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THE EFFECT OF HEN BREEDS ON THE EGG RESPONSE TO THE NON DESTRUCTIVE IMPACT

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Abstract

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The paper deals with the evaluation of the effect of hen breed on the egg response to the non-destructive impact. The eggs of four hen breeds (Leghorn White, Rhode Island Red, Bar Plymouth Rock and Sussex Light) were tested. An experimental system was set up to generate the impact force, measure the response wave signal, and analyse the frequency spectrum in the three direction of loading (sharp end, equator, blunt end). The egg dynamic resonance frequency was obtained through the analysis of the dynamically measured frequency response of an egg excited by light impact of a bar. The results showed that the dominant frequency was significantly affected by the hen bread and not significantly affected by excitation velocity. The dominant frequency enables to estimate the eggshell strength under quasi static compression.

Keywords: hen breed, eggshell strength, non-destructive impact, frequency response, dominant frequency, dynamic stiffness

INTRODUCTION

One of the main problems in commercial egg production is to avoid cracks in eggshell because the presence of cracks in the eggshell leads to the increase of the egg vulnerability to bacterial infections (Jindal & Sritham, 2003). The solution of this problem needs to measure the strength of eggshell, so as to maintain the balance between eggshell strength and the handling load in the processing of egg collection, sorting and transportation.

One of the methods is dynamics excitation and response analysis. This method was introduced by Coucke (1998). It is based on the analysis of the egg response to the non destructive impact. This analysis consists namely in the evaluation of resonant frequency of egg and its damping ratio. This technique can also be used to detect cracks in the eggshell (De Ketelaere *et al.,* 2000; Wang & Jiang, 2005; Trnka *et al.,* 2013). De Ketelaere *et al.* (2003) estimated eggshell stiffness using vibration measurements. It was found that both the damping and the shape characteristics are of major importance to explain eggshell strength. Wang *et al.* (2004) established relationship between the dominant frequency and the egg physical properties and come to the conclusion that the dominant frequency increased with an increase of shell stiffness. Bain *et al.* (2006) showed that dynamic shell stiffness provides a good estimation of eggshell strength in relation to the likelihood of breakage in practice. Eggshell qualities with different strains of laying hens were compared based on acoustic impulse analysis (Amer Eissa, 2009).

The aim of this paper consists in the evaluation of eggshell response on eggs of different hen bread.

The experimental set up developed by Nedomová *et al.* (2009a) was used. This experimental arrangement enables the recording of time history of the force at the contact area between the falling rod and eggshell and eggshell surface displacement. The objectives of the research were to: 1) analyse the response time signals and frequency signals of eggs, 2) find the effect of hen bread on dynamic resonance frequency, and 3) establish relationship between the dominant frequency and the eggshell strength under quasi-static compression.

MATERIALS AND METHODS

The eggs of four hen breeds were tested – namely Sussex Light (SU), Bar Plymouth Rock (BPR), Leghorn White (LW) and Rhode Island Red (RIR). Hens were kept in cage technology. Double-yolked eggs, rough shelled eggs and abnormally shaped eggs were not considered.

For the given eggs their mass, m, and main geometrical characteristics have been evaluated. The geometric characteristics are: length (L) and width (W) of eggs, shape index (SI), the geometric mean diameter (D_g), sphericity (Φ), volume (V) and surface area (S). These quantities were described e.g. by Mohsenin (1970) and/or Kumbár *et al.*, (2015a). The data are given in the Tab. I.

In the next step the exact description of the eggshell contour was performed. The procedure suggested in (Severa *et al.*, 2013) was used. This approach enables *e.g.* to evaluate radii of the eggshell contour curvature. The knowledge of these parameters is significant namely at the solution of contact problems.

The values of this radius have been evaluated at the blunt end (R_1), at the sharp end (R_2) and at the maximum of the egg width (equator) – R_3. Values of these radii for eggs of different hen breed are given in the Tab. II.

In the next step the eggshell strength under quasi static compression was determined. The eggs have been compressed between the two plates using testing device TIRATEST 27025. The egg sample was placed on the fixed plate and loaded at the compression velocity 0.167 mm.s^{-1} and pressed with a moving plate connected to the load cell until the egg ruptured. Two mutually perpendicular compression axes (X, Z) corresponding to main geometrical axes were used.

