*ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 15, No. 4. 2009*

# The Effect of Zonal Deformations on the Mechanical Properties of Circular Saws

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*Received 28 August 2009; accepted 08 October 2009*

In this paper the effect of zonal saw deformation on its elastic plastic properties is presented. Experiments were carried out using a special vibrating stand. A hand-operated saw-tooth setting machine was used to form the saw path by selecting the following three values for bending teeth $\zeta$: 0.4 mm (0.2 mm to one side), 0.6 mm (0.3 mm to one side) and 0.8 mm (0.4 mm to one side). For the research five circular crosscut saws with a diameter of 400 mm each were selected. During the tests saw tightening moment was 150 Nm and measurements were performed within the range of 20 Hz – 2000 Hz. The results include established coefficient of damping and dynamic Young`s modulus for all zones of the saws. It was determined that zonal deformation has a significant impact on the distribution of elastic-plastic properties within the saw plane. It was found that by bending saw teeth from 0 mm up to 0.4 mm in one of the saw plane zones, the average coefficient of damping increases by 5.57 times with the distance changing from flanges to the teeth zone, meanwhile the dynamic Young's modulus decreases by approximately 25 % in each case. By forming the saw path and obtaining a higher value of the coefficient of damping, the circular saw can operate in a more stable manner.

*Keywords:* circular saw, dynamic Young`s modulus, coefficient of damping, deformation.

## INTRODUCTION

There is a relation between the dynamic stability of circular saws and the transverse resonant vibrations of saws [1]. The main factors contributing to the resonant vibrations of saws in a wide range of frequencies include the alternating force of sawing resistance, the uneven heating of saws and others [2 – 3]. In order to reduce the friction between the saw blade of circular saws and kerf walls, as well as saw heating, it is necessary to set/compress saw teeth or to use hard alloy plates and etc. [4 – 8]. In addition, alterations in the teeth construction of circular saws lead to saw vibration reduction, straighter cuts, smoother surface and better productivity [9 – 11].

However, setting and compressing teeth, as well as welding plates imply additional stresses in the zone of saw teeth, which affects its running behavior, especially within the zone of critical speeds [6].

Vibration damping appears to be one of the most significant factors in determining the saw efficiency, since the coefficient of damping has direct impact on the vibration decay time and kerf quality in addition to the vibration amplitude.

The value of coefficient of damping is dependent on the material properties, construction of flanges, initial stresses and other attributes specific to the saw. The saw teeth construction is regarded to be important in defining the value of dynamic Young`s modulus [12 – 16].

It becomes evident that it is impossible in one or another way to achieve forming all the saw teeth at the same time. As a result of this, the distribution of deformation and elastic plastic properties within the plane of the saw blade becomes affected.

The main objective of this work is to evaluate the effect of zonal saw deformation on elastic plastic properties.

## EXPERIMENTAL

The testing involved a special dynamic stand and a standard measuring instrument comprising a set of units [16]. In this stand the vibrator generates resonant vibrations in the circular saw and the sensor measures the vibration response.

By using a manual saw-tooth setting machine R-CZ (Fig. 1), the saw blade is mounted on a special axis and the hold down clamp 3 deforms its teeth (every tooth separately). The head 4 fixates the size of a tooth slightly bent away from the plane of the saw and the scale of the measurer 5 shows the results.

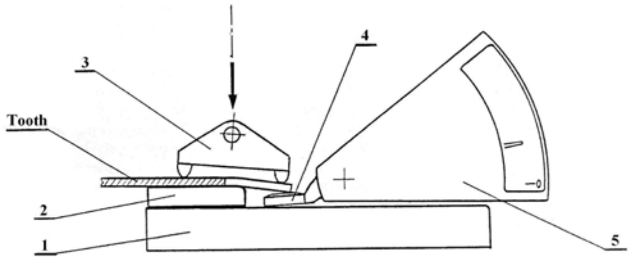

**Fig. 1.** Measurement scheme for the teeth bending: 1 – stand; 2 – pad; 3 – hold down clamp; 4 – head of measurer; 5 – measurer

While assessing the measurement errors of the instruments, it was found that the measurement errors of the resonant frequency and the coefficient of damping are ±0.1 Hz and around 0.3 % respectively. Saw teeth were bent away from the centerline of the blade with the accuracy of 0.1 mm.

