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Comparison of the impact test and the harmonic test in measurements of natural resonant frequencies of circular saw blades

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Abstract: *Comparison of the impact test and the harmonic test in measurements of natural resonant frequencies of circular saw blades.* In this paper results of measurements of natural resonant frequencies of circular saw blades with the impact test and the harmonic test are presented. Comparison of these two methods revealed that during testing of circular saw blades, in which bodies the open and closed notches (cuts) for cleaning of knives are present, with the harmonic test method it has been observed appearing of quasi-twin resonant frequencies, whereas the impact test method could not allow to recognize them , because it does not clearly confirm the occurrence of such frequencies.

Keywords: impact test, harmonic test, resonant frequencies, circular saw blades

INTRODUCTION

The range of circular saw blade rotational speed is define by the critical rotational speed of such circular saw blade. It is usually the maximum speed in which the circular saw blade can work with required stability. This critical rotational speed can be determine as well by stationary methods as for rotating circular saw blades. Those methods are based on knowledge of value of the circular saw blade resonant frequency, which is necessary to calculate its critical rotational speed. (***Orłowski et al 2007; Stakhiev 1998, 2000, 2003; Šteuček 1971; Nishio and Marui 1996***). Analytics methods, which are based on the finite element method FEM, have been described by ***Gogu*** (***1988***), ***Strzelecki*** (***1974***), and I***ngielewicz*** and ***Wittbrotd*** (***1992***). Whereas, among empirical methods there can be indicate three main methods: the harmonic method, the impact test (***Orłowski et al. 2007***; ***Kaczmarek et al. 2014***), and the non-stationary method (***Javorek 2000, Svoreň 2011, 2012***).

For circular saw blades there exists theory, which says that resonance of circular plates is a result of the superposition of two component waves in which the first is traveling forward and the second is traveling backward (***Schajer 1986; Nishio and Marui 1996***):

$$f_{f/b} = f_{s(N)} \pm \frac{n \cdot N}{60} \qquad \text{[Hz]} \qquad (1)$$

where: N – rotational speed of saw [rpm], n – number of nodal diameter [-], f_s – natural frequency of saw [Hz]:

$$f_{s(0)}^2 = f_{(N=0)}^2 + \lambda \cdot \left(\frac{N}{60}\right)^2 \qquad \text{[Hz]} \qquad (2)$$

where: $f_{(N=0)}$ – is the natural frequency of non-rotating saw (n = 0) [Hz], λ – coefficient of centrifugal force.

The value of critical rotational speed may be calculated from the following equation:

$$n_{cr} = \frac{60 \cdot f_{(N=0)}}{\sqrt{n^2 - \lambda}} \qquad \text{[rpm]} \qquad (3)$$

In practice, the critical rotational speed for circular saw blades is determined for nodal diameter with number k=2, k=3 or k=4. From calculated critical rotational speeds of these nodal diameters should be chosen the lowest value. In fact the maximum rotational speed for a such circular saw blade, which is applied by the user, must not be higher than its permissible rotational speeds, which can be applied calculated as (***Stakhiev 1998, 2000, 2***003):

$$n_p = 0.85 \cdot n_{cr} \qquad \text{[rpm]} \qquad (4)$$

The value of the aforementioned coefficient of centrifugal force λ is possible to be calculated from following empirical equation (***Šteuček 1971***):

$$\lambda = \frac{m_P - 1}{4 \cdot m_P} \cdot n^2 + \frac{3 \cdot m_P + 1}{60} \cdot n \qquad \text{[-]} \qquad (5)$$

where: m_P – is Poison’s ratio [-].

MATERIALS AND METHODS

Experiments were carried out at the laboratory of the Department of Woodworking Machines and Equipment of the Technical University in Zvolen. Four circular saw blades type “Multix” made by ASPI TECH Sp. z o.o., Sp. k. from Suwałki (PL) were tested objects. The circular saw blades data is as follows: outside diameter D = 350 mm, clamping hole diameter d = 30 mm, saw blade thickness a = 2.8 mm, teeth number z = 18. The examined saw blades have only one difference among them just in the length of cutting wedges situated in the open notches (cuts), which for circular saw blades were as follows: 45 mm (Fig.1a = saw disc **P1**), 35 mm (Fig.1b = saw disc **P2**), 25 mm (Fig.1c = saw disc **P3**) and 15 mm (Fig.1d = saw disc **P4**). The tested circular saw blades were clamped with collars of the external diameters equal to d_z = 90 mm.

