Experimentální Analýza Napětí 2007

EGGSHELL BEHAVIOUR OF A CHICKEN EGG UNDER NON-DESTRUCTIVE IMPACT

Jaroslav Buchar[1],Jan Trnka[2].Pavla Dvořáková[2], Šárka Nedomová[1]

Abstract: *In the given paper the main attention is focused on the vibration behaviour of the egg after impact excitation by a steel ball. A dynamic stiffness parameter, kdyn , is introduced which is based on a mathematical mass-spring model of the dynamic behaviour of the egg. A finite element model of the static and dynamic eggshell behaviour has been developed in order to understand better the relationships between the two parameters. The comparison of experimental results with numerical ones are used for the evaluation of the egg model reliability.*

Keywords: *eggshell, impact,vibration,finite elemnt model, siffness*

1. Introduction

Many methods are available for quality detection and sorting of agroproduct based on external properties such as size, shape, and external defects. One of the methods is dynamics excitation and response analysis. Dynamic excitation and response analysis is an acceptable method for determination of physical properties for quality evaluation of fresh products. Fruit response to impact and sonic excitation has been well documented in the literature for the last three decades. Many researchers have analysed acoustic impulse responses in various kinds of products [1-6]. Certainly, the method based on dynamic excitation and response analysis could be considered in application of the egg physical properties (Overfield, 1987), and the factors affecting the acoustic response of egg must be investigated to find out the optimal parameters for egg physical properties, and an acoustic impulse response technique might be proposed to replace human egg sorting, including crack detecting. In this research, eggs were excited by the impact of the steel ball on the blunt side, and the response signals were detected by the laser vibrometers at the differentdifferent 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- to develop a finite element model of the egg in order to limit number of experiments.

In order to develop a model of the egg some brief description of the egg structure is presented in the following chapter.

The main goal of the present study was intended to better understanding the vibration characteristics of an egg. For this purpose, an experimental modal analysis was performed on an intact egg. This analysis gives the possibility to visualize the spatial motion of the egg after being impacted. In this way, an optimal test set-up can be created, regarding optimal supporting points of the egg, and the exact positioning of the impactor and the response-measuring device.

[1] Mendel University of Agriculture and Forestry, Zemedelska 1, 613 00 Brno, Czech Republic

[2] Institute of Thermomechanics, Czech Academy of Science, Dolejškova 5, 182 00, Praha 8

2. Structure of the egg and finite element model.

The schematic of the hen`s egg is hown in the Fig.1. The detail description of the single elemnts of this structure is given e.g. in [7,8]. The finite element model has been developed using the following assumption :

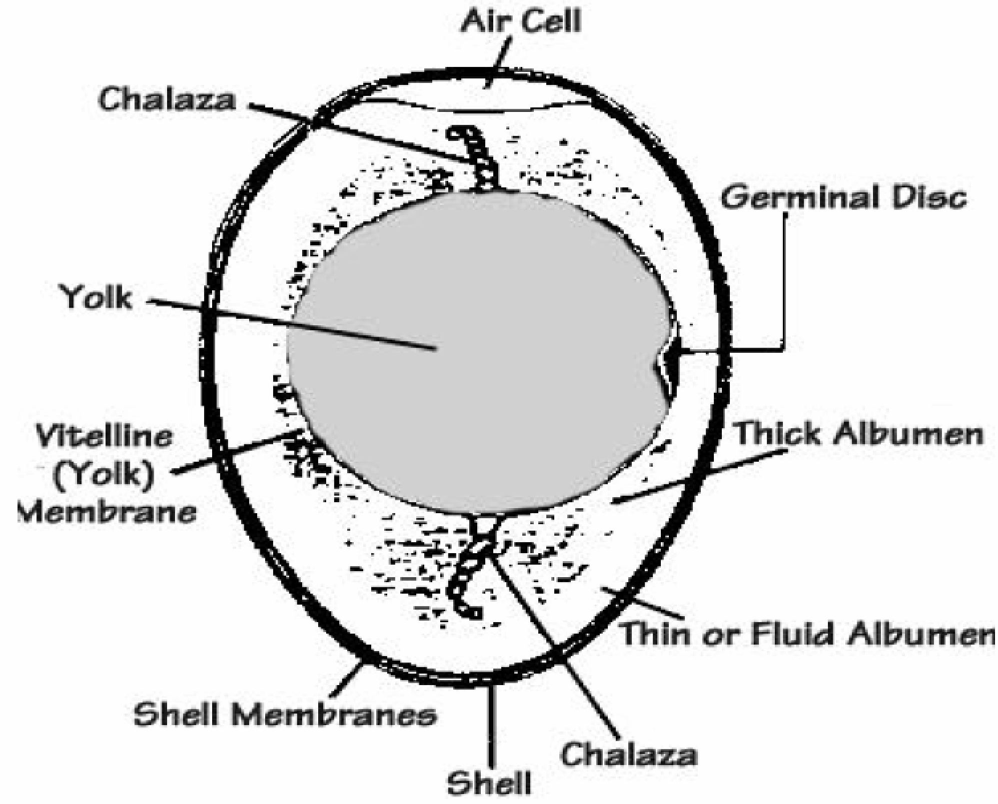

Fig.1. Schematic of the egg structure.

