XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

DETERMINATION OF THE DAMPING COEFFICIENT OF COFFEE BRANCHES USING IMAGE PROCESSING TECHNIQUES

DANIEL MARÇAL DE QUEIROZ[1], GEICE PAULA VILLIBOR[2], FRANCISCO DE A. C. PINTO[1], DENIS MEDINA GUEDES[3]

[1]Depto. of Agricultural Engineering, Universidade Federal de Viçosa, MG, Brazil, queiroz@ufv.br
[1]F. De A.C. Pinto, facpinto@ufv.br
[2]Ph. D. Student, Dept. of Agricultural Engineering, Universidade Federal de Viçosa, MG, Brazil, geice.villibor@ufv.br
[3]D. M. Guenes, denisguedes@yahoo.com.br

CSBE100714 – Presented at Section III: Equipment Engineering for Plant Production Conference

ABSTRACT The damping coefficient of coffee branches is a mechanical property used for simulating coffee fruit harvesting process. This property is an input in transient dynamic analysis when using finite element technique. The objective of this work was to develop a methodology to determine, in laboratory, the damping coefficient of coffee branches by using digital video end image processing of coffee branch vibration tests. The calculation of system damping ratio was performed by logarithmic decrement method. The oscillation decay process of the branches was recorded by using 1000 frames per second digital camera. Monitoring points were marked in each tested branch. Fours control points, located in the image background and with actual known coordinates, were kept fixed in all tests. By using by video and image processing tools, the coordinates, in pixel, of all control points were obtained for each frame. One interpolation function, based on the position of the control points, allowed the determination of the actual coordinates of the monitoring points. Two distinct experiments with coffee branches of Arabica coffee, Catuai Vermelho and Mundo Novo variety were performed. The values of the damping coefficient were 0.03295 and 0.02041, and 0.02175 and 0.01942 N s m^{-1}, for Catuaí Vermelho and Mundo Novo variety, respectively. The proposed methodology worked well for determining the damping coefficient of coffee branches. The coffee branches of Catuai Vermelho variety had greater values of damping coefficient, therefore dissipated more energy in vibration process than Mundo Novo variety.

Keywords: logarithm decrement, image processing, mechanical properties, coffee harvesting.

INTRODUCTION Coffee trees are dynamic structures that have a complex response to the vibration application in mechanical harvesting process. Forced vibration applied to trunk and branches for harvesting many tree crops had been utilized and investigated in many countries (Aristizábal *et al*., 2003; Garcia-Uribe & Oliveros-Tascón, 2003; Souza, 2004). Inertial forces are transmitted to coffee fruit, when vibration is applied to trunk and branches, taking just few seconds for fruit detachment. The transmission of vibration to the fruit depends on the dynamic and mechanical properties of coffee trees. Dynamic properties of coffee trees, as damping ratio and natural frequencies, define the system response. The trees response to vibration depends on the tree organs. Vibration analysis and damping coefficient determination for crop trees, under different dynamic loads, have recently been studied by many researchers (James *et al*., 2006; Jonsson *et al*., 2007; Spatz *et al*., 2007; Castro-Garcia *et al.*, 2008). The damping coefficient of coffee branches is a mechanical property, used to simulate the harvesting process. This property is an input in transient dynamic analysis when using finite element technique. The damping of branches could be grouped in an internal and an external damping. Internal damping is due internal friction within the wood material of the branches and external damping is due to aerodynamic drag and viscous damping (Hoag *et al.*, 1971). Three main methods are generally used for the experimental determination of damping coefficient: the logarithmic decrement, the resonant amplification, and the half-power (Clough & Penzien, 1993). The first method is the simplest one and the damping of system is evaluated in time-domain. Logarithmic decrement method include the determination of the natural logarithmic from the ratio of any two successive amplitudes in the same direction, measured over n cycles of oscillation (Beards, 1996). Several sensors are applied to measure the oscillation of systems in engineering problems. The trunk oscillation was determined utilizing LDVT (linear variable displacement transducers) by Aristizábal *et al*. (2003); accelerometers by Jonsson *et al*. (2007), strainmeter sensors to different trees by James *et al*. (2006). However, sometimes is not possible to connect the sensors to the system under study due mechanical and physical limitation. Liang (2005) proposed the used of acceleration decrements for determination of viscous damping of mass-spring system when displacements are difficult to be obtained. An alternative, to determine the damping of the different systems is the use of digital images. The use of digital images, in several areas of engineering, has contributed significantly to the interpretation of different phenomena. Some advantages are observed with the use of digital images to determine the dynamic structural behaviour because the location of sensing system is outside the structure, different points on the structure can be sampled and possibility of detection of tridimensional vibration. Nogueira *et al.* (2006) used digital images to determine three-dimensional natural frequencies of structures. High speed video capture coupled with segmentation techniques makes the use of digital images a powerful tool for determining the different mechanical properties of vibrating systems. To contribute to a better understanding of the mechanical characteristics of coffee branches, the objective of this work was to develop a methodology to determine, in laboratory, the damping coefficient of coffee branches by using digital video and image processing of vibration tests.

