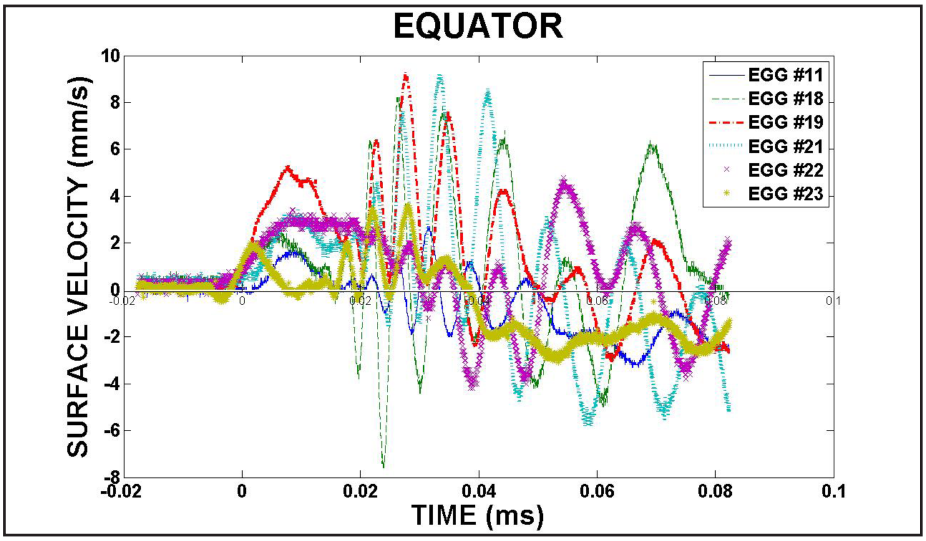
4: *Time history of the surface velocities at the different points around the meridian*

The highest attenuation is observed at the transit point from the air bubble to the liquid area. The attenuation of the stress wave around the meridián in the white egg area is shown in the Fig. 5.



5: *The surface velocity history around the meridian – white egg liquid area*

The surface velocity is also dependent on the egg-shape – see Fig. 6. The qualitative features of the surface response are also dependent on the eggshell thickness and egg mass. The detailed investigation of the influence of these factors on the egg acoustic response must be based on the performance of much higher number of experiments than those presented in the given paper.



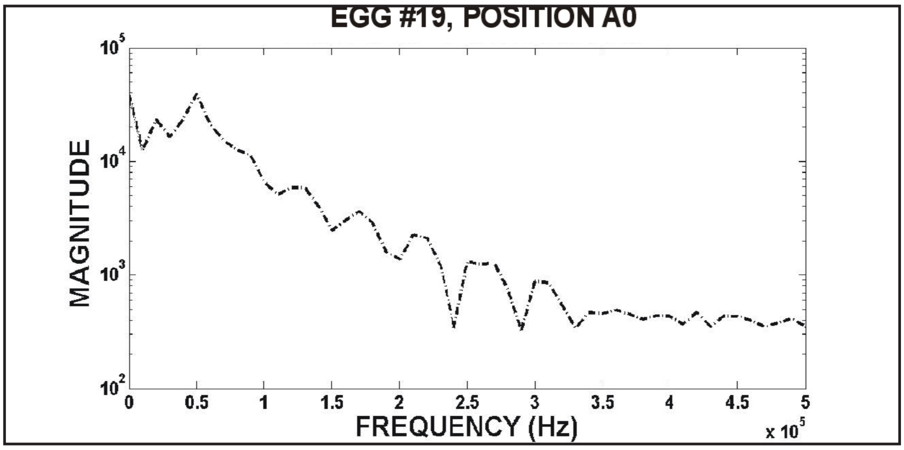
6: *Surface velocities for th e eggs of different shape index L/D – see Table I*

Frequency domain

In the next step the acoustic response of the eggs have been examined in the frequency domain. This analysis is based on the Fourier transform. If we denote the surface velocity as v(t) than the Fourier transform of this funcion is:

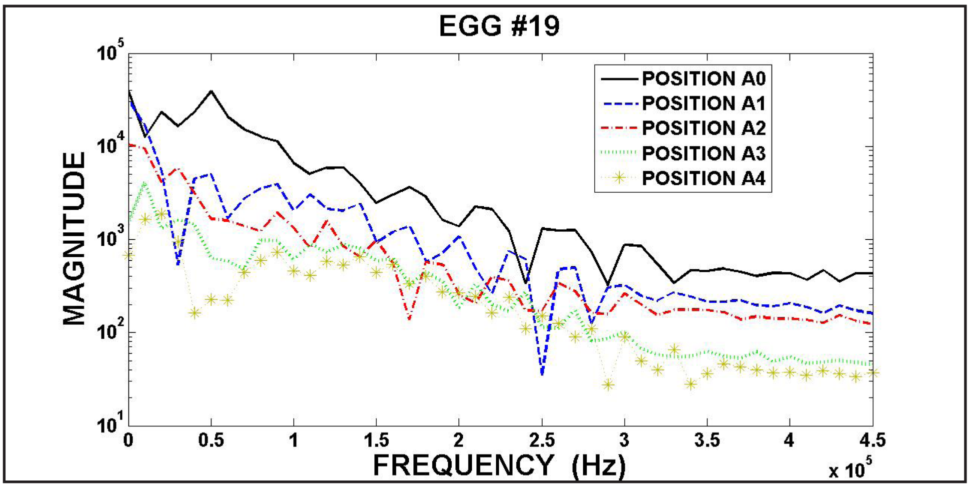
$$S(\omega) = \frac{1}{\pi}\int_0^\infty v(t)e^{i\omega t}dt = |S(\omega)|e^{i\phi} = Se^{i\phi},$$

where S(ω) is the spectral function, ω is the angular frequency and i denotes the imaginary unit. S denotes the amplitude of the spectral function and ϕ its phase. An example of the magnitude of the Fourier spectra is shown in the Fig. 7.



7: *Example of the Fourier spectrum*

The frequency analysis shows that there is a peak frequency (the response magnitude is the highest, called as the dominant frequency) in the frequency domain. The position of this peak frequency may be affected by the position on the eggshell as shown in the Fig. 8.

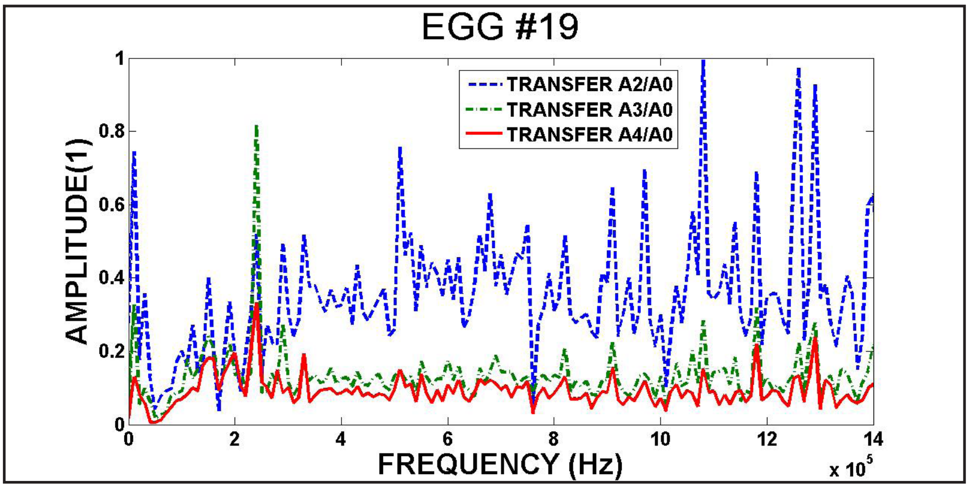


8: *Frequency response around the meridian*

The knowledge of the spectral functions can be used for the design of the transfer function. The transfer function is definied as the ratio of the spectral functions at two different points. If we denote the single points around the meridian by 0, 1, 2, 3, 4, we obtain the following transfer function T(ω):

$$T_{01} = \frac{S_1(\omega)}{S_0(\omega)} \quad T_{02} = \frac{S_2(\omega)}{S_0(\omega)} \quad T_{03} = \frac{S_3(\omega)}{S_0(\omega)} \quad T_{04} = \frac{S_4(\omega)}{S_0(\omega)}.$$

Amplitudes of the transfer functions are shown in the Fig. 9.