The X-axis represented loading axis along the length dimension and the Z-axis represented the transverse axis covering the width dimension. Two more orientations were considered in case of X-axis. If the egg sharp end is in contact with the moving plate the symbol X_s is used. The symbol X_b corresponds to the orientation where egg blunt end is in contact with the moving plate.

The response of eggs to non-destructive impact has been measured using an experimental setup, which was developed and built to evaluate the resonance signal and analyze the frequency domain for egg. The experimental setup consisted of an egg-bed mad from the polyurethane foam, a mechanical impulse excitation device (a bar falling on the egg from a definite height), signal amplifiers, and a personal computer and software to control the experimental setup and to analyse its results. The instrumentation of the bar by the strain gauges enables to record (time) history of the force at the

I: *Main characteristics of the tested eggs. Data are presented as average ± standard deviation. (Different letters indicate significant differences among the means in each raw, P < 0.05).*

	SU	RIR	BPR	LW
m **(g)**	63.001 ± 3.289^{a}	63.376 ± 4.217^{a}	56.652 ± 4.344^{b}	65.533 ± 4.281^{c}
L **(mm)**	57.469 ± 1.632^{a}	57.599 ± 1.768^{a}	56.666 ± 2.297^{ab}	59.516 ± 2.015^{ab}
W **(mm)**	44.464 ± 0.896^{a}	44.103 ± 1.082^{ab}	42.132 ± 1.073^{ab}	44.301 ± 1.259^{c}
SI **(%)**	77.425 ± 2.458^{a}	76.621 ± 2.403^{b}	74.437 ± 2.723^{b}	74.511 ± 3.051^{c}
D_g **(mm)**	48.429 ± 0.858^{a}	48.203 ± 1.075^{ab}	46.500 ± 1.204^{c}	48.873 ± 1.141^{ab}
Φ (%)	84.309 ± 1.786^{a}	83.724 ± 1.752^{b}	82.123 ± 2.010^{b}	82.174 ± 2.245^{c}
V **(mm³)**	59527 ± 3171^{abc}	58729 ± 3950^{c}	52747 ± 4079^{b}	61224 ± 4345^{ac}
S **(mm²)**	7370 ± 261^{ab}	7303 ± 327^{a}	6797 ± 351^{b}	7508 ± 353^{a}

II: *Radii of the curvature. Data are presented as average ± standard deviation. (Different letters indicate significant differences among the means in each raw, P < 0.05).*

	SU	RIW	RIR	BPR	SU
R_1 **(mm)**	18.489 ± 1.563^{a}	17.716 ± 1.590^{b}	17.480 ± 1.318^{b}	17.965 ± 1.383^{ab}	16.488 ± 1.290^{c}
R_2 **(mm)**	15.068 ± 1.250^{a}	14.673 ± 1.091^{a}	14.707 ± 1.251^{a}	14.813 ± 1.335^{a}	13.030 ± 0.942^{b}
R_3 **(mm)**	35.972±4.732a	38.167 ± 3.844^{b}	36.411 ± 3.163^{ab}	35.180 ± 3.205^{a}	39.157 ± 3.535^{c}

area of (Nedomova *et al.*, 2009a; Buchar *et al.*, 2015) bar-eggshell contact. The egg response has been measured in terms of the surface displacement and/or surface velocity as well. The laser interferometer CLV 2000 fy. POLYTEC has been used. The signals were sampled at a rate of 200,000 samples per second for a period of 50 ms.

All of the experimental data were analysed with analysis of variance (ANOVA) and Duncan's test with P < 0.05 using the MATLAB® statistics toolbox (MathWorks 274 Inc., Natick, MA, 275 USA). All experiments were performed at the room temperature (20 °C).