MATERIALS AND METHOD The experiment was performed in the Laboratory of Power and Machinery of Universidade Federal de Vicosa, MG, Brazil. For vibration tests branches of Arabica coffee, variety Catuai Vermelho and Mundo Novo were used. The branches were collected in the middle part of the coffee plants and their length was kept in 30 cm. The main physical characteristics were determined including the diameter, mass and number of nodes of each tested branch.

The damping coefficient (c) was calculated by Equation 1, considering the coffee branches as a single-degree-of-freedom system.

$$c = c_c\ \zeta = 2\, m\, \omega\ \zeta \quad (1)$$

where:
c_c = critical damping coefficient, N s m^{-1};
m = mass of coffee branch, kg;
ω = natural frequency of coffee branch, rad s^{-1};
ζ = damping ratio of coffee branch.

The calculation of branch damping ratio was performed by logarithmic decrement method (Beards, 1996; Aristizábal *et al*., 2003; Moore & Maguire, 2004). The relationship between the damping ratio and the logarithmic decrement is presented in Equation 2.

$$\Lambda = \frac{1}{n} \ln\left(\frac{X_1}{X_{1+N}} \right) = \frac{2\pi\zeta}{\sqrt{(1-\zeta^2)}} \quad (2)$$

where:
X_1 and X_{1+N} = two successive amplitudes;
Λ = logarithmic decrement of the two different amplitudes of vibration;
n = number of cycles of vibration.

The oscillation period of the damped system obtained from two consecutives cycles was determined though damping curves of the system. Then, the damped natural frequency (ω_v) was calculated by Equation 3. Knowing the damped natural frequency and damping ratio, the natural frequency each branch was calculated by Equation 4.

$$\omega_v = \frac{2\pi}{\tau_v} \quad (3)$$

$$\omega = \frac{\omega_v}{\sqrt{(1-\zeta^2)}} \quad (4)$$

where:
ω_v = natural frequency of the damped system;
ω = natural frequency of the undamped system;
τ_v = period of the damped oscillation

The leaves and fruits were removed from the branches to be tested. The sample branches were painted using white color and attached in mobile base of an electromagnetic shaker. The coffee branches were subjected to an initial displacement and vibrated until returned to the equilibrium state. The initial displacement was imposed to system by an electromagnetic shaker, made by LDS (*Ling Dynamic Systems*). The system was composed by a signal generator $\text{COMET}_{\text{USB}}$, an amplifier PA100E-CE and a vibrating machine, model V406. The applied impulse wave was a half sine with time duration of 11 ms and an acceleration peak of 10.92 ± 0.053 g's. The decay curves of coffee branches were obtained by image processing techniques. Five monitoring points (MP1 - MP5), in black color, were market in each tested branch. The distance between the monitoring points was kept as 5 cm. In the image background, four controls points (CP1 - CP4) were distributed in each corner, in a rectangle shape, with dimension of 30 cm by 15 cm, with sides parallel to the image principal axes (Figure 1). Control points were kept fixed in all tests and with actual coordinates known, in cm.