9: *Amplitudes of the transfer functions*

One can see that the most of components of the Fourier spectra are damped.The transfer function can be futher used for the estimation of the system linearity. This research will be content of the forthcoming papers.

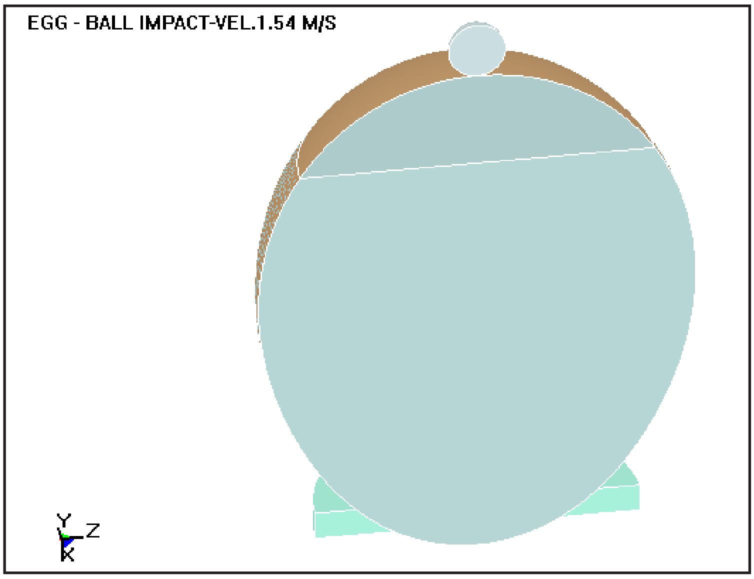
Numerical simulation

The experimental study of the acoustic response of the eggs can and does bring many useful information on the egg prperties. This research needs the study of the influence of many factors on the acoustic response (different kinds of the impactors, diffrent impact velocities etc.) In order to minimize the number of experiments some reliable numerical simulation of the given test is urgently needed. In this paper some preliminary results of the numerical simulation of the ball impact on the egg are presented. The numerical simulation has been performed using the finite element metod. The numerical model is shown in the Fig.10.

Parameters of the model are:

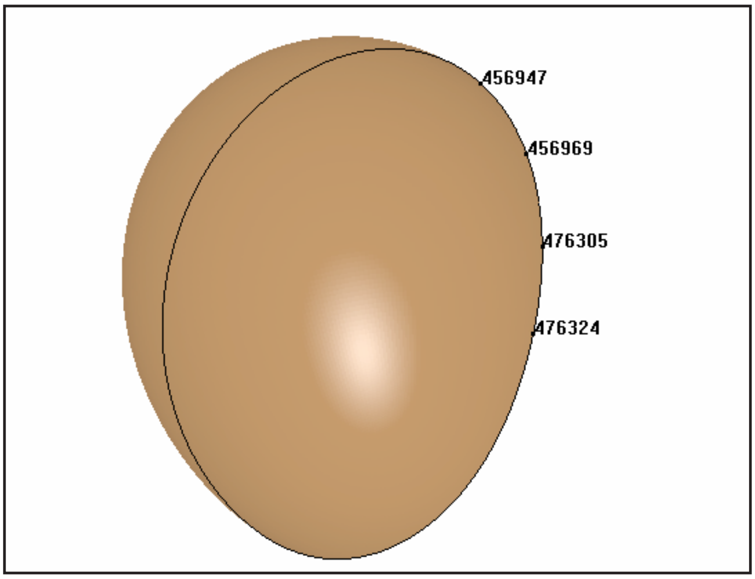
- Total number of nodes 141249
- Total number of solid elements 88050
- Total number of shell elements 46710.

