333. Vibration Based Research into Temperature Influence on Circular Saw Parameters

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Abstract. The study presents the research results of transverse sawing circular saws in conjunction with the oscillatory research of a non-rotating circular saw. It reveals that amplitude-frequency characteristics, resonance frequencies and modes were established and operative heating regimes of the saws were modelled. It was determined that the form of the main modes insignificantly changes when the saw is heated. At the same time heating temperature considerably influences the value of both high and low resonance frequencies, as well as the size of amplitude. During the examination damping coefficient within temperature interval was estimated and both surface and deep hardness of the saw were determined. The study shows that the temperature of the saw significantly changes its surface hardness, but its deep hardness remains less changed. The research results allow forecasting the behaviour of saws during operation.

Keywords: Circular saw, vibration, vibration mode, damping coefficient, deep hardness, lateral surface hardness.

1. Introduction

When cutting with circular saws, a peripheral area of the saw heats up more than a central one [1]. Due to temperature differences in the direction of radius, and temperature tensions as a result of them, the saw may loose flat form stability. The saw temperature, at which the flat form of the saw changes, depends on saw dimensions, centrifugal forces, rolling, etc. Also the alignment and wear of the arbour have some influence [2, 3]. While using the saw at a speed of 50 m/s (when the diameter of the saw is 400 mm), the temperature difference becomes over 100^{o}C in the direction of radius. The geometrical shape of the saw tends to change. With an increase in diameter of the saw, the temperature difference, at which the saw looses its balance form, decreases [1].

Seeking to reduce temperature tensions of the saw, its construction is modified – the central segment of the saw is hammered out or is rolled, initial tensions are created by the thermoplastic processing and surface plastic deformation, various notches are made on the saw disk [2, 4]. High friction between serrations of the saw and the saw plane, which causes the saw to heat, reduces the efficiency of rolling [3]. To solve this problem the guides of the saw are used. However, inadequately cooled guides can increase saw heating. In the other work [7] researchers Danielson and Worzala proposed using low-expansivity alloy called Inco 909 as a sawblade material to minimize the degree of thermal expansion. In preliminary industrial trials of sawblades made of low-expansivity alloy, sawing accuracy was improved 22 to 38 percent during normal sawing.

It is known that when cutting at a different speed, separate zones of the saw disk reach a temperature of 150^{o}C, and the zones of the serrations can even reach a significantly higher temperature. When a speed of push is near 100 m/s, the average temperature of the serration zone is about 500^{o}C, and that of impulse reaches about 1100^{o}C. Such temperature fluctuations may result in structural changes of saw material [2]. Many studies are related with saws geometrical form change during operation. It is very important to evaluate change of saw material when it is heated. Subsequently that would be related with parameters of resonance oscillations. Therefore, the research for evaluating temperature changes of the saw is highly relevant.

The objective of the research is to determine the impact of saw operational temperature on its mechanical properties, and structural changes in material.

2. Methodology and study equipment

The oscillatory research was performed by using a dynamic research method [5, 6]. A non-spinning saw was analysed (Fig.1). Resonant oscillations of a circular saw were invoked by an oscillator, and with their help Young`s modulus E, damping coefficient tg δ , and saw modes were evaluated.

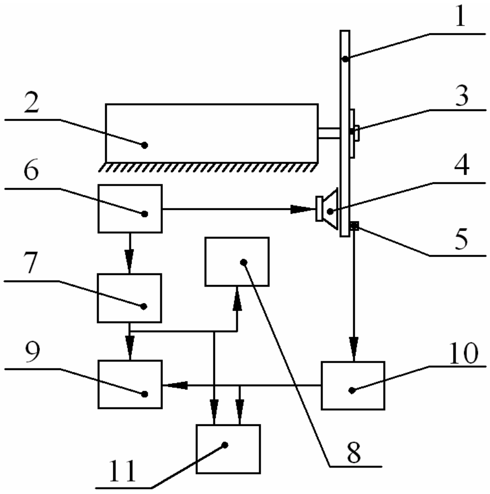

Fig. 1. Circular saw study stand: 1 – circular saw; 2 – shaft; 3 – flanges; 4 – vibrator; 5 – sensor; 6 – generator of electric signals; 7 – amplifier, 8 – frequency measurer; 9 – phasometer; 10 – vibrometer; 11 – oscilloscope

The saw is partitioned into separate segments, deriving a particular number of diameters and annular circles (Fig. 2.). In the places of their intersection a gauge is mounted and measurements are made. To reach a more precise saw mode, measurements are made in 96 points.