RESULTS AND DISCUSSION

Quasi – static compression has been performed for all eggs. All free main orientations of the loading were tested. The series of 10 eggs was tested for each orientation. Response of the egg to compression loading between two parallel plates is characterized by nearly linear increase in the loading force F with moving plate displacement p. The slope of this curve is used for the assessment of a static stiffness parameter (k_s) which is defined as:

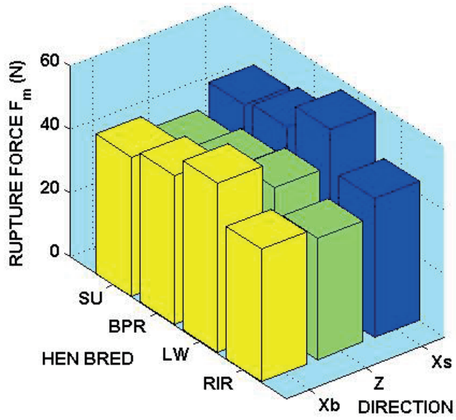
$$k_s = \left(\frac{dF}{dx}\right)_{x=0} \qquad (1)$$

This parameter can be used for a relatively good estimation of the eggshell strength of chicken eggs (Anderson *et al.*, 2004).

At the moment of eggshell break the loading force rapidly decreases. This behaviour was observed in number of researches and described in many papers; see e.g. De Ketealere *et al.* (2004) and Lim *et al.* (2004). Maximum of the loading force is than defined as the rupture force, F_m.

The values of stiffness are given in the Tab. III. One can see that for all loading directions there is no significant difference between eggs of hens RIR and SU. The effect of the loading direction was found for the eggs of LW hens.

The values of the rupture forces, F_m (in N) are displayed in the Fig. 1 and presented in the Tab. IV.



1: *Rupture force of the tested eggs (average values)*

The values of the rupture forces are different for the eggs of tested hen breeds and for the single loading orientation. The highest values of the rupture forces were reported for the X_s direction and the smallest ones for the Z direction of the eggshell loading. At the loading in the X_s direction the eggshell curvature ($1/R_1$) at the point of contact between the egg and moving (loading) plate exhibits the highest value. At the loading in the Z direction the curvature is the lowest. It means the rupture force increases with the curvature of the eggshell at the point of the loading. At the same time the curvatures of the eggshells, see Tab. II, cannot explain the differences in the values of the rupture force reported in the Tab. IV.

III: *Stiffness of the tested eggs.*

Breed	X_b direction	Z direction	X_s direction
SU	147.68 ± 9.036^{aA}	146.61 ± 5.907^{aA}	150.71 ± 10.78^{aA}
BPR	155.67 ± 9.036^{aB}	150.71 ± 5.907^{aB}	181.91 ± 10.78^{bB}
LW	198.81 ± 9.036^{aC}	163.79 ± 5.907^{bC}	211.21 ± 10.78^{cC}
RIR	147.03 ± 9.036^{aA}	144.84 ± 5.907^{aA}	148.56 ± 10.78^{aA}

Different small letters indicate significant differences among the means in each raw, P < 0.05. Different capital letters indicate significant differences among the means in each column, P < 0.01

IV: *Rupture force F_m (N) of the tested eggs.*

Breed	X_b direction	Z direction	X_s direction
SU	43.82 ± 1.019^{aA}	39.17 ± 1.592^{bA}	46.53 ± 0.816^{cA}
BPR	46.67 ± 2.057^{aB}	42.43 ± 1.431^{bB}	48.37 ± 1.623^{cB}
LW	53.36 ± 2.019^{aC}	45.02 ± 1.967^{bC}	56.54 ± 1.567^{cC}
RIR	41.61 ± 1.553^{aD}	37.96 ± 2.436^{bD}	43.81 ± 1.502^{cD}

Different small letters indicate significant differences among the means in each raw, P < 0.05. Different capital letters indicate significant differences among the means in each column, P < 0.01

Next information on the eggs mechanical behaviour has been obtained from the impact tests using the equipment shown in the. Three values of the bar fall, h, has been chosen: h = 10, 20 and 30 mm. During the bar impact no eggshell damage was observed. Eggs were impacted at the three points – X_s direction (sharp end), X_b direction (blunt end), and *Z* direction (equator).

Response function, i.e. surface displacement was measured at the point on the eggshell's equator. For the impact in the Z direction this measurement was performed at 90° from the impact point.

In the Fig. 2 example of experimental records of the force – time at the impact point are displayed.