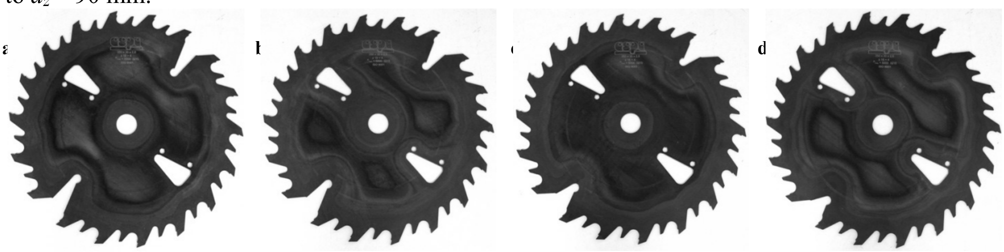


Fig. 1 Tested saw blades with external cut for cleaning knife with dimension equal to:
a) 45 mm, b) 35 mm, c) 25 mm, d) 15 mm

A harmonic method was the first used method , which is based on the classical Chladni patterns method of identity the modal shape of resonant of plates. (***Orłowski and Javorek 2009***). Each tested saw blade is clamped by clamping collars with similar force by a torque wrench. The circular saw blade was sprinkled with semolina. An input function generator FG-506 (f. AMERICAN RELIANCE INC) is connected to a signal amplifier QSA260 (f. Q'Sound). A sinusoidal signal forces the vibration of saw blade by an inductor. A contactless inductive sensor BAW M08EI-UAD15B-BP03 (f. Balluff) transmits a signal about displacement of the saw blade to an analog oscilloscope OS-9020P (f. GoldStar). Now the value of the resonant frequency can be noticed from the generator. The laboratory stand for testing circular saw blades with the harmonic method is presented in Fig. 2.

The second method was an impact method, in which the tested circular saw blade has been hit one time with a small hammer, what causes saw blade vibrations. Displacements of the saw blade were measured by the same contactless inductive sensor as in the above mentioned test. These data were converted by a digital oscilloscope type PicoScope 2205 (f. Pico Technology) as a time function. The sampling frequency of measurement was equal to 3000 Hz, and the number of samples was 16 384 for each measurement. Then data were changed by FFT (Fast Fourier Transform) into an amplitude spectrum by software Labview (v. 8) or AnalizaDAQ. It allowed to obtain the values of the resonant frequencies of tested circular saw blades from the amplitude spectra (***Orłowski et al. 2007***). The laboratory stand for testing circular saw blades with the impact method is presented in Fig. 3.