Surface hardness of the saw was also measured in measuring points. Measurements were made using Rockwell's method of measuring with a manual meter of hardness „Hardness Tester".

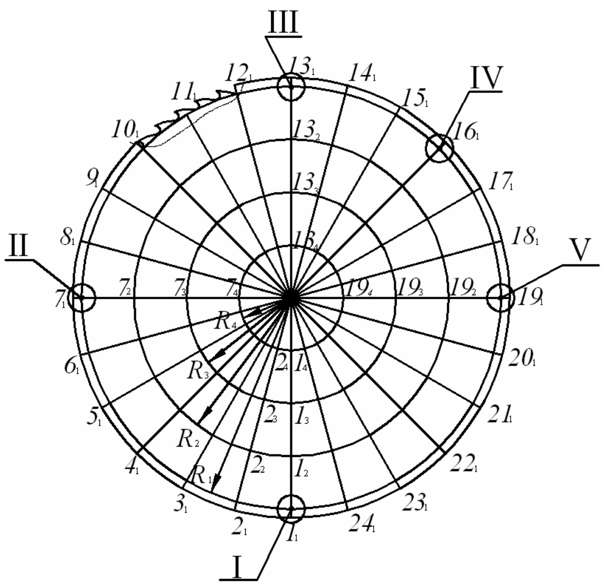

Fig. 2. Circular saw partitioning scheme: 1_1, 1_2, 1_3, 1_4, 2_1, 2_2, 2_3, 2_4 etc. – points, where vibrations, are measured; R_1, R_2, R_3, R_4 – radii of circles; *I*, *II*, *III*, *IV*, *V* – characteristic saw vibration measurement points

Heating regimes of the saw (the evaluation of operational temperature) were simulated by cutting an ash timber plank of 50 mm thickness. Therefore, a plank push trajectory was altered, and a different heating rate of the saw was obtained. Due to the saw and timber friction, separate parts of the surface heated up differently (the colour of different zones changed visually). In such a way separate zones of the saw were heated up to 40^{o}C, 90^{o}C and 120^{o}C. The temperature of these zones was measured by using non-contact infrared rays thermometer "Velleman", model DVM8810. Measuring accuracy was $\pm$ 2^{o}C.

Later, the oscillatory research with the saws heated at different rates were performed, by assessing damping coefficient, as well as the alteration of modes and surface hardness of the saw additionally, which was also evaluated by Rockwell's method with a stationary meter of hardness TK-2, (load – 1500 N).

For more detailed evaluation of changes in a saw material structure, deep measurements of hardness were additionally performed. For this, 8 specimens of the most heated zone of the saw were cut out, their surface and one edge were polished, and surface hardness of such edge was measured. Vickers' method was used for the measurements. Measured with an ocular microscope MOB-1-15X N653 695, GOST 7865-56 (load – 2 N).

The diagram of specimen preparation and hardness measurement is shown in Fig.3

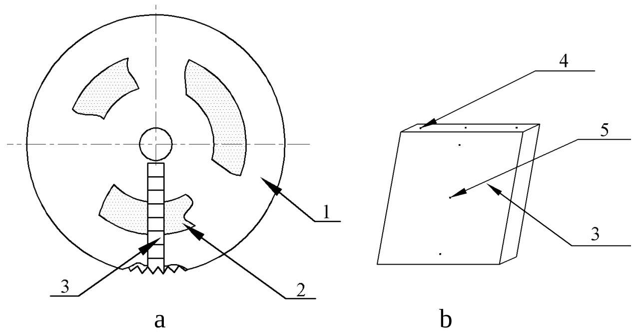

Fig. 3. Specimen preparation diagram: a – saw; b – specimen; 1 – saw; 2 – zone of heating; 3 – specimens, cut out of the saw; 4 – measurement points of deep hardness; 5 – measurement points of surface hardness