By dividing the saw blade into three different zones (Fig. 2), it was possible to introduce four circles with radii 90, 120, 150 and 180 mm, as well as a respective number of diameters. The saw vibrations were measured at the points of their intersection with the following distribution: 28 points in zone I, 24 points in zone II and 44 points in

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zone III. Vibration measurement also involved determining amplitude-frequency characteristics, the coefficient of damping (tg$\delta$) and the dynamic Young's modulus ($E$).

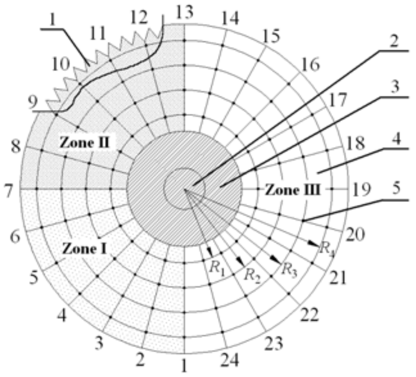


**Fig. 2.** The scheme for circular saw zones: 1 – teeth zone; 2 – centre hole; 3 – flanges; 4 – saw blade; 5 – measurement points; $R_1$, $R_2$, $R_3$, $R_4$ – circle radii; zone I – 28 measurement points of vibrations; zone II – 24 measurement points of vibrations; zone III – 44 measurement points of vibrations

Subsequently, a hand-operated saw-tooth setting tool was used to form the saw path by selecting the following three values for bending teeth $\zeta$: 0.4 mm (0.2 mm to one side), 0.6 mm (0.3 mm to one side) and 0.8 mm (0.4 mm to one side). Initially, 0.2 mm were bent to one side in the first zone of the saw blade without deforming the remaining zones. Then the zone of the entire saw blade underwent measurement. Having established amplitude-frequency characteristics together with the coefficient of damping within the first zone, it became possible to bend teeth up to 0.2 mm in the second zone and to perform analogous measurements. Afterwards the teeth were bent up to 0.2 mm in the third zone and measurement procedures were executed. Then, once again, teeth were bent up to 0.3 mm in the first zone with the entire saw zone undergoing measurement. Analogous teeth bending followed in the second and third zone. Measurements continued to be carried out until 0.4 mm were bent to one side within the entire plane of the saw blade.

The coefficient of damping was calculated according to [16]:

$$\mathrm{tg}\delta \approx \eta = \frac{f_2 - f_1}{f_{res}}, \tag{1}$$

where tg$\delta$ is the loss angle tangent; $\eta$ is the coefficient of damping; $f_{\mathrm{res}}$ is the resonant frequency; $f_1$, $f_2$ are the frequencies corresponding to the amplitude less by $\sqrt{2}$ times than the resonant amplitude.

The dynamic Young's modulus was calculated by using the expression for resonant frequency and evaluating geometrical and other parameters of the circular saw [16]:

$$E = \frac{48\pi^2 f_{res}^2 R^4 \left(1 - \nu^2\right)\rho}{f^1(k,l)^2 s^2}, \tag{2}$$

where $f_{res}$ is the resonant frequency; $R$ is the radius of circular saw; $f^1$ $(k, l)$ is the dimensionless function depending on the number of nodal diameters and ratio of flanges and saw diameters; $k$ is the number of nodal diameters; $l$ is the ratio of flanges and saw diameters; $\nu$ is the Poisson's ratio ($\nu = 0.3$); $\rho$ is the density of saw material.