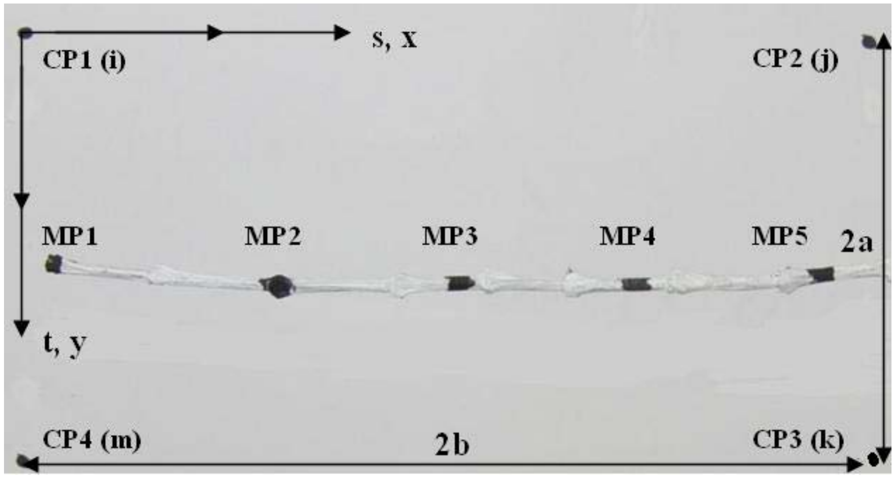

Figure 1. Coffee branch painted with monitoring points and background image with control points in test

The oscillation decay process of the branches was recorded by using a digital camera, made by Casio, model EX-FH20. The camera captured 1000 frames per second. The distance between coffee branch and the camera and between the camera and the image background was kept constant, in 50 cm and 7.5 cm, respectively. The system was illuminated by two spotlights composed of halogen lamps of 300 W.

It was developed a computational routine for processing digital video acquired using MatLab® R2009b. After reading the digital video in AVI format, frames were extracted and saved as individual RGB images, with a resolution of 280 x 64 pixels. Each digital video originated in average 7962 images to be segmented. The RGB images were read and converted to grayscale. The images in grayscale were cut, close to control points, to eliminate unnecessary information and to facilitate the interpolation process. With images in grayscale a threshold necessary to automatically detect the monitoring points of the system was calculated. Using the calculated threshold the images were converted into binary images. Next, the binary images were reversed (1 to zero and vice versa) to detect interest object. After detecting the objects of interest, the corresponding centroid to each object was determined for each image. The objects of interest were control points and monitoring points. The centroid coordinates of each interest point, in pixels, were stored in an array for later interpolation. The coordinates of monitoring points, in pixels, were converted to actual coordinates, in centimeters, using the following interpolation functions (Segerlind, 1984):

$$x = \varphi_{ix} + \frac{1}{2b}(\varphi_{jx} - \varphi_{ix})s + \frac{1}{2b}(\varphi_{mx} - \varphi_{ix})t + \frac{1}{4ab}(\varphi_{ix} - \varphi_{jx} + \varphi_{kx} - \varphi_{mx} \quad (5)$$

(6)

$$y = \varphi_{iy} + \frac{1}{2b}(\varphi_{jy} - \varphi_{iy})s + \frac{1}{2b}(\varphi_{my} - \varphi_{iy})t + \frac{1}{4ab}(\varphi_{iy} - \varphi_{jy} + \varphi_{ky} - \varphi_{m}$$

where:
x and y = actual estimated coordinates of monitoring points, cm;
s and t = coordinates of monitoring points in image, pixel;
φ_{ix}, φ_{jx}, φ_{kx} and φ_{mx} = actual values of x-coordinate in control points, cm;
φ_{iy}, φ_{jy}, φ_{ky} and φ_{my} = actual values of y-coordinate in control points, cm;
2b = length of rectangle formed, pixel;
2a = height of rectangle formed, pixel.

The decay curves were plotted using the displacement in the y direction, of the last two monitoring points localized in free end of coffee branch. The damping coefficient was calculated by monitoring point located in free end of coffee branch (MP 1). The experiments were conducted with branches collected on two different dates. The tests were performed using six replications. The mean period of the damped oscillation, damping ratio, damped natural frequency, natural frequency and damping coefficient, among the varieties, was compared using t-student test, with 1% of probability.

RESULTS AND DISCUSSION The main physical characteristics of coffee branches are presented in Table 1. The values of coefficient of variation for mean diameter and mass of the coffee branches were lower in experiment 1 than the ones obtained in experiment 2, except for Mundo Novo variety that showed higher values of coefficient of variation for branch mass.