Numerical analysis has been performed by LS DYNA 3D finite element code (LS-DYNA Keyword User´s Manual, 2003).



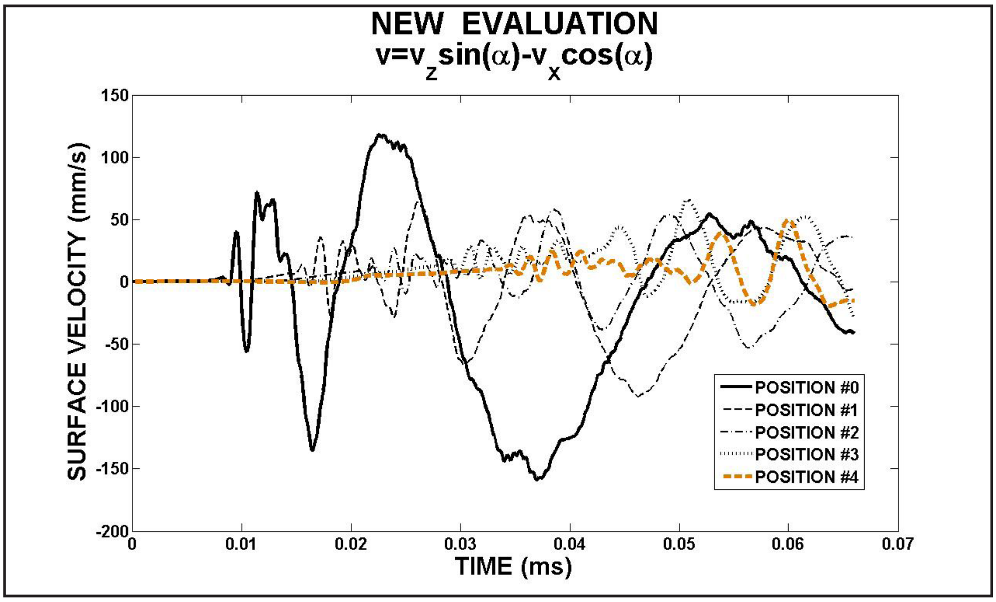
10: *Numerical model of the experiment*

As the main rsults of the computation have been choosen as eggshell surface velocities. The points of the velocities determination are shown in the Fig. 11.



11: *Points of the surface velocities evaluation (number of the node is shown)*

The attenuation of the surface velocity along the meridian is shown in the Fig. 12.



12: *Numerical results on the time history of the surface velocities*

More detailed analysis has shown a relatively very good agreement between experimental and numerical results. It means that proposed finite element model can be used for the solution of some other problems mentioned e.g. in (Wittel et al., 2005).

SUMMARY

The egg dynamic response to the ball impact has been examined experimentally. The experiments revelaed that there is a dominant frequency which may be independent on the point of measurement. The next verification of this hypothesis should lead to a proposoal of the using this parameter for the description of the crack influence, egshell strength and some other factors on the egg quality.

The proposed numerical model should be able to describe many other dynamic eggs loads. Its improvement will be also subject of the next research.

SOUHRN

Analýza odezvy dynamického buzení skořápek slepičích vajec

Chování komerčně produkovaných slepičích vajec bylo testováno pomocí dynamického buzení skořápek s následným sledováním jejich odezvy. Vejce byla zatěžována pádem ocelové kuličky a odezva skořápky byla zaznamenávána pomocí laserového vibrometru. Reprodukovatelnost experimentů byla poměrně vysoká. Snímaná povrchová rychlost vykazovala silnou závislost na poloze vzhledem k meridiánu skořápky. Analýza frekvenčního spektra ukázala zřetelné frekvenční píky a umožnila popis frekvenčního průběhu. U navrženého numerického modelu bylo dosaženo velmi uspokojivé shody s experimentálními daty. Model může být využit i pro další obdobné či podobné experimenty.

vaječná skořápka, rázové zatěžování, vibrace, metoda konečných prvků

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