

# Measuring stand for research of circular saws' natural frequencies and vibration modes

Bolesław Porankiewicz\*, Paweł Bachman\*\*, Marcin Chciuk\*\*

\*retired professor

\*\*Faculty of Mechanical Engineering, University of Zielona Góra, Poland

**Abstract:** In the article issues associated with the measurement of saw based natural frequencies are presented. Then construction of measuring stand to observe circular saw's Chladni figures is shown. The stand consists of: precise DDS signal generator, high-speed power amplifier, electromagnetic actuator, white powders and digital camera. With this stand it was possible to obtain Chladni figures for frequencies up to 5 kHz. The end of the article contains results of a sample measurement of used up circular saw.

**Keywords:** circular saw, saw based natural frequencies, vibration modes, Chladni figures

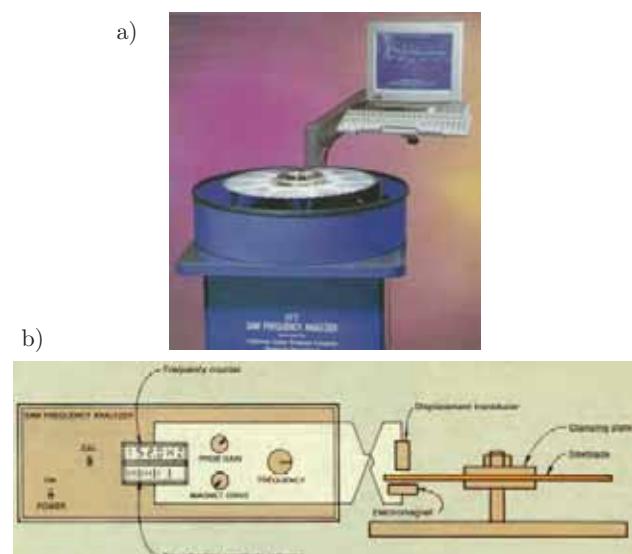
## 1. Introduction

The dynamic stiffness of circular saws depends upon proper natural frequencies of important vibration modes. Good dynamic stiffness of circular saws, is expressed by low tendency to fall into vibrations, what is the condition of proper operation of circular saws in the wood industry. Good dynamic stiffness of circular saws can be obtained by initial tensioning by means of rolling what is widely applied industrial method. Specific technological operation, for example, thin and super thin rip sawing of high quality, of expensive wood, requires appropriate initial tensioning to get smooth work piece surface after machining and the highest sawing dimensional accuracy (0.1 mm or less). There were several ways of evaluation of the initial tensioning effects, like:

- an area of a rolling path,
- a depth of a rolling path,
- a light gap between deformed blade and a straight edge rule [3],
- a static stiffness of a saw blade [10],
- a compression stresses inside a rolling path.

However, as a best measure of the effect of a saw blade initial tensioning was recognized a shift of natural frequencies and critical rotational speeds of several initial vibration modes [5, 8]. There are available from literature important facts concerned with amount of tensioning necessary to insert in a saw blades of different dimensions and for different sawing operations, in order to obtain stable work [4, 7, 9]. However, from practical point of view, there were missing, in Polish conditions, equipment allowing for fast and accurate measurement of actual state of circular saw's natural frequencies of important vibrations. There were available measuring stand developed at Research

Department (not existing any more) of California Cedar Products Company (CCPC), Stockton, CA, USA, illustrated in fig. 1. This measuring stand was successfully used for evaluation of super thin circular saws designed, manufactured and exploited at the CCPC for about 50 years.



**Fig. 1.** Measuring stand for circular saws' natural frequencies and vibration modes developed at CCPC: a) general view [13], b) schematic diagram [14]

**Rys. 1.** Stanowisko do pomiaru częstotliwości rezonansowych pił tarczowych zbudowane w CCPC: a) widok ogólny [13], b) schemat działania [14]

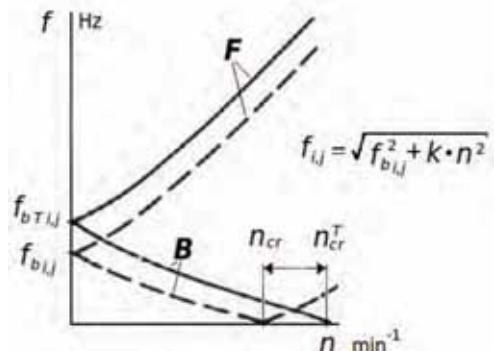
Recently has been presented method for evaluation of circular saws' natural frequencies and vibration modes measurements with use of one fixed and one rotating inductive sensor [11], which is interesting step forward that eliminates necessity to observe and register Chladni figures illustrating vibration modes [1]. However, this idea may work properly only in case of regular shapes of the vibration modes. Real, not best filled circular saws, having more or less irregular shape of Chladni figures will be difficult to measure in this way.