This dependence exhibits a nearly „half–sine" shape. The same qualitative features were observed for all tested eggs and for all values of *h*.

The course of the force, *F*, – time, *t*, curves can be generally represented by three parameters:

- Maximum value of the force, $F_{m.}$
- Time of the maximum force achieving, $t_{I.}$
- Time of the pulse F(t) duration, λ.

Analysis of our experimental data shows that the eggs of different hens influence only the value of the maximum force and impulse. The values of t_I and λ remains unchanged. Their average values are:

$$t_I = 2.49 \pm 0.0499 \text{ ms}, \lambda = 5.18 \pm 0.0805 \text{ ms}.$$

Values of the maximum force are displayed in the Fig. 3.

These force increases with the height of the bar fall, i.e. with the impact velocity. For all tested eggs and for all values of h the force F_m is lowest for the *Z* direction and maximum values is reached for the X_s direction. For all values of h and for every directions of the impact the order of the eggs according to the value F_m is: RIR, SU, BPR, LW.

The differences are statistically significant. It means the knowledge of the maximum force can be used for the characterization of eggs of different hen's breeds. Examples of the time histories of the surface displacements are displayed in the Fig. 4.

It is obvious that the time history of the eggshell response to the impact is dependent on the direction of the loading. This displacement corresponds to the elastic wave which propagates from the point of bar impact. For the *Z* and *Xs* directions the eggshell surface displacement exhibits some oscillations. The example of the eggshell displacement for another eggs are shown in the Fig. 5.

The knowledge of the time history of the egg response to the bar impact is insufficient for the detection of different kinds of the eggs.

The response of the eggs can be also described in the frequency domain. This procedure is based on the Fourier transform technique – see e.g. (Nedomová *et al.*, 2009b; Kumbár *et al.*, 2015b) for a review.

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

$$F(\omega) = \int_{-\infty}^{+\infty} f(t) e^{-i\omega t} dt \tag{2}$$

And the inverse transform as

$$f(t) = \int_{-\infty}^{+\infty} F(\omega) e^{i\omega t} d\omega \tag{3}$$

where *F* is the spectral function and *ω* is the angular frequency.

The same procedure can be used for the Fourier transform of a series *x(k)* with *N* samples. This procedure is termed as the Discrete Fourier Transform (DFT). A special kind of this transform is Fast Fourier Transform (FFT). This procedure is part of the most software packages dealing with the signal processing. The transform into the frequency domain will be a complex valued function, that is, with magnitude and phase:

$$\begin{aligned} &F(\omega) = \mathrm{Re}(F) + i\,\mathrm{Im}(F) \\ &amplitude = \sqrt{\mathrm{Re}(F) + \mathrm{Im}(F)} \\ &phase = \arctan\left[\frac{\mathrm{Im}(F)}{\mathrm{Re}(F)}\right] \end{aligned} \tag{4}$$

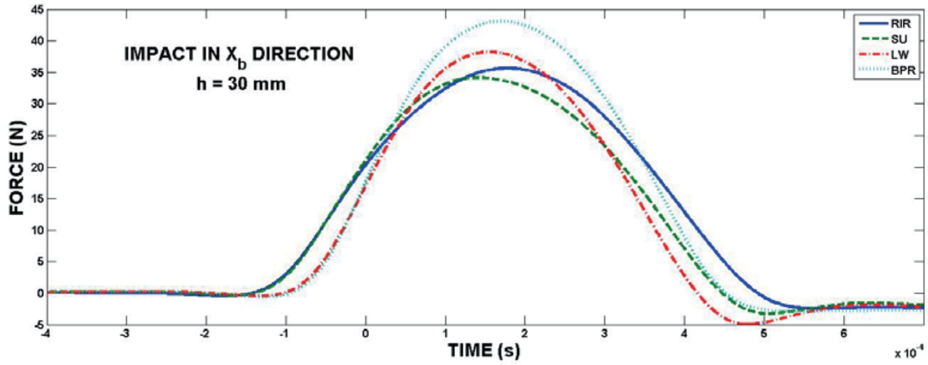
In the Fig. 6 an example of the frequency dependence of the amplitude of the spectral function (force) is shown. One can see that the amplitudes of the spectral function bellow ca. 2000 Hz are very small.