a) Eggshell is homogeneous isotropic linear elastic material. The properties of such material are described by the Young modulus E, Poisson ratio ν and material density ρ

b) Membranes are also taken as linear elastic material. No difference between membranes has been considered.

c) Air is considered as ideal gas.

d) Egg yolk as well as egg white are considered as compressible liquids.

The next difficulties in the egg description are consequence of the high variability of shell egg shapes. A number of authors have tried to derive mathematical equations that express the contour of individual eggs. References to these descriptions can be found in the review of Narushin [9]. The presented decription of the egg shape is very questionable. This is why a new procedure was developed, using a graphical user interface (GUI), which allowed the user to accurately determine the necessary dimensional properties of eggs from digital photographs of the eggs. The application required one measured dimension (the egg length, *L*, measured with vernier callipers), and calculated any user-defined distance on a digital egg photograph from the derived number of pixels per unit length. Based on a user-defined 2-D cartesian coordinate system, the coordinates of the required points were defined in a plane of symmetry. After this determination step, the egg contour was calculated and plotted on the egg picture according to the selected equations, and the agreement was visually evaluated. Cross section of the used model is shown in the Fig.2.

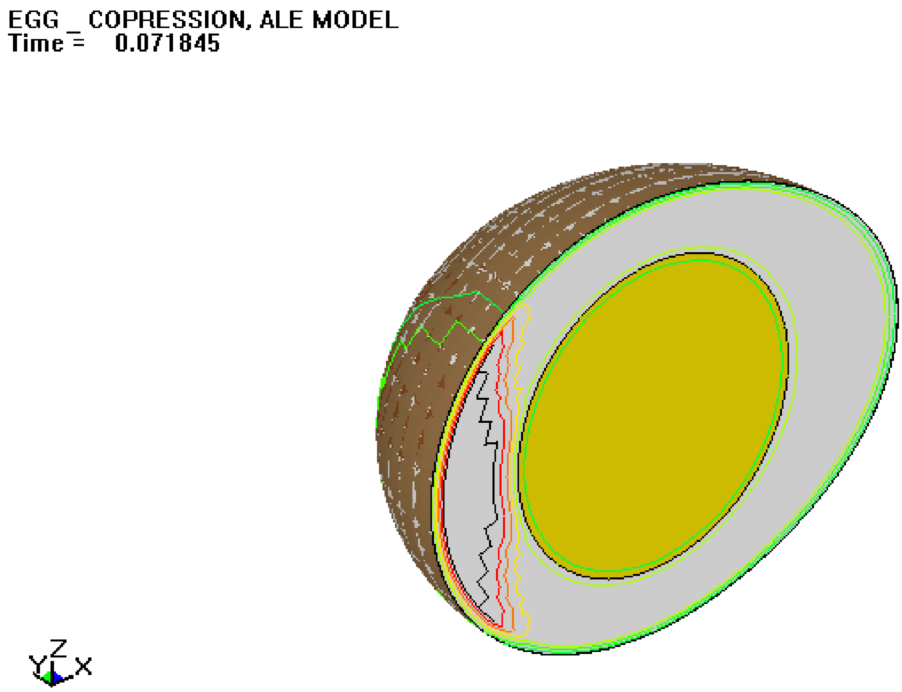

Fig.2. Scehematic of the egg model used for the numerical simulation.

The elastic properties of the eggshell has been obtained using of the procedure developed in [10]. Elastic properties of the membranes weree determined by the method described in [11]. The compressibility of the egg liquids was taken from the study [12]. The elastic properties are given in Table 1.

Egg part	ρ (kg/m^3)	E (GPa)	ν
eggshell	2140	20.8	0.37
membrane	1005	0.0035	0.45

Table 1.Elastic properties of the egg parts

Egg liquid	ρ (kg/m^3)	K (GPa)
white	2140	2.0
yolk	1005	1.8

Table 2. The properties of the egg liquids. (K- bulk modulus)

3. Materials and Methods

3.1. Egg samples.

Eggs were collected from a commercial packing station. The main geometric properties of the eggs are presented in the Table 3.