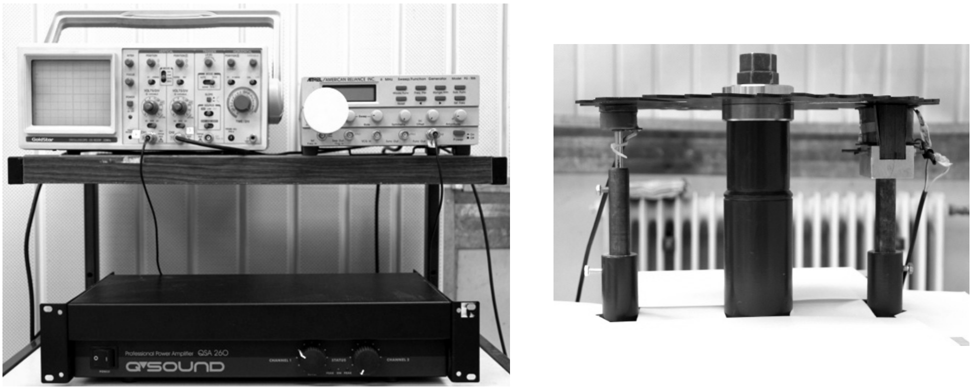


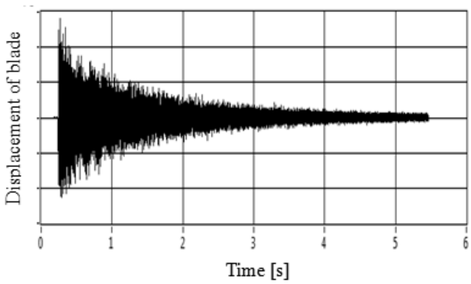
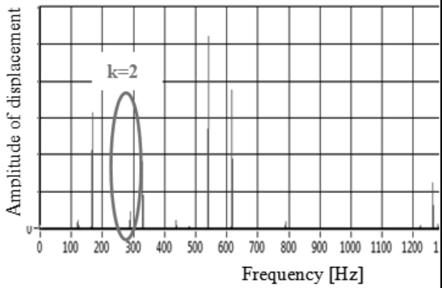
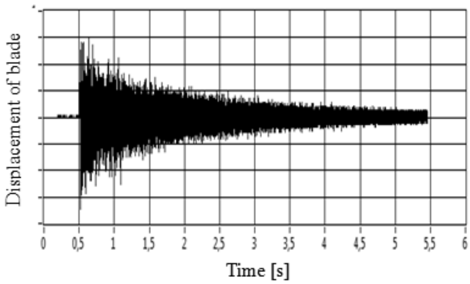
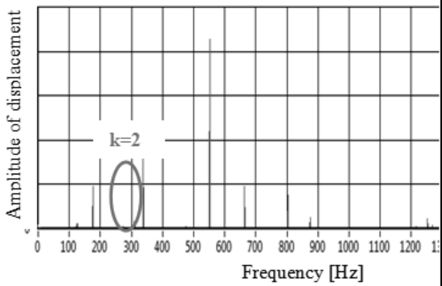
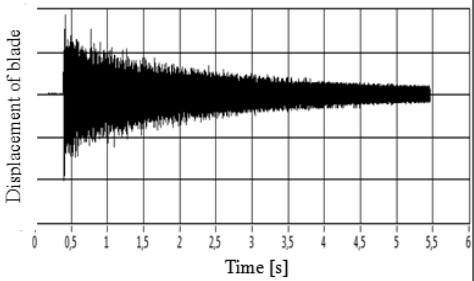
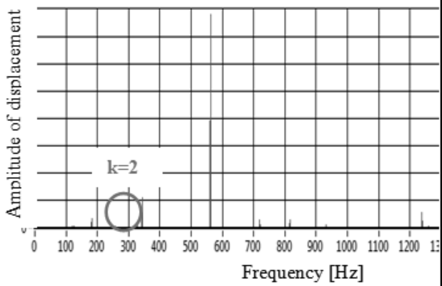
Fig. 2 Laboratory stand for testing circular saws with harmonic method, where: 1 – input function generator, 2 – signal amplifier, 3 – oscilloscope, 4 – inductor, 5 – contactless magneto-inductive sensor

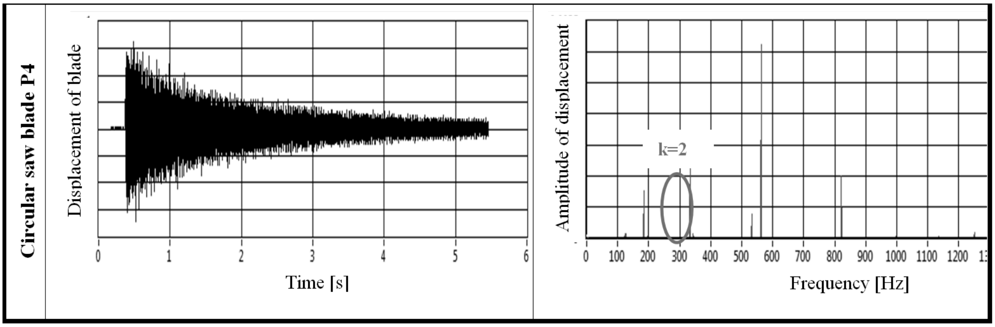
Fig. 3 Laboratory stand for testing circular saws with impact method, where: 1 – contactless inductive sensor, 2 – digital oscilloscope, 3 – NTB with software PicoLog Recorder