3. Experimental part

Five steel 9XΦ longitudinal cutting saws were studied, the diameter of which was 400 mm, thickness – 2.81 mm. The moment of tightening of the saw was 150 Nm. The measurements were taken in a range of 20–2000 Hz. Measuring oscillations' resonant frequencies, amplitude-frequency characteristics, oscillation modes of saws were determined as well as damping coefficient and surface hardness (before heating and after), and deep (only after heating) hardness.

In Fig. 4 amplitude-frequency characteristics of one of the saws (D = 400 mm) before heating and after different heating regimes – I (40^{o}C), II – (90^{o}C) and III (120^{o}C) are shown.

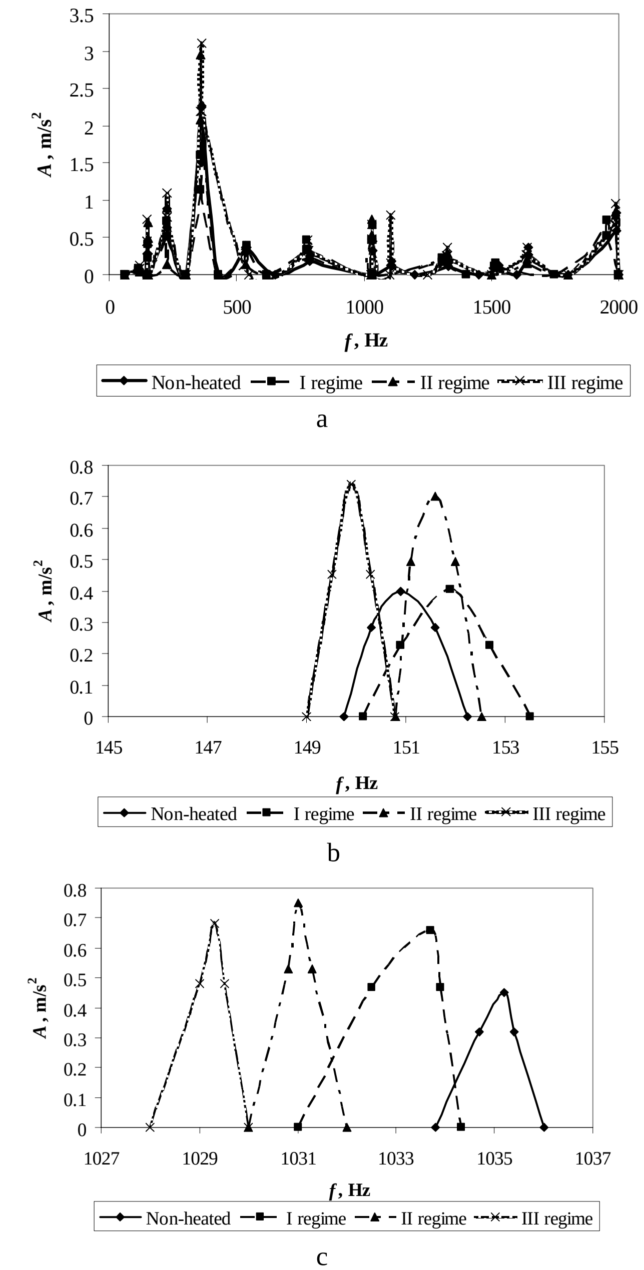

Fig. 4. Amplitude-frequency characteristics of differently heated saw (D = 400 mm): a – diapason of frequencies 20 – 2000 Hz; b – at f_{res} ≈ 150 Hz, c - f_{res} ≈ 1031 Hz

Fig. 4 indicates that being at the largest amplitudes the saw vibrates in a range of low frequencies (from 20 to 500 Hz) without any exceptions. It was determined, that resonant amplitude values of the heated saw increased. At the resonant frequency f_{res} ≈ 150 Hz the oscillation amplitude of non-heated saw was 0.4 m/s^2, after heating regime I – 0.405 m/s^2, after II– 0.7 m/s^2, and after III – 0.74 m/s^2. Analogous results were obtained also in the cases of other saws. Values of resonant frequencies of the saw are shown in Table 1.