The goal of the present work was to develop, construct, and test measuring stand for saw based measurements of circular saws' natural frequencies and vibration modes.

## 2. Natural frequencies and modes of fixed not rotating saw

Fixed, not rotating, circular saw natural frequencies and modes (saw based  $f_b$ ), are subject of many theoretical stud-

ies with application of classical methods [6] and finite elements methods. The characteristic saw based natural frequency before and after tensioning is shown in fig. 2.



**Fig. 2.** Saw based natural frequency before  $f_{bi,j}$  and after tensioning  $f_{bTi,j}$  [7]

**Rys. 2.** Wykres częstotliwości rezonansowej bazowej przed  $f_{bi,j}$  i po naprężaniu  $f_{bTi,j}$  [7]

Outcomes of theoretical calculations of natural frequencies and modes are idealized (smooth) because of impossibility of taking into account unknown real residual stress distribution in the saw blade, and, not match results of measurements of the saw in details. Deformations of Chladni figures as well as larger than one number of present natural frequencies of the same vibration modes in results of measurements can be observed [2]. Number of additional (in comparison to theoretically predicted) natural frequencies for the same vibration modes and Chladni figures deformations increase when quality of the saw decreases [2]. An indicator of poor quality of circular saw was found to be bending of diameter node as shown in fig. 3 [2, 12, 13].



**Fig. 3.** Bent diameter node of the (0,4) vibration mode [12, 13]

**Rys. 3.** Wygięty węzeł średnicowy postaci drgań (0,4) [12, 13]

An increase of natural frequencies for vibration mode higher than (0,0) (i.e. number of circle and diameter nodes is equal to zero) and for vibration mode (0,1) (number of circle nodes is equal to 0, and number of diameter nodes is equal to 1), obtained after initial tensioning (by means of rolling), reduces a circular saw susceptibility to transverse, simultaneous vibration excitation. Optimal initial tensioning of a circular saw is particularly important to prevent the occurrence of a standing wave when sawing, for all vibration modes with the exception of the mode (0,0). Large amplitude standing wave may occur in idling, when a design of circular saw is chosen inappropriately to existing machining

parameters. Reduction to zero of natural frequency of backward traveling wave (fig. 2), and generation of a standing wave can be caused by too large heating of outer region of circular saw during sawing. For this situation a critical circular saw rotational speed ( $n_{cr}$ ) (fig. 2), for diameter vibration modes, drops down and equals to the rotational speed. Theoretical value of the  $n_{cr}$  as well as natural frequencies and vibration modes, for particular saw design, clamping condition and rotational speed can be predicted with application of computer program CSAW 4.0 [6].

### 3. Method of evaluation of circular saw natural frequencies

The developed measuring stand, shown in fig. 4, consists of a heavy stiff base with cooler and mounted circular saw. The excitation electromagnetic actuator, fixed to the base, is fed from power amplifier via adjustable, precision signal generator. Thanks to cooler, saw excitation system can work long time without overheating with unchanging parameters. The electromagnetic actuator has been designed to faithfully reproduce the signal from generator after amplification over a wide frequency band.



**Fig. 4.** Developed measuring stand

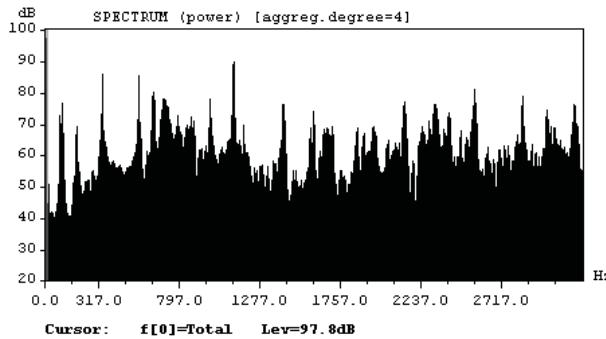
**Rys. 4.** Zbudowane stanowisko badawcze

For measuring and recording vibrations generated by excited saw, precision microphone connected to SVAN 912 meter is used (fig. 5).