No	Mass (g)	Width (cm)	Length (cm)	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
average	***64,29***	***44,88***	***56,87***	***78,99***	***1,80***

Table 3. Main characteristics of the used eggs.

3.2. Experimental system

The measurement set-up is shown in Fig. 3 and has three major parts, namely the product support, the excitation device and the response-measuring device.

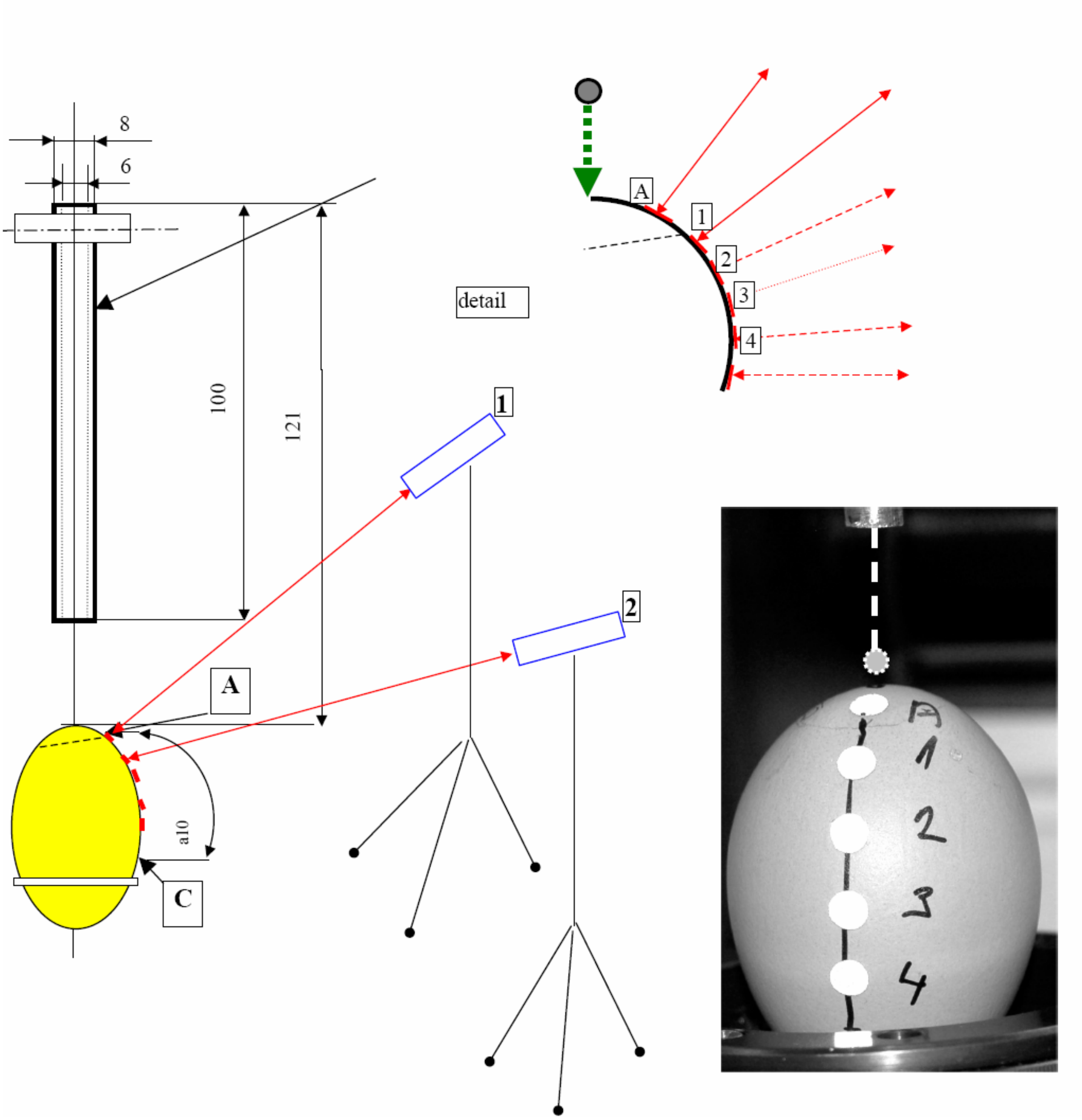

Fig.3. Experimental set up.(Positions A,1,2,3,4 are denoted as A0,A1,A2,A3,A4)

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.

The impact excitation method is 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. We then gained and analysed the dynamic response curves in the time and frequency domain of all the eggs, statistically. The experiments were conducted five replicates.

4.Results and Discussion.

4.1. Experimental results.

In Fig.4 example of the surface velocity of the egg surface is given.