Table 1 Resonant frequencies of the saw

	Resonant frequencies of a saw [Hz]			
Non-heated saw	119	150.9	228.2	362.5
	537.9	788.9	1035.2	1107.8
	1331.6	1528.7	1644.5	1992.4
Heated in regime I	117.9	151.1	226.5	359.1
	540.4	787.1	1033.7	1330.1
	1517.1	1954.1		
Heated in regime II	115.6	151.6	225.4	360.9
	537	784.5	1031	1328.6
	1640.6	1986.9		
Heated in regime III	115.8	149.9	226.1	360.3
	781.4	1029.3	1103.5	1326.8
	1639.4	1985.8		

Table 1 demonstrates, in the cases of the heated saw, the number of resonant frequencies decreased from 12 to 10. It was determined, that the value of resonant frequency of a more heated saw in most cases decreases from 0.36 to 2.7 %.

Also the alteration of saw modes was assessed. Fig. 5 shows the change of the saw mode (f_{res} = 150 Hz), obtained for various modes of saw heating.

Fig. 5 shows that the heating regime of the saw "enhances" the form of the mode. After heating up the saw, the area of a saw bend alters as well as the symmetry of separate parts of the mode.

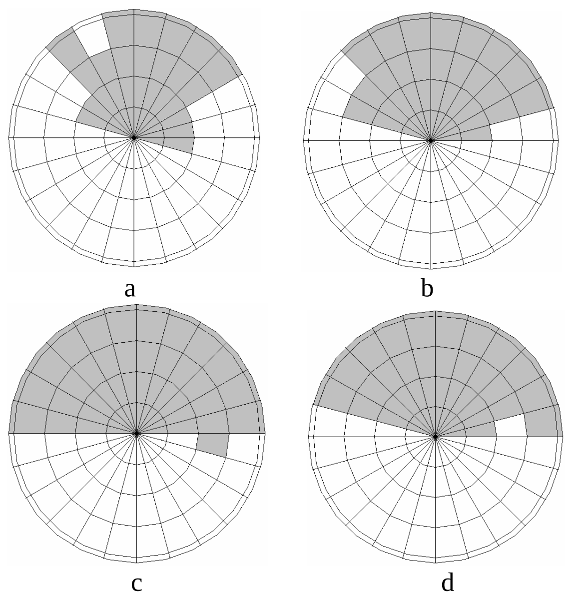

Fig. 5. Law of saw mode alteration subject to saw heating rate: a – of non-heated saw, b – of heated in regime I, c – heated in regime II, d – heated in regime III

After measuring amplitude-frequency characteristic, also damping coefficient was evaluated. Fig. 6 shows the laws of alternating damping coefficient subject to the rate of saw heating.

Fig. 6 indicates that after heating up the saw in regime I, the damping coefficient significantly decreased in a range of low frequencies. Later, by heating in other regimes, the damping coefficient in this range of frequencies practically did not change. When $f_{res} \approx 116$ Hz, the damping coefficient of the non-heated saw was 0.01117, after heating regime I – 0.00779 (decreased by 30%), after regime II – 0.00751 (decreased by 3.6 %), after regime III – 0.00756. In a range of higher frequencies (above 1000 Hz) the decrease of the damping coefficient was different. When $f_{res} \approx 1030$ Hz, the damping coefficient of the non-heated saw was 0.00068, after heating regime I – 0.00059 (decreased by 13 %), after regime II – 0.000485 (decreased by 17.8 %), after regime III – 0.000485.