Table 1. Physical characteristics of coffee branches for Catuaí Vermelho and Mundo Novo varieties used in vibration tests

Characteristic	Catuaí Vermelho Variety	Mundo Novo Variety
	Experiment 1	
Diameter*	4.19 mm and CV(%) = 4.56	4.22 mm and CV(%) = 9.25
Mass	5.50 g and CV(%) = 7.72	4.91 g and CV(%) = 26.49
Number of nodes	10	12
	Experiment 2	
Diameter*	4.14 mm and CV(%) = 11.07	4.23 mm and CV(%) = 6.84
Mass	4.98 g and CV(%) = 15.03	6.03 g and CV(%) = 10.23
Number of nodes	10	14

* Average of six values measured along the each coffee branch

In Figure 2, extracted images from one test at different time are shown. After cutting the image, its size was reduced to 104 per 52 pixels. The monitoring points could be clearly seen in each image, both in the gray scale (upper part of Figure 2) and binary images (down part of the Figure 2). Based on the binary images the coordinate of the centroid of each monitoring point was found. Using the interpolation functions (Equations 5 and 6) and the coefficients shown on Table 2, the corrected displacement of each monitoring point was calculated.

The obtained damping ratio (ζ) values are shown in Table 4. There was no significative difference between varieties and experiments. The coffee branch system was considered to be subdamped ($0 < \zeta < 1$). The damped and undamped natural frequencies values are shown in Table 5 e 6, respectively.

In Figure 3, decay curves of monitoring points MP1 and MP2 are shown. In Table 3, the period of the damped oscillation (τ_v), for both varieties, are shown. There was no significative difference between the calculated period of damped oscillation for both experiment and both varieties.

The obtained damping coefficient values are shown in Table 7. The damping coefficients of both varieties and for both experiments were significantly different. The damping coefficient of Catuai Vermelho variety branches was higher than the one for Mundo Novo variety. The coefficient of variation of the damping coefficient of Catuai Vermelho Variety was considered to be high in Experiment 2, and high for both experiment for Mundo Novo variety according to the Gomes (2000).

The experimental and theoretical decay curves for Catuai Vermelho and Mundo Novo varieties are shown in Figure 4. The averages of maximum observed amplitudes in experiment 1 were 4.84 cm and 5.93 cm, for Catuai Vermelho and Mundo Novo varieties, respectively. For experiment 2, the maximum values were 3.94 cm and 4.28 cm. The decay of oscillation for Mundo Novo variety was greater than the one for Catuai Vermelho variety. The decay curves for both varieties are shown in Figure 5.

Table 2. Coefficient of interpolation functions used to calculate monitoring point actual coordinates in each experiment

Variety	Exp	Constant	s	T	s.t
Catuaí Vermelho	1	0	0.277	0.289	0
		0	0.294	0.294	0
Mundo Novo	2	0	0.291	0.280	0
		0	0.294	0.294	0

Table 3. Period of the damped oscillation (τ_v, s) for two variety of coffee and t test result for varieties, in two different experiment

Variety	Catuaí Vermelho		Mundo Novo		
	Mean	CV (%)	Mean	CV (%)	t test
Experiment 1	0.07465	10.34	0.07397	18.12	**
Experiment 2	0.08378	17.83	0.09113	23.02	**

** significativo ao nível de 1% de probabilidade; ns - não significativo

Table 4. Damping ratio (ζ) for branches of both varieties and for both experiments

Variety	Catuaí Vermelho		Mundo Novo		
	Mean	CV (%)	Mean	CV (%)	t test
Experiment 1	0.03545	14.28	0.02719	36.29	**
Experiment 2	0.02553	50.63	0.02164	18.61	**

** significative at 1% of probability level; ns – not significative

Table 5. Damped natural frequency (ω_v, Hz) for branches of both varieties and for both experiments

Variety	Catuaí Vermelho		Mundo Novo		
	Mean	CV (%)	Mean	CV (%)	t test
Experiment 1	84.96	10.88	87.63	22.86	**
Experiment 2	77.72	20.18	74.50	15.76	**

** significative at 1% of probability level; ns – not significative

Table 6. Natural frequency (ω, Hz) for branches of both varieties and for both experiments

Variety	Catuaí Vermelho		Mundo Novo		
	Mean	CV (%)	Mean	CV (%)	t test
Experiment 1	85.02	10.87	87.66	22.85	**
Experiment 2	77.75	20.18	74.51	15.76	**