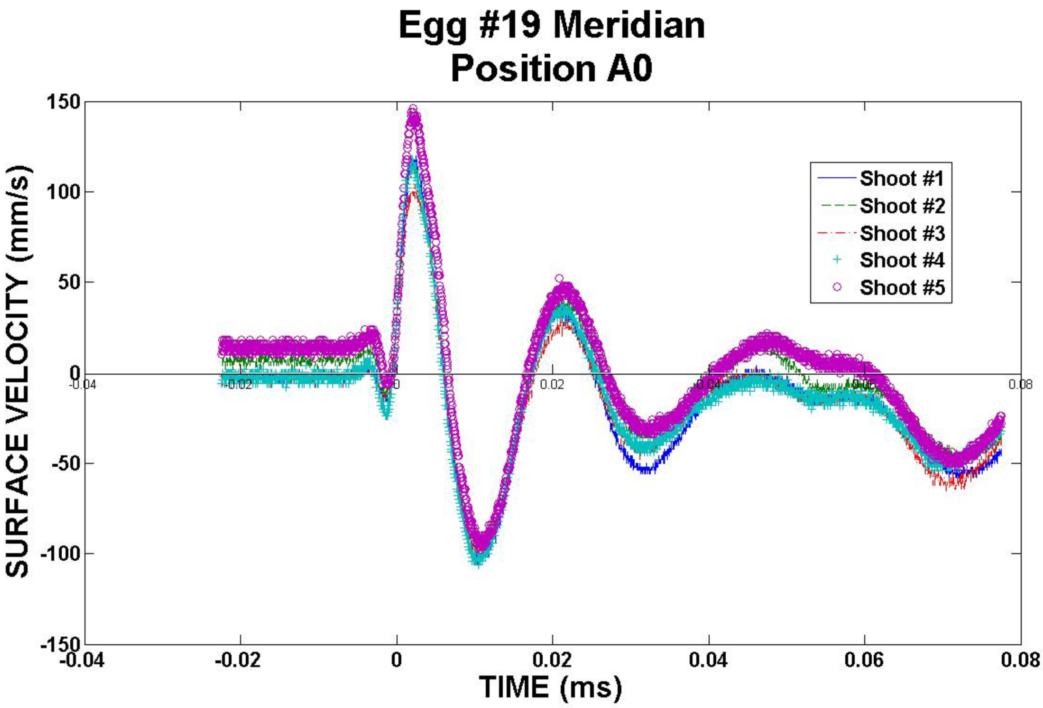

Fig.4. Time history of the surface velocities at the impact point..

It can be see that the reproducibility of the experiments is relatively very high. If we perform soome measurements on the equator the experimental records exhibit some time shift. – see Fig.5.

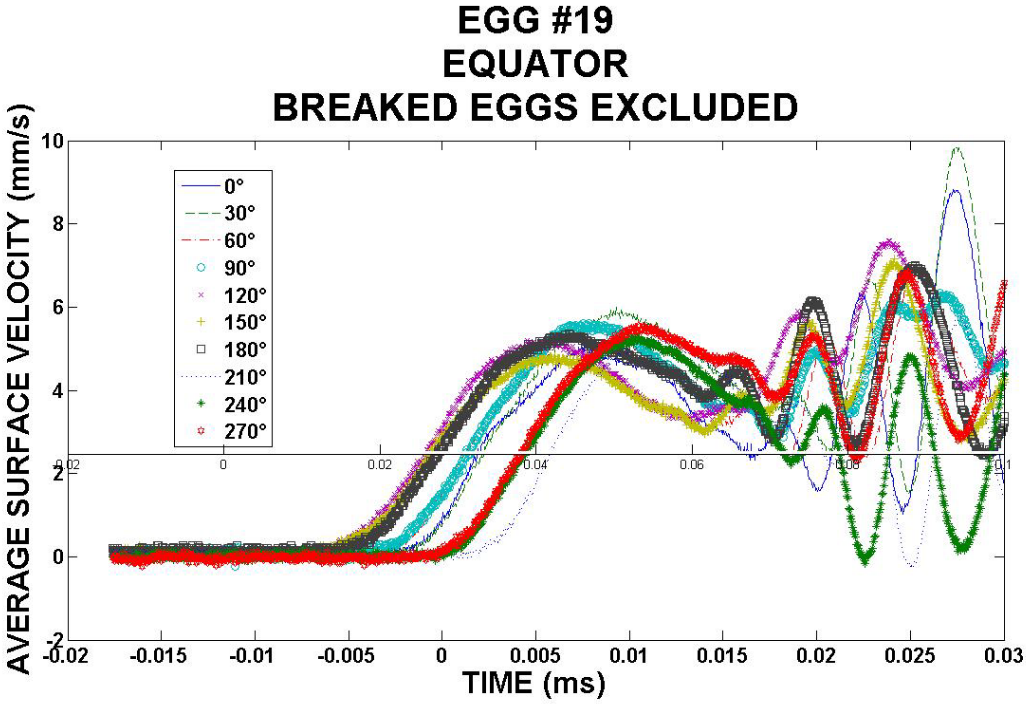

Fig.5. Experimental records at different points of the egg equator.(The distance between points is 30°)

The surfece velocity decreases with the increase of the distance from the impact point – see Fig. 6.