## RESULTS AND DISCUSSION

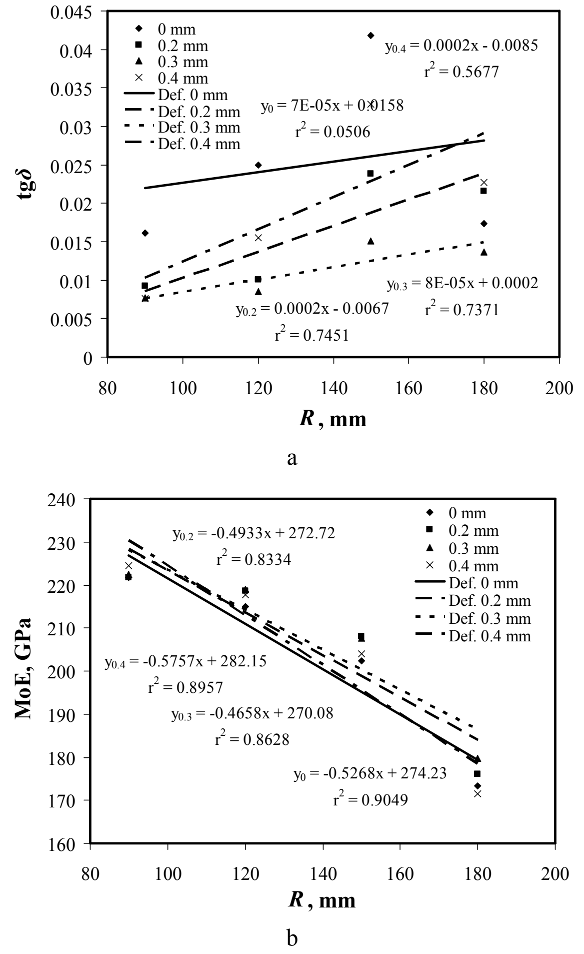
The testing involved circular crosscut 9XΦ steel type saws referred to as E1-E5 with their technical parameters indicated in Table 1. During the tests their tightening moment was 150 Nm and measurements were performed within the range of 20 Hz – 2000 Hz.

Vibration measurement allowed determining resonant frequencies and amplitude-frequency characteristics specific to the circular saws, meanwhile the expression for resonant frequencies enabled to assess the change in the dynamic Young's modulus towards the radius direction of circular saws. Figures 3, 4 and 5 show dependencies of dynamic Young's modulus and coefficient of damping on the distance between a measurement point and the saw centre, by evaluating the deformation of teeth zone.

The evaluation of the change in the coefficient of damping towards the radius direction of the saw showed that without setting saw teeth the coefficient of damping does not change in terms of the linear dependency within the zone towards the radius intersecting point 2 (Fig. 3, a). The obtained correlation coefficient is equal to 0.0506. By setting saw teeth 0.2 mm – 0.4 mm to one side, the linear dependency between the distance from the saw center and the coefficient of damping of the circular saw becomes noticeable (with the correlation coefficient ranging from 0.5677 to 0.7451). It can be observed that as the distance from the saw center increases, the coefficient of damping tends to rise up to 150 mm and with radius $R$ = 180 mm, it tends to decrease.

**Table 1.** Technical parameters of the circular saws

| Saw | Saw diameter $D$, mm | Flanges diameter $d_{\mathrm{f}}$, mm | Teeth number $z$, units | Thickness $s$, mm | Mass, kg | Density $\rho$, kg/m$^3$ |
|---|---|---|---|---|---|---|
| E1 | 400 | 140 | 72 | 2.83 | 2.4 | 7614 |
| E2 | 400 | 140 | 72 | 2.87 | 2.5 | 7684 |
| E3 | 400 | 140 | 72 | 3.04 | 2.6 | 7545 |
| E4 | 400 | 140 | 72 | 2.77 | 2.35 | 7484 |
| E5 | 400 | 140 | 72 | 2.77 | 2.35 | 7484 |