** significative at 1% of probability level; ns – not significative

Table 7. Damping coefficient ($N\ s\ m^{-1}$) for both varieties in each experiment

Variety	Catuaí Vermelho		Mundo Novo		
	Mean	CV (%)	Mean	CV (%)	t test
Experiment 1	0.03295	13.36	0.02175	29.20	**
Experiment 2	0.02041	61.25	0.01942	22.11	**

** significativo ao nível de 1% de probabilidade; ns - não significativo

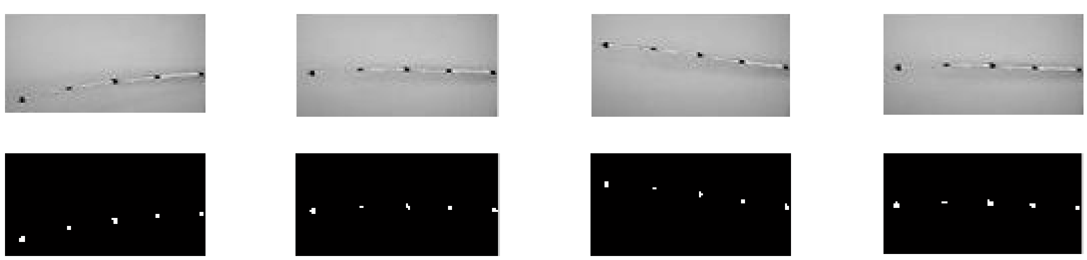

Figure 2. Gray scale images (upper part) and processed images (down part) showing the monitoring points in one of the performed tests

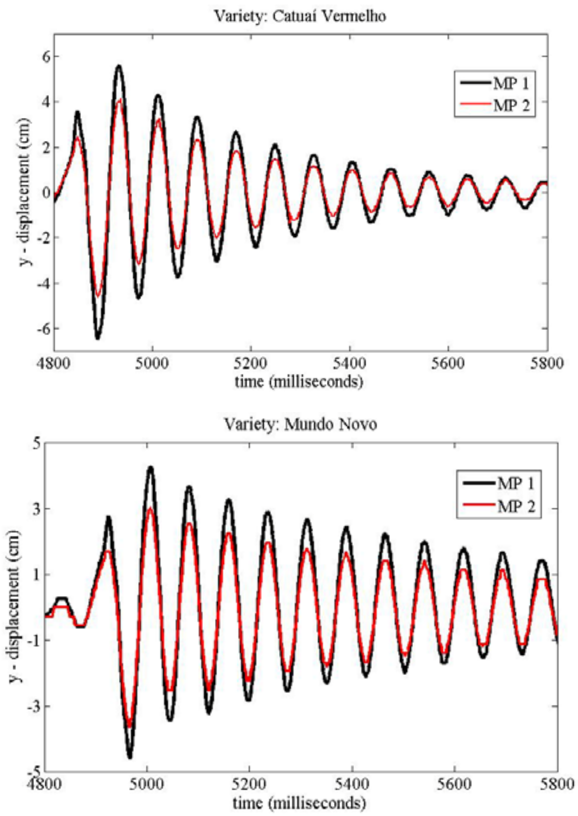

Figure 3. Decay curves for two different monitoring points for branches of both varieties.