Example of the spectral function of the displacement is shown in the Fig. 7.

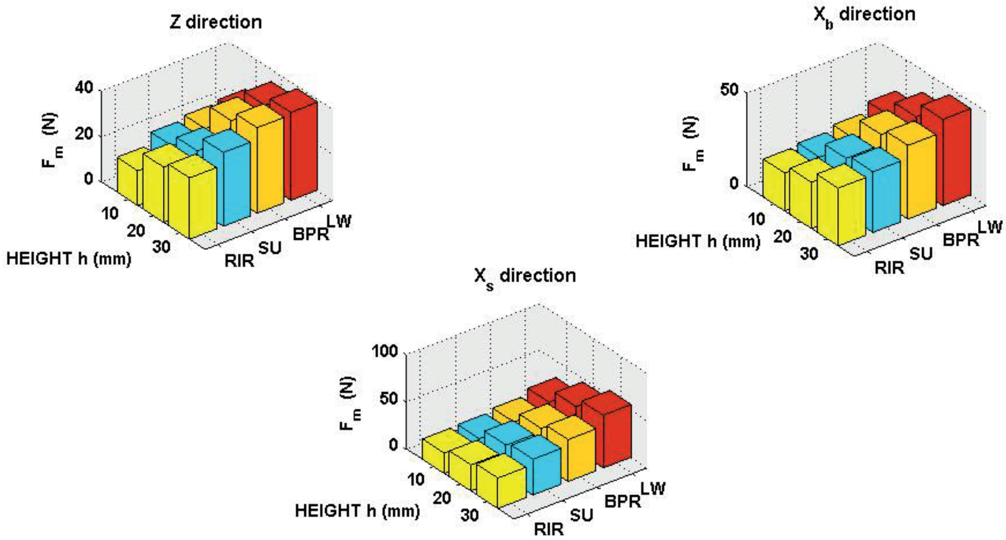
The amplitude versus frequency function is characterized by a maximum. Corresponding frequency is usually denoted as a dominant frequency (Wang *et al.*, 2004). Its value ω_c is then used to calculate the dynamic eggshell stiffness (K_{dyn}). Modelling the egg as a mass spring system, the dynamic stiffness K_{dyn} is given as:

$$K_{dyn} = m\omega_c^2 \tag{5}$$

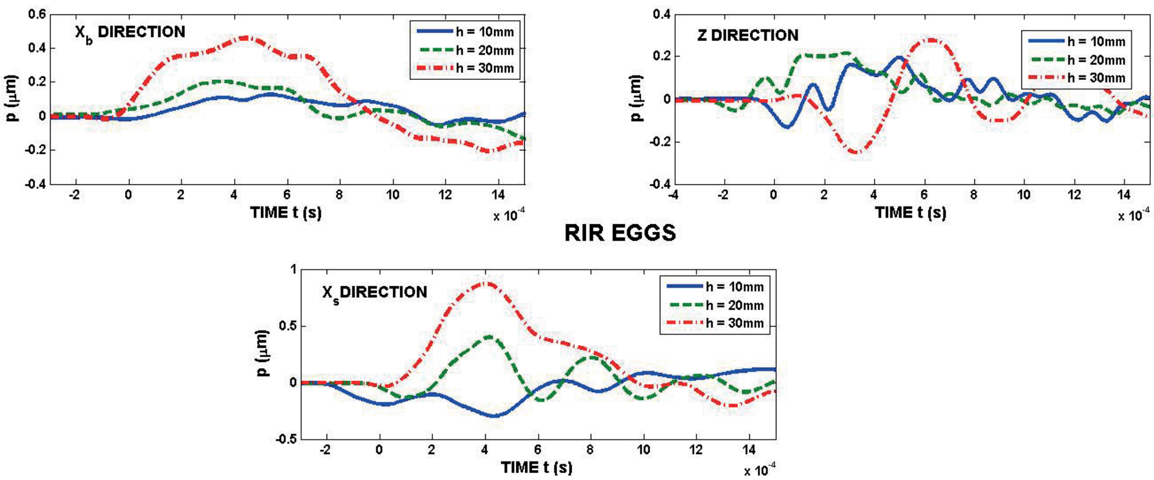
Analysis of the data led to the conclusion that dominant frequency did not depend on the height of the bar fall, i.e. on the striking velocity. The values of dominant frequency as well as the dynamic eggshell stiffness are given in the Table V.