a

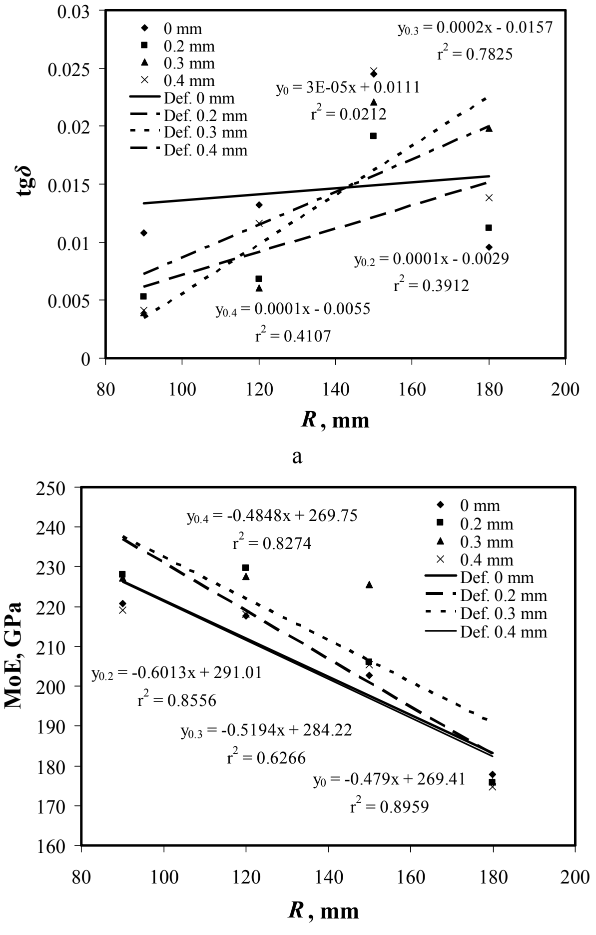
b

**Fig. 3.** The dependency of the coefficient of damping (a) and the dynamic Young's modulus (b) on the distance to the saw centre with the diameter intersecting point 2 (saw E1 ($D$ = 400 mm), zone I)

Without setting saw teeth, the coefficient of damping at the point with $R$ = 150 mm exceeds the one at the point with $R$ = 90 mm by 2.6 times. However, at the point with $R$ = 180 mm the coefficient of damping declines by 2.5 times in comparison to the point with $R$ = 150 mm. When saw teeth are set 0.2 mm to one side, the coefficient of damping at the point with $R$ = 150 mm is higher than the one at the point with $R$ = 90 mm by 2.58 times. However, at the point with $R$ = 180 mm the coefficient of damping decreases by 1.1 times in comparison to the point with $R$ = 150 mm. By setting saw teeth 0.3 mm to one side, the coefficient of damping at the point with $R$ = 150 mm exceeds the one at the point with $R$ = 90 mm by 1.97. However, at the point with $R$ = 180 mm, the coefficient of damping tends to decline by 1.1 times in comparison to the point with $R$ = 150 mm. When saw teeth are set 0.4 mm to one side, the coefficient of damping at the point with $R$ = 150 mm is higher than the one at the point with $R$ = 90 mm by 4.3 times. However, at the point with $R$ = 180 mm, the coefficient of damping decreases by 1.45 times in comparison to the point with $R$ = 150 mm. Analogous results were obtained in relation to the entire zone I.