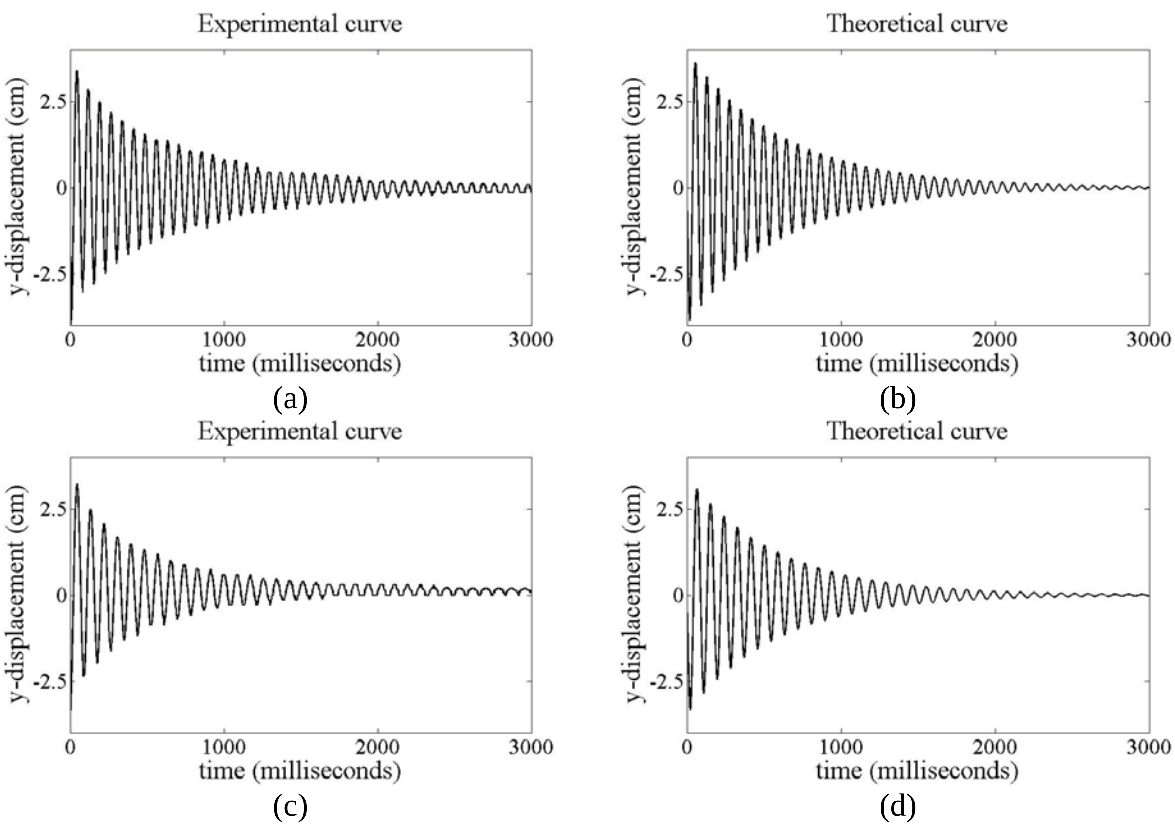

Figure 4. Decay oscillation curves for Catuai Vermelho variety (a and b) and for Mundo Novo Variety (c and d).