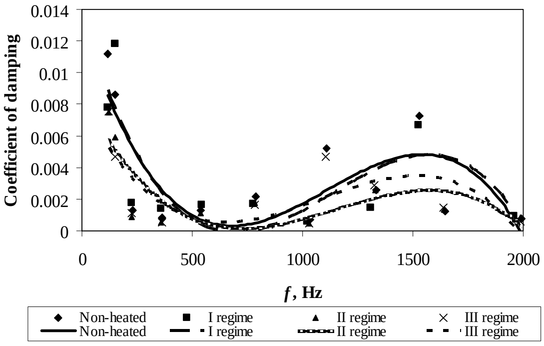

Fig. 6. Law of alternating damping coefficient of the saw within frequency range

The regularity of alternating surface hardness of the saw plane is presented in Fig. 7.

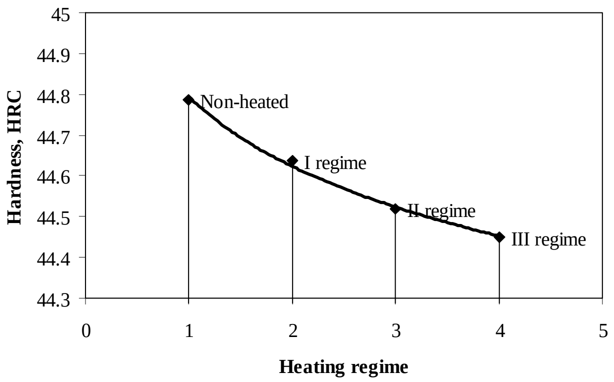

Fig. 7. Hardness alteration law of surface layer of the saw with a change in its heating regime

It was determined (Fig.7) that with an increase in saw heating temperature from 40°C to 120°C, surface hardness decreases by about 1 %.

Deep hardness was also evaluated by measuring hardness on the surface of specimens edge, which were cut out of saws, as well as surface hardness of specimens (Fig.3). Surface hardness in this case was measured by Rockwell's method, whereas the deep one– by Vickers' method. Fig. 8 shows data obtained in heating regimes I and III.

It was estimated (Fig. 8) that the heating regimes have no significant influence neither on surface hardness of specimen edge plane nor on deep hardness of the saw. Surface hardness in this, and in the previous cases, decreased about 1 % on average, and the deep one did so around 0.2 %.

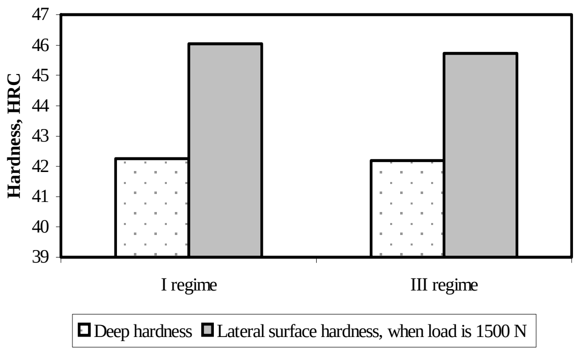

Fig. 8. Laws of alternating deep and surface hardness of a differently heated saw

Thus, operational temperature of the saws highly affects both mechanical properties of the saw and its stability during operation. Therefore, while manufacturing saws and choosing timber cutting regimes, it is necessary to consider a presumable heating temperature value.

4. Conclusions

1. It was determined, that in a range of operational temperature of the circular saw, resonant frequency in most cases decreases to 0.36 – 2.7 %.
2. It was estimated, that with the saw heating up to operational temperature, the forms of its mode "enhance": the symmetry of separate mode segments changes.
3. It was obtained, that heating up the saw to 40°C, the damping coefficient in the range of low frequencies decreases to 30 %. A higher operational temperature practically has no influence on the damping coefficient – it alters additionally by about 3 %.
4. It was estimated, that with an increase in saw heating temperature from 40°C to 120°C, surface hardness decreases by around 1 %, and deep – about 0.2 %.

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