Fig. 3, b, demonstrates a decline in the dynamic Young's modulus within zone I in terms of the linear dependency, when the point distance from the saw center tends to increase. The dynamic Young's modulus reaches its highest value ($E$ = 221.8 GPa) in the diameter intersecting point 2 with $R$ = 90 mm without forming the saw path. In the case of $R$ = 120 mm the dynamic Young's modulus decreases by 3.1 % up to 215 GPa. When the distance from the saw centre is $R$ = 150 mm, the dynamic Young's modulus continues to fall by 5.9 % up to 202.4 GPa, whereas in the case of 180 mm it tends to decline by 14.4 % up to 173.2 GPa. Having set teeth 0.3 mm to one side, the dynamic Young's modulus increases by 1.8 % (with $R$ = 120 mm), when deformation is absent, meanwhile after bending them up to 0.4 mm, there was a decline by 0.6 %. Analogous results are obtained with changes in the distance from the saw center. In the case of $R$ = 150 mm after bending teeth 0.3 mm to one side, the dynamic Young's modulus rises by 2.6 %, meanwhile setting saw teeth up to 0.4 mm led to a decrease by 1.76 %. With $R$ = 180 mm and teeth bent 0.3 mm to one side the dynamic Young's modulus increases by 3.58 % and begins to fall by 4.78 % when teeth are set 0.4 mm. Analogous results were obtained in relation to the entire zone I.

The same as in the case of the first zone there are analogous changes in the coefficient of damping and the dynamic Young's modulus within the second zone of the circular saw (Fig. 4).



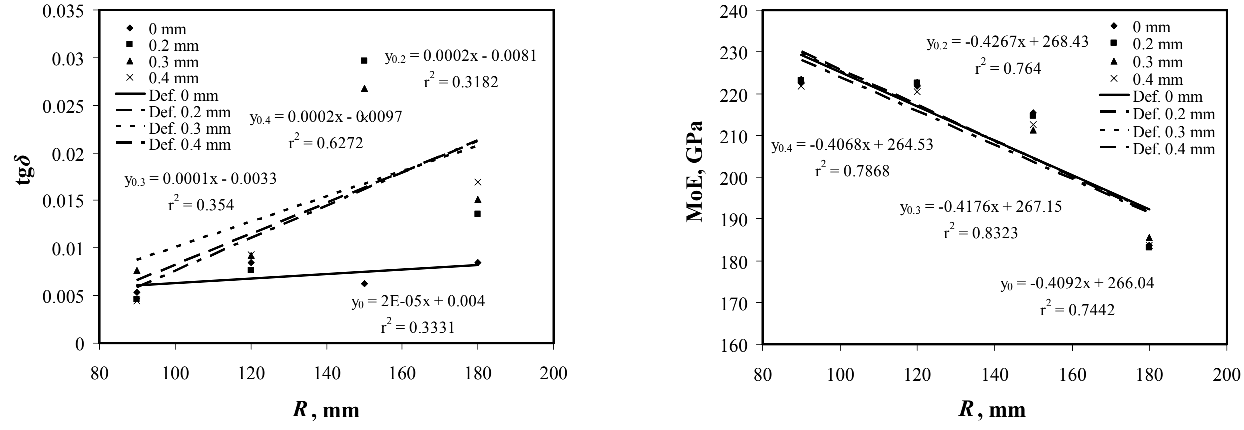
a

b

**Fig. 4.** The dependency of the coefficient of damping (a) and the dynamic Young's modulus (b) on the distance to the saw centre with the diameter intersecting point 8 (saw E1 ($D$ = 400 mm), zone II)