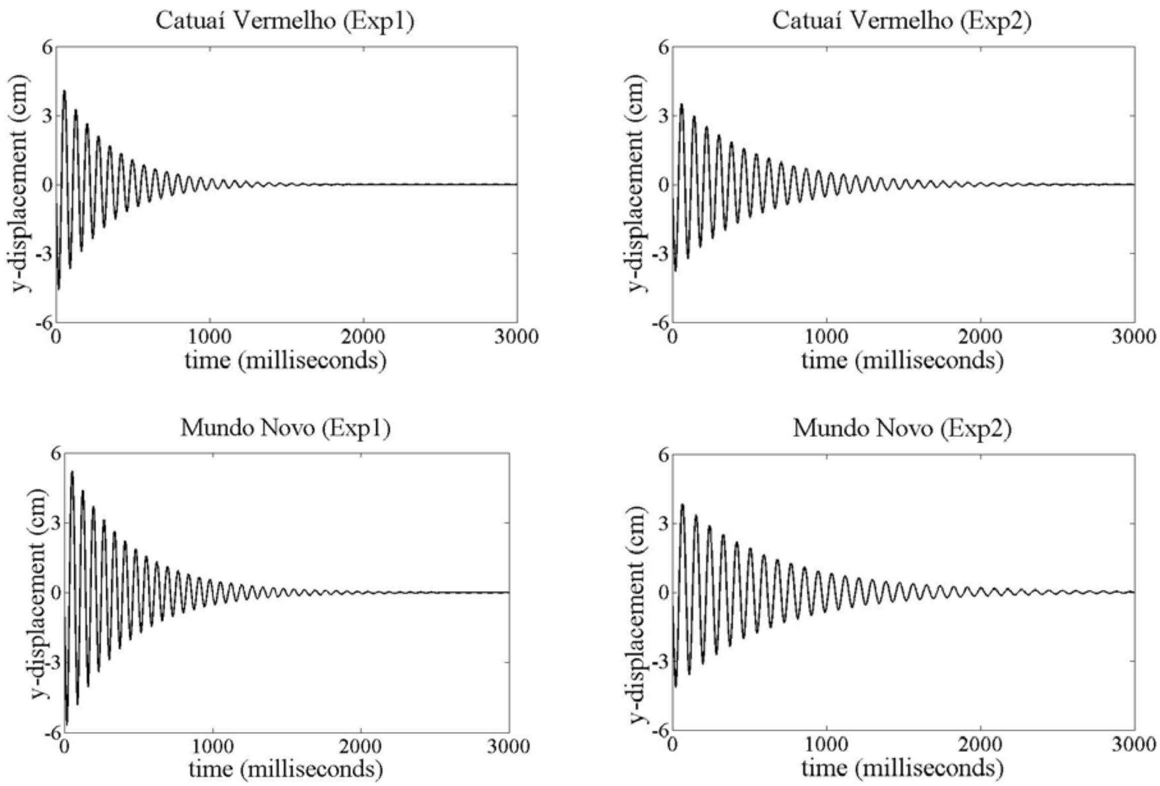

Figure 5. Decay curves for the average oscillation for both varieties and both experiments.

CONCLUSION: The developed methodology worked well to obtain the damping coefficient of coffee branches. The damping coefficient of Catuai Vermelho variety branches was higher than the one for Mundo Novo variety.

Acknowledgements. The authors of the work thank the FAPEMIG - Foundation for Research Support of the State of Minas Gerais, Brazil – and the CNPQ - National Council of Scientific and Technological Development, Brazil - for the support for accomplishment of this research.

REFERENCES

Aristizábal, I. D., Oliveros, C. E., Alvarez, F. 2003. Physical and mechanical properties of the coffee tree related to harvest mechanization. Trans. ASAE 46(2): 197–204.

Beards, C. E. 1996. Structural Vibration: Analysis and Damping. Butterworth-Heinemann, Burlington, 276p.

Castro-Garcia, S., Blanco-Roldán, G.. L., Gil-Ribes, J. A., Agüera-Vega, J. 2008. Dynamic analysis of olive trees in intensive orchards under forced vibration. Trees (22):795-802.

Clough, R. W., Penzien, J. 1993. Dynamics of Structures. Second edition, McGraw Hill, New York, 738p.

García-Uribe, F., Oliveros-Tascón, C. E. 2003. Design of a shaker-clamp system for inertial shaker of coffee trees. ASAE Meeting Presentation, paper number 031143:1-14.

Gomes, F. P. 2000. Curso de estatística experimental. 14. ed. Nobel, Piracicaba, 477 p.

Hoag, D.L., Fridley, R.B., Hutchinson, J.R. 1971. Experimental measurement of internal

and external damping properties of tree limbs. Trans. ASAE 14:20–28
James, K. R., Haritos, N., Ades, P. K. 2006. Mechanical stability of trees under dynamic loads. American Journal of Botany 93(10): 1522–1530.
Jonsson, M. J., Foetzki, A., Kalberer, M., Lundström, T., Ammann, W., Stöckli, V. 2007. Natural frequencies and damping ratios of Norway spruce (*Picea abies* L. Karst) growing on subalpine forested slopes. Trees (21):541–548.
Liang, J. 2005. Identifying Coulomb and viscous damping from free-vibration acceleration decrements. Journal of Sound and Vibration (282): 1208 - 1220.
Moore, J. R., Maguire, D. A. 2004. Natural sway frequencies and damping ratios of trees: concepts, review and synthesis of previous studies. Trees (18):195–203.
Nogueira, F. M. A., Barbosa, F. S., Barra, L. P. S. Determinação de freqüências naturais de estruturas sob vibrações tridimensionais a partir de imagens oriundas de uma câmera. 2006. Procceding of the VII Simpósio de Mecânica Computacional, Brazil.
Segerlind, L. J. 1984.Applied finite element analysis. Second edition. John Wiley & Sons Inc.New York, 427p.
Souza, C. M. A. Desenvolvimento e modelagem de sistemas de derriça e de abanação de frutos do cafeeiro. 2004. Viçosa, MG: UFV. Ph.D. Thesis. 123p.
Spatz, H, Brüchert, F., Pfisterer, J. 2007. Multiple resonance damping or how do trees escape dangerously large oscillations? American Journal of Botany 94(10): 1603–1611.