RESULTS

In Tab. 1, Tab. 2. and Fig. 4 the results of the impact method for tested circular saw blades are shown. For circular saw blade with smaller external cuts for cleaning knives resonant frequencies are moving to higher value and it is true for number of vibration mode between k = 2’ up to k = 5’’, for example k = 2 (Tab. 1). For number of vibration mode which is higher than k = 5’’ it can be observed change in behavior of resonant frequencies, which started appearing with lower values for the next circular saw blades (Tab. 2). At the first glance it was almost impossible to notice the quasi-twin resonant frequencies phenomenon in the amplitude spectra (***Kaczmarek et al. 2014***). Fortunately, the program Labview gives the opportunity to expand the frequency scale, what allows for accurate preview of amplitude spectrum. In the case if there was no information of the possibility of quasi-twin resonant frequency existence, probably this phenomenon would have been omitted at all.

Tab. 1 Results of impact method for circular saw blades with external diameter D = 350 mm and clamping diameter d_z = 90 mm

	Lateral displacements versus time	Amplitude spectrums
Circular saw blade P1		
Circular saw blade P2		
Circular saw blade P3		



Tab. 2 Data from harmonic method and impact method

Number of vibration mode *k*	Resonant frequency [Hz]							
	HARMONIC METHOD				IMPACT METHOD			
	P1	P2	P3	P4	P1	P2	P3	P4
1	123.26	123.80	122.62	125.70	125.074	125.623	124.341	126.905
k0,o1	139.82	141.64	141.32	142.40	142.104	142.837	142.287	142.104
2'	165.82	178.58	182.32	186.68	167.558	175.982	182.391	184.955
2	**194.66**	**199.84**	**200.14**	**199.98**	**194.477**	**198.506**	**195.027**	**196.309**
3'	293.30	314.90	331.70	338.50	289.610	310.395	327.792	334.201
3	332.50	341.60	348.10	347.40	329.440	337.497	343.540	341.441
4'	444.00	482.60	519.60	540.90	437.483	475.939	512.563	532.890
4	548.40	559.30	566.70	569.80	540.581	551.752	562.190	563.289
5'	623.30	672.20	730.00	776.00	616.395	663.457	719.127	765.091
5	799.40	812.80	827.80	834.20	789.996	803.700	816.732	820.578
5''	846.90	884.60	942.80	935.00	834.863	875.515	900.969	997.658
k2,o1	1044.20	1079.60	1066.00	1081.40	**1223.080**	**1215.390**	**1211.550**	**1205.690**
6	1132.60	1163.20	1204.80	-	**1263.190**	**1252.750**	**1237.920**	**1251.470**
k3,o1	1308.20	1327.80	-	-	**1279.120**	**1269.230**	**1258.980**	**1257.880**

In Tab. 2. and Fig. 5 the results of the harmonic method for tested circular saw blade are presented. The same as previously, for the circular saw blade with smaller external (open) cuts for cleaning knives for number of vibration mode between k = 2' up to k = 5'' resonant frequencies are moving to higher value. It is also true for number of vibration mode higher than k = 5''.

It can be also noticed, that for higher values of frequency it was harder to get the accurate moment of resonance, because of too low power of the input signal amplifier. That is why it was hard to sufficiently compare these values of frequency with those from the impact test – in area of frequency above 1000 Hz the impact test gives a lot of small "peaks", which without some filtering of data are impossible to be analyzed properly. Furthermore, the latter phenomenon could be also caused by existence in the spectrum of the aliasing frequencies (***Sampling 2015***).

Moreover, for number of vibration mode between k = 2’ up to k = 5 there is some analogy between results from both methods. The difference between values of resonant frequencies is equal to circa 2 Hz for k = 2’ and it increase progressively up to circa 13 Hz for k = 5.

CONCLUSIONS

1 – for circular saw blade with smaller external cuts for cleaning knives for number of vibration mode between k = 2’ up to k = 5’’ resonant frequencies are moving to higher value and it is true as well for the impact method as for the harmonic method;

2 – the comparison of both methods shoved an analogy difference between their results, which slowly changes from circa 2 Hz up to 13 Hz for next numbers of vibration modes;

3 – for number of vibration mode higher than k = 5’’ in the harmonic method resonant frequencies have also trend to increase, whereas for the impact method it was observed completely different situation.