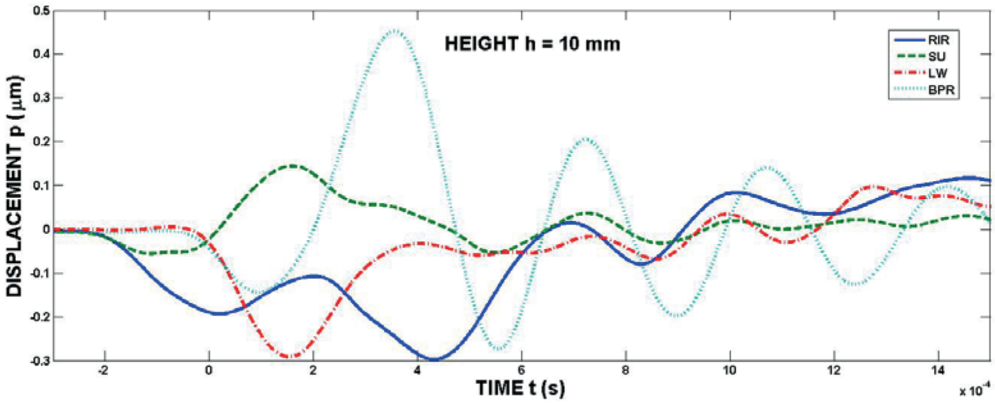
2: *Experimental records of the force at the impact point.*



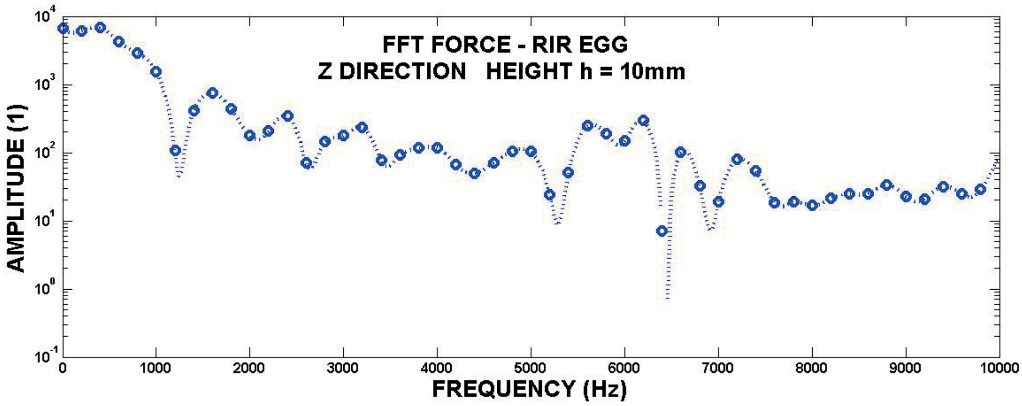
3: *Maximum of the force at the impact point. (Average values)*



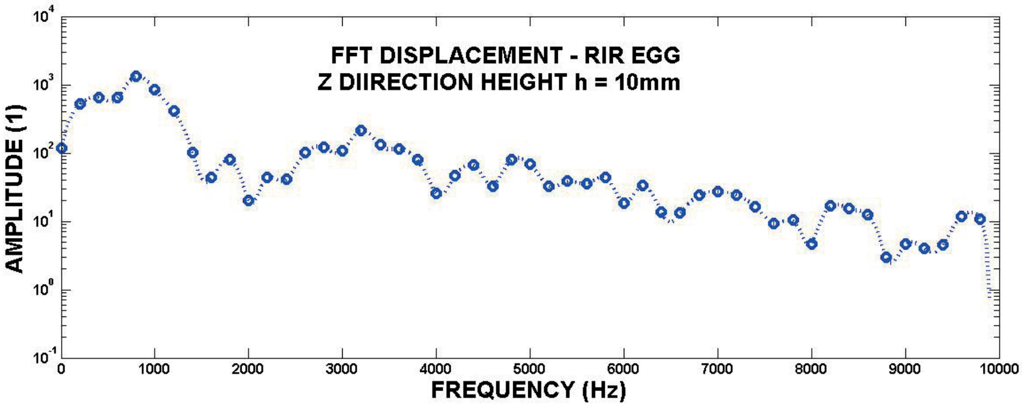
4: *Eggshell surface displacements p recorded on the equator.*