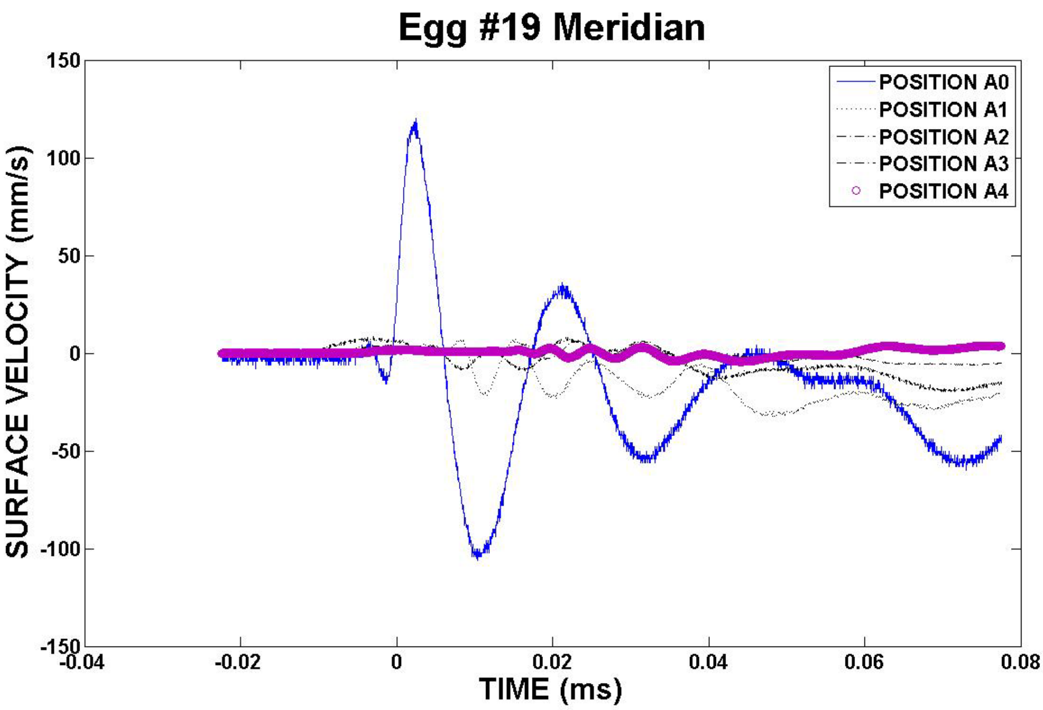

Fig.6. Surface velocity at the different points along the meridian.

The impact point is located on the egg surface above the air bubble. The attenuation of the surface velocity at the points which lie above egg liquid. This attenuation is shown in the Fig.7.

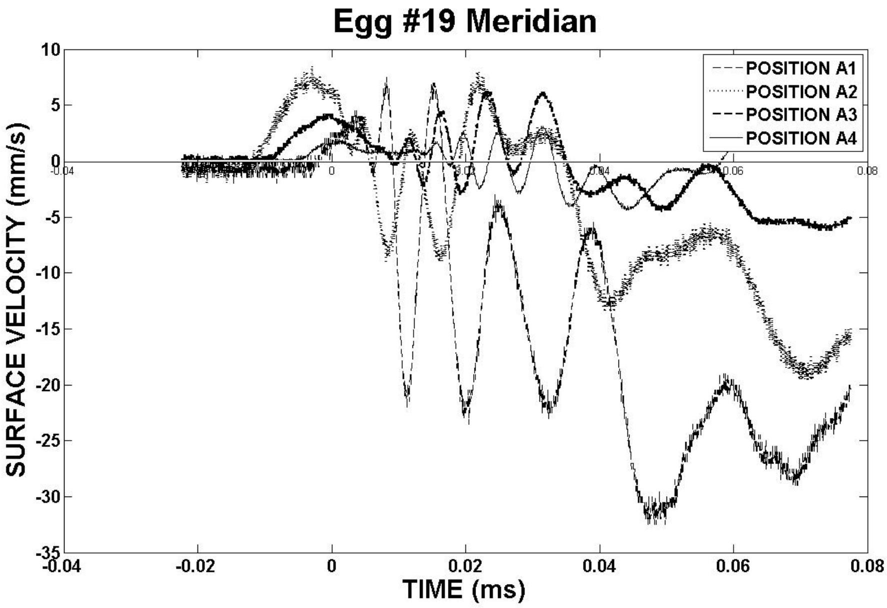

Fig.7. Surface velocity at the different points along the meridian

In the Fig.8 an example of the frequency response is shown.