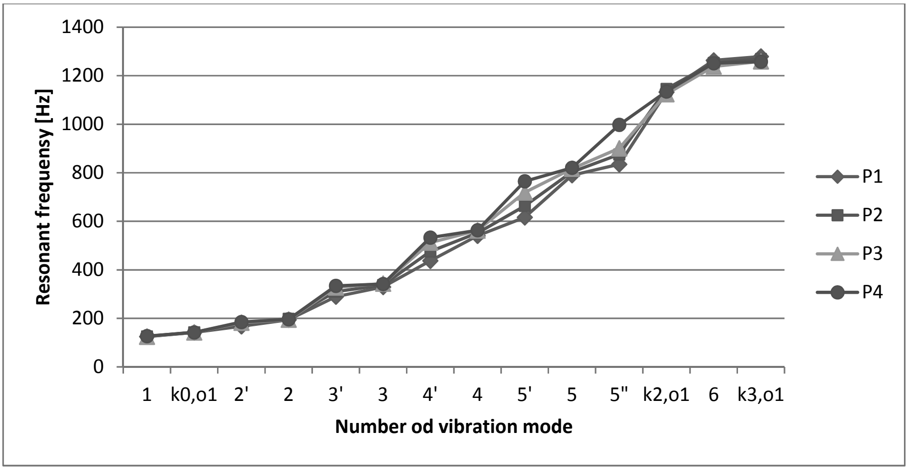


Fig. 4 Results of impact method for circular saw blades P1, P2, P3 and P4

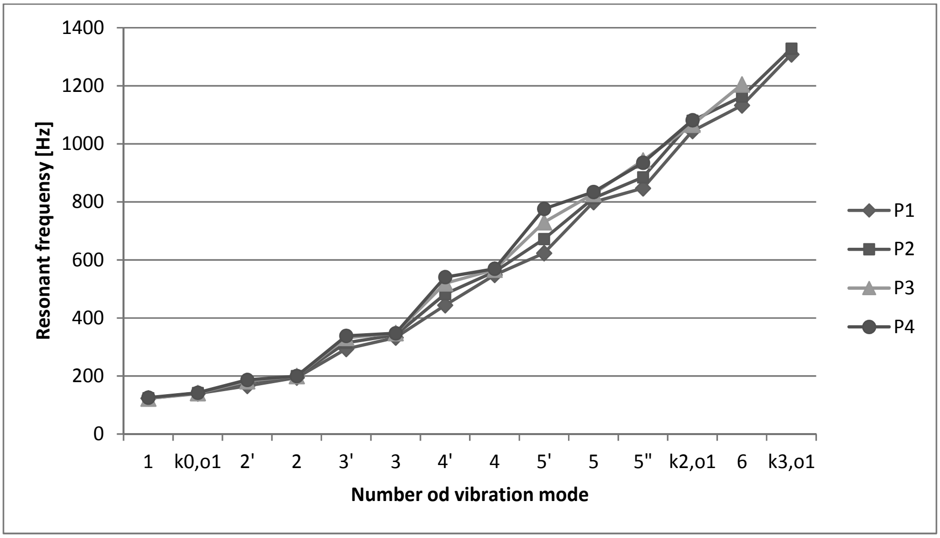


Fig. 5 Results of harmonic method for circular saw blades P1, P2, P3 and P4

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Streszczenie: *Porównanie testu impulsowego i testu harmonicznego przy pomiarze naturalnych częstotliwości rezonansowych pił tarczowych*. W niniejszej pracy przedstawiono wyniki pomiarów naturalnych częstotliwości rezonansowych pił tarczowych za pomocą metody testu impulsowego oraz testu harmonicznego. Porównanie tych dwóch metod wykazało, że dla pił tarczowych, w których korpusach znajdują się wewnętrzne otwory i zewnętrzne nacięcia na noże czyszczące, podczas pomiaru metodą harmoniczną zaobserwowano występowanie „bliźniaczych” częstotliwości rezonansowych, podczas gdy metoda impulsowa okazała się niewystarczająco przydatna, ponieważ nie potwierdza ona jednoznacznie występowanie tego zjawiska.

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