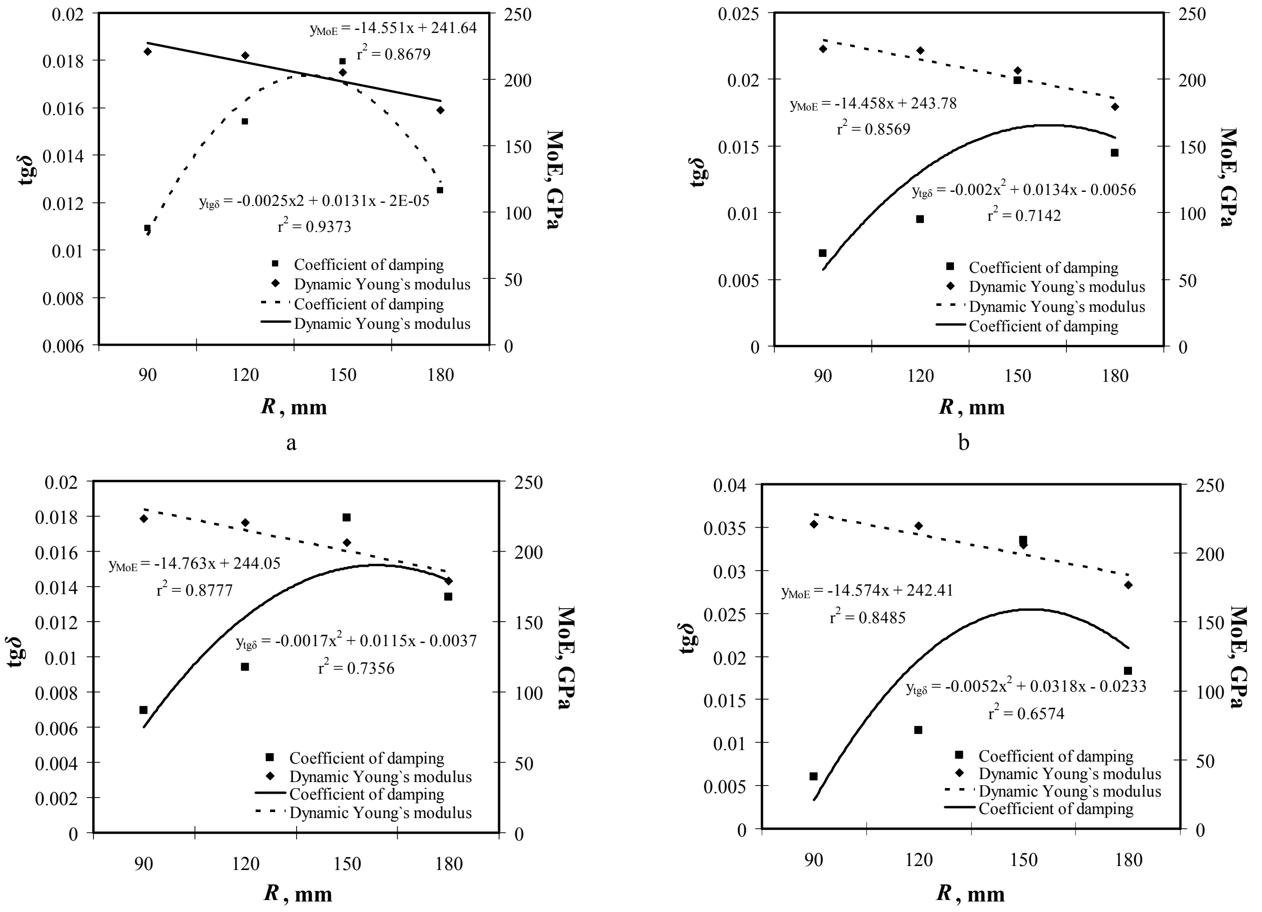
Without setting saw teeth, the linear dependency is absent between the coefficient of damping and the distance from the saw center (coefficient of correlation $r^2 = 0.0212$). By setting teeth 0.2 mm – 0.4 mm to one side, there is a linear relationship of average strength ($r^2 = 0.3912 – 0.7825$). As the distance from the saw center varies between 90 mm and 150 mm, the coefficient of damping becomes higher by 2.26 – 6.0 times, whereas in the case of $R$ = 180 mm it is lower by 1.11 – 2.55 times (Fig. 4, a). There is a strong linear dependency between the dynamic Young's modulus and the distance to the saw center ($r^2 = 0.6266 – 0.8959$). Analogous findings were obtained within the entire second zone.