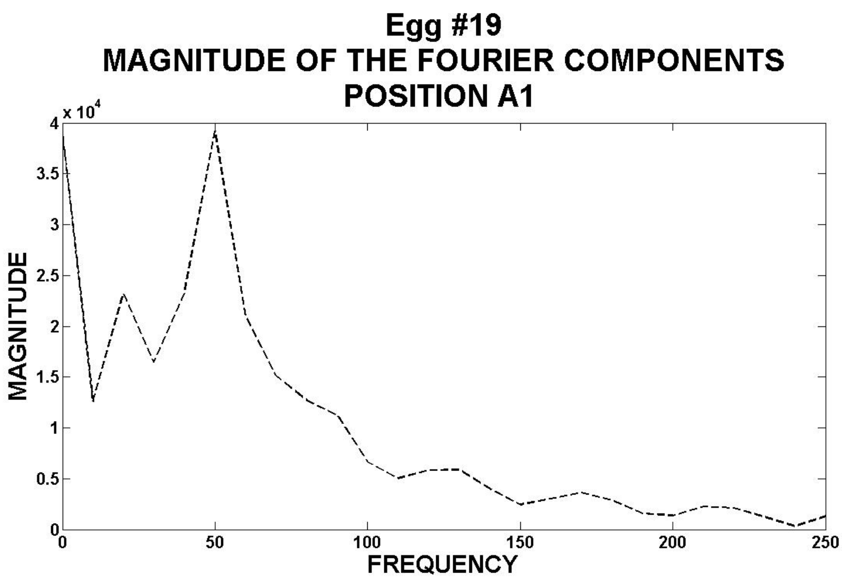

Fig.8. Example of the frequency response.

The peak frequency (the response magnitude is the most, called as the dominant frequency) can be observed in the frequency domain . A detail analysis leads to the conclusion that this frequency is probably independent on the position of the point on the eggshell surface. This position affects only the magnitude. This conclusion must be verified by the next measurements.

4.2 Numerical results

The numerical model is shown in the Fig.9.
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 [13].

Fig.9. Numerical model of the experiment.