5: *Displacements of the eggshell of different eggs. (Xs direction of the loading).*



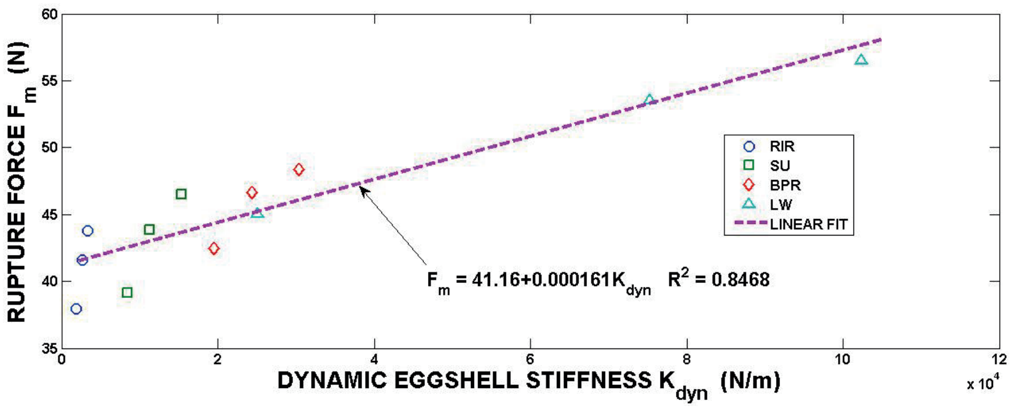
6: *Amplitude of the spectral function of the force.*



7: *Amplitude of the spectral function of the surface displacement.*

V: *Dominant frequencies and dynamic eggshell stiffness of the tested eggs. (SD –standard deviation)*

Breed	Direction of loading	ω_c (s^{-1})		K_{dyn} ($N.m^{-1}$)	
		Mean	SD	Mean	SD
RIR	Z	203.89	8.58	1898.02	276.81
	X_s	265.67	7.31	3311.65	253.11
	X_b	240.11	8.89	2641.85	233.79
SU	Z	413.00	9.85	8398.08	286.46
	X_s	569.67	11.05	15334.65	321.87
	X_b	481.67	5.57	11232.09	221.12
BPR	Z	648.11	9.75	19531.80	441.32
	X_s	825.00	10.70	30377.22	334.22
	X_b	733.33	11.75	24457.66	362.81
LW	Z	631.89	14.25	25118.61	575.23
	X_s	1428.22	16.11	102398.50	612.87
	X_b	1229.89	12.43	75299.52	583.11



8: Rupture force vs. dynamic eggshell stiffness.

CONCLUSION

An experimental system was set up to generate the impact force, measure the response wave signal, and analyse the frequency spectrum for physical property detection of hen`s eggs. The dominant and/or egg dynamic resonance frequency was obtained through the analysis of the dynamically measured frequency response of an egg excited by the impact of a bar.

The knowledge of the force following from the striking of egg by falling bar enables to distinguish among eggs of different hen breeds. For the given striking velocity (i.e. for the height of the bar fall) the maximum of this force strongly depends on the point of impact. This dependence can be described using of the eggshell curvature at the given point. The response functions, i.e. time histories of the eggshell surface displacement involve valuable information on the eggshell properties. The dominant frequency evaluated using of the Fourier transform of displacement – time curve depends on the position of the excitation point. I tis independent on the bar striking velocities. This frequency was used to the evaluation of the dynamic eggshell stiffness, K_{dyn}. It was found that the rupture force of the eggshell determined at the quasi static compression of the egg lineally increases with the dynamic eggshell stiffness. It means that the measurement of the eggs response to the non-destructive impact can be used for very good estimation of their strength.

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