Similar dependencies were obtained in the third zone as well (Fig. 5). When the distance begins to increase up to $R$ = 150 mm, the coefficient of damping rises by 1.16 – 6.46 times, meanwhile with the distance reaching $R$ = 180 mm, it decreases by 1.39 – 2.19 times (Fig. 5, a).



a b

**Fig. 5.** The dependency of the coefficient of damping (a) and the dynamic Young's modulus (b) on the distance to the saw centre with the diameter intersecting point 16 (saw E1 ($D$ = 400 mm), zone III)



c d

**Fig. 6.** The dependency of the average coefficient of damping and the dynamic Young's modulus within three zones on the distance to the saw center, saw E1 ($D$ = 400 mm): a – teeth without deformation; b – teeth bent 0.2 mm; c – 0.3 mm; d – 0.4 mm

There is a decline in the dynamic Young's modulus by approximately 1.2 times, as the distance from the saw center reaches as high as 180 mm (Fig. 5, b).

It can be observed (Figs. 3 – 5) that when the first zone of the circular saw undergoes deformation, the average change in the dynamic Young's modulus within the second and third zone exceeds the one within the first zone by 4.5 % – 5.4 % times. For example, after setting saw teeth up to 0.4 mm within zone I with the diameter intersecting point 2, the dynamic Young's modulus decreased by 26 % in the radius direction, whereas within zone II with the diameter intersecting point 8, it was lower by 31.4 %.

Fig. 6 shows all three zones and value dependencies between average coefficient of damping and dynamic Young's modulus on the distance in the radius direction of the circular saw. It also indicates a nonlinear dependency between the coefficient of damping and the distance from the saw center in the present case. In each case there is an increase in the coefficient of damping from the point closest to saw flanges ($R = 90$ mm) to the point next to the saw teeth zone ($R = 150$ mm). When deformation is absent, the coefficient of damping rises by 1.64 times, meanwhile having bent saw teeth 0.2 mm, 0.3 mm and 0.4 mm, it becomes higher by 2.88, 2.57 and 5.57 times respectively. It was found that in each case the coefficient of damping reaches its minimum value in the zone of saw flanges and teeth ($R = 180$ mm). If the circular saw does not undergo deformation, the coefficient of damping begins to fall by 1.43 times, whereas by setting teeth to 0.2 mm, 0.3 mm and 0.4 mm, it declines by 1.38, 1.34 and 1.84 times respectively.

It was determined that there is a strong linear relationship between the dynamic Young's modulus and the distance in the radius direction of the circular saw ($r^2 = 0.8485 – 0.8777$). As the distance from saw flanges increases, the dynamic Young's modulus decreases approximately by 25 % in each case.

Other researchers found that the uneven and higher than the permissible teeth setting deforms saw blade and changes saw oscillation frequencies. These phenomenons affects saw`s dynamic behavior during cutting and are the reason of unbalance [3, 17]. Since the crosscut saw teeth have a higher load on the front surface of the teeth compared with longitudinal sawing saws, between teeth rather appears cracks [3].

Thus, the zonal deformation has a significant impact on the distribution of elastic-plastic properties within the saw plane. It is especially noticeable in terms of plastic properties. By forming the saw path and obtaining a higher value of the coefficient of damping, the circular saw can operate in a more stable manner. In the present case generated vibrations tend to decay faster.

## CONCLUSIONS

1. It was determined that when the circular saw does not undergo deformation, the average coefficient of damping increases by 1.64 times with the distance changing from flanges to the teeth zone, meanwhile by bending teeth up to 0.4 mm in one of the saw plane zones, it rises by 5.57 times.

2. It was established that with the distance increasing from saw flanges to the teeth zone, the dynamic Young's modulus decreases by approximately 25 % in each case. When deformation is absent, it declines from 221 GPa to 176.85 GPa, whereas after setting saw teeth 0.2 mm, 0.3 mm and 0.4 mm, the dynamic Young's modulus begins to fall from 222.7 GPa to 179.4 GPa, from 223.2 GPa to 178.76 GPa and from 221 GPa to 177.2 GPa respectively.

3. It was found that the change in the dynamic Young's modulus present within the zones without deformation exceeds the one in the zone with deformation by 5 %.

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*Presented at the National Conference "Materials Engineering'2009"* (*Kaunas, Lithuania, November 20, 2009*)