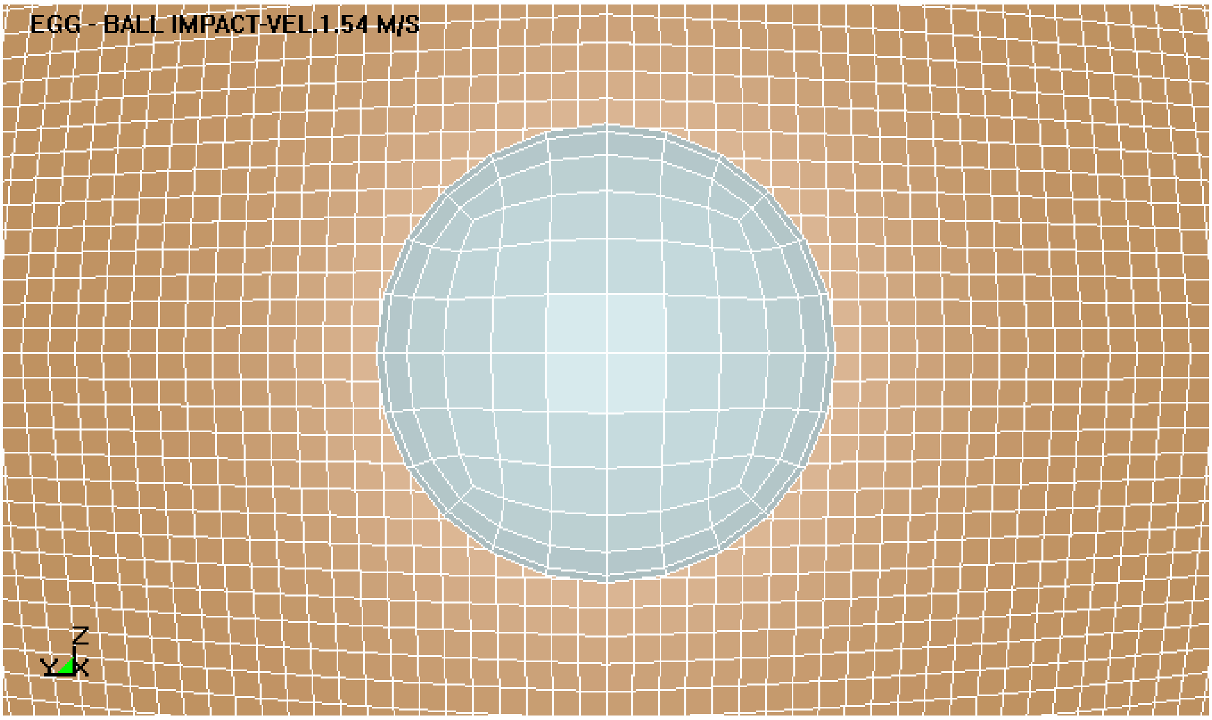

Fig.9. A detail of the mesh (view from the ball impact.

The attenuation of the surface velocity along the meridian is shown in the Fig. 10.

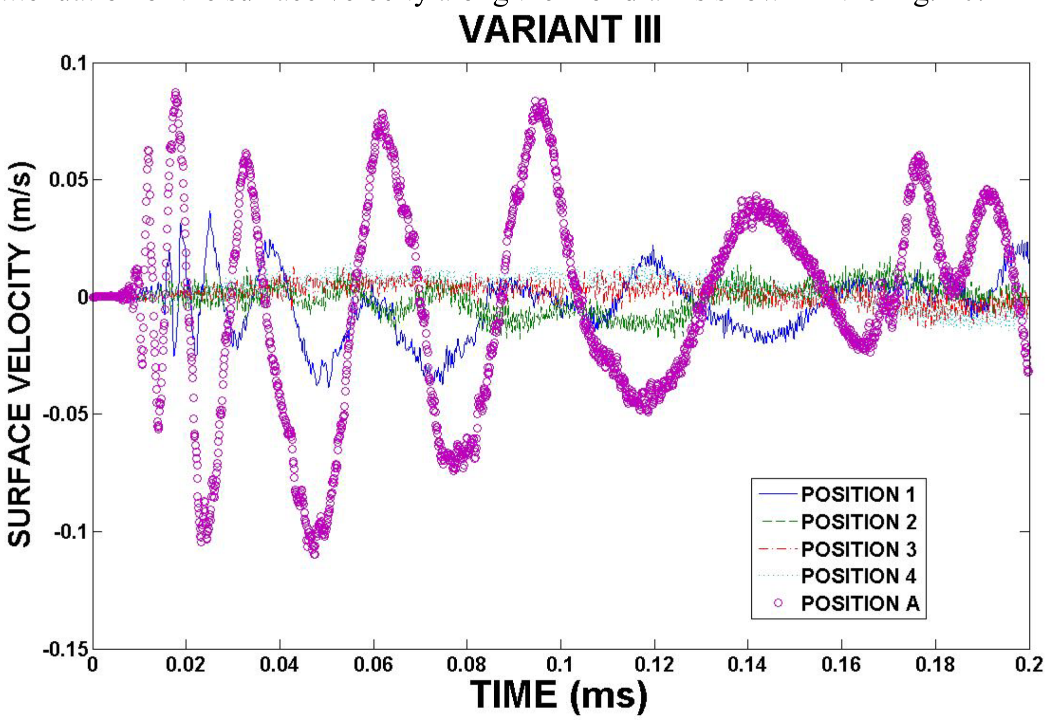

Fig.10. Numerical results.

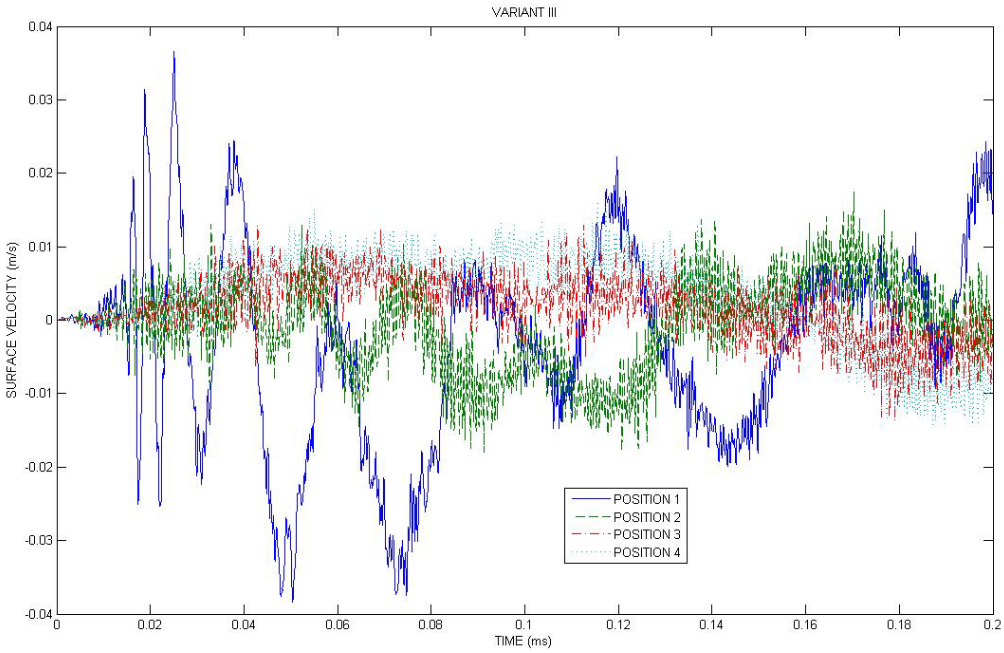

Fig.11. Numerical results

By the more detail analysis has been shown a relatively very good agreement between experimental and numerical results. It means that the used finite element model can be used for the solution of some other problems mentioned e.g. in [14].

5. Conclusion

The egg dynamic response to the ball impact has been examined experimentally. The experiments revelaed that there is a dominant frequency which is independent on the point of measurement. The next verification of this hypothesis should lead to a proposoal of the use this parameter to 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 others dynamic eggs loads. Its improvement will be also subject of the next research.

Acknowledgements: The research has been supported by the Grant Agency of the Czech Academy of Sciences under Contract No.IAA201990701.

References

[1] Armstrong, P., Zapp, H. R., & Brown, G. K.. *Impulsive excitation of acoustic vibrations in apples for firmness determination.* Transactions of the ASAE,1990. 33(4), 1353–1359.

[2] Chen, P., Sun, Z., & Huang, L. . *Factors affecting acoustic responses of apples*. Transactions of the ASAE,1992, 35(6), 1915–1920.

[3] Duprat, F., Grotte, M., Pietri, E., & Loonis, D.. *The acoustic impulse response method for measuring the overall firmness of fruit.* 1997,Journal of Agricultural Engineering Research, 66(1), 251–259.

[4] Hayashi, S., Sugiyama, J., Otobe, K. *Nondestructive quality evaluation of fruits and vegetables by acoustic transmission waves*. 1995,Proc. ARBIP95 (JSAM) (pp. 227–234).

[5] Overfield, N. D. *Egg grading as a form of quality control*. Poultry-Misset ,1987,(pp. 10–13).

[6] Stone, M. L., Armstrong, P. R., Zhang, X., Brusewitz, G. H., & Chen, D. D. . *Watermelon maturity determination in the field using acoustic impulse impedance techniques.* Transactions of the ASAE, 1996,39(6), 2325–2330.

[7] Rodriguez-Navarro A, Kalin O, Nys Y, Garcia-Ruiz JM (2002) *Influence of themicrostructure and crystallographic texture on the fracture strength of hen's eggshells*. Br Poult Sci 2002,43:395–403

[8] Wells, R.G., *Egg quality Characteristics*. pp: 214- 225 in Egg Quality: A Study of the Hens Egg. T.C. Carter, ed. Oliver and Boyd, Edinburgh. 1968.

[9] Narushin VG. *The avian egg: geometrical description and calculation of paramet*ers J Agric Engineer Res ,1997,68: 201-5.

[11] Bing Feng Ju *, Kuo-Kang Liu, Shih-Fu Ling, Woi Hong Ng. *A novel technique for characterizing elastic properties of thin biological membrane.* Mechanics of Materials 34 (2002) 749–754

[10] Buchar J. and Simeonovova J. : *On the identification of the eggshell elastic properties under quasistatic compression*. In: 19th CAD – FEM USERS MEETING 2001-International Congress on FEM Technology.17-19.October 2001, Potsdam,Berlin Germany,Vol.2,paper No 2.2.1-8pages. Published by CAD – Fem GmbH, Munchen.

[12] Chung, R. A., & Stadelman, W. J. A study of variations in the structure of the hens egg. British Poultry Science,1965, 6, 277-282.

[13] LS-DYNA Keyword User´s Manual, Version 970, Livermore Software Technology Corporation, April 2003.

[14] Wittel F.K. Kun F. ,. Herrmann H.J. Kröplin1 B.H. *Breakup of shells under explosion and impact*. PHYSICAL REVIEW , 2005,E **71**.