**Fig. 5.** FFT measurement with the Svan 912 meter

**Rys. 5.** Pomiar FFT miernikiem Svan 912



**Fig. 6.** FFT spectrum measurement with the Svan 912 meter

**Rys. 6.** Spektrum FFT zmierzone miernikiem Svan 912

Measuring signal from excited and vibrated circular saw was captured and stored using features of the SVAN 912 meter, which is the precision sound and vibration analyzer, equipped with very sensitive capacitive microphone. The microphone was mounted very close to the excited saw. In the surrounding space (laboratory) no sound and vibration sources were present during measurements.

Data recorded in the SVAN 912 meter memory were exported to PC computer and the FFT spectrums of natural frequencies (fig. 6) were extracted with application of SVAN 912 software.

#### 4. Registration and evaluation of vibration modes

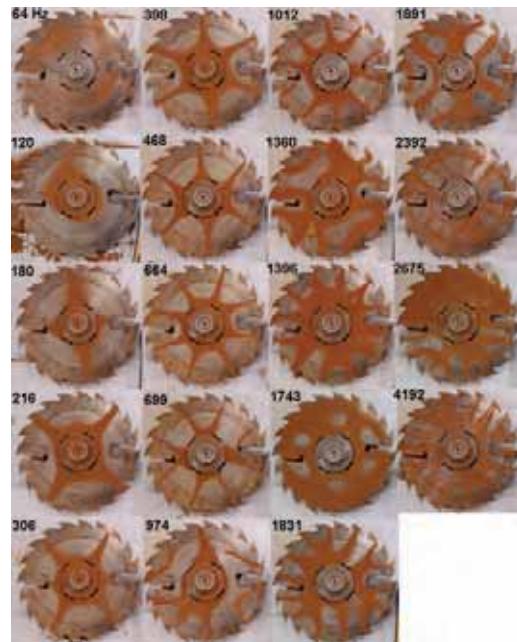
The vibration modes, shown by Chladni figures were generated on horizontally fixed circular saw, carefully cleaned up using organic solvent and evenly sprinkled by white microfine organic powder. The powder was selected to not have the tendency to adhere to the surface of the blade. For obtaining Chladni figure of particular vibration mode it was applied adjustable with step of 0.1 Hz DDT (Direct Digital Synthesizer) signal generator. The well formed Chladni figures were registered using digital camera.

#### 5. Discussion

Theoretically, the figure's frequency of excited signal from generator should correspond to the frequency recorded by FFT analysis. Based on the data collected in tab. 1 it can be seen that in 13 cases failed to obtain images, in 9 cases occurred resonance frequency similar to measured measure, and only 1 at the frequency where the SVAN 912 meter did not take into account in the spectrum (4192 Hz).

Sample images of the Chladni figures for used up circular saw, with a scraper edge, were shown in fig. 6. The vibration modes have to be recognized manually on the images. It can be seen that figures for frequencies (in Hz): 64, 120, 974, 1360, 1831, 1891, 2392, 2675, 4192 are so highly deformed that it was unable to recognize vibration modes (*i, j*). The figure for 120 Hz represents deformed vibration mode (0,1). The figures for 180 and 216 Hz represent vibration mode (0,2), where the 216 case seems to be harmonical. The figures for 306, 398 and 468 Hz represent vibration mode (0,3), where the 306 and 398 Hz cases seem to be harmonical vibration. The figures for 664 and 699 Hz represent slightly deformed vibration mode (0,4),

where 664 Hz case seems to be harmonical vibration. The figure for 1012 Hz represents deformed vibration mode (0,5). The figure for 1396 Hz represents deformed vibration mode (0,6). The figure for 1743 Hz represents deformed vibration mode (1,3).



**Fig. 7.** Sample images of the Chladni figures for used up circular saw

**Rys. 7.** Przykładowe obrazy figur Chladniego dla zużytej piły

**Tab. 1.** Natural frequencies FFT (Hz) obtained from SVAN 912 and generator frequencies for which Chladni figures were observed

**Tab. 1.** Zestawienie własnych częstotliwości rezonansowych płyty uzyskanych z FFT oraz tych, dla których zaobserwowano obrazy Chladniego

| FFT  | figures | FFT  | figures |
|------|---------|------|---------|
| 54   | 64      | 1740 | 1743    |
| 120  | 120     | 1832 | 1831    |
| 180  | 180     | 1892 | 1891    |
| 210  | 216     | 2154 |         |
| 306  | 306     | 2238 |         |
| 398  | 398     | 2292 |         |
| 468  | 468     | 2392 | 2392    |
| 664  | 664     | 2566 | 2568    |
| 700  | 699     | 2676 | 2675    |
| 974  | 974     | 2818 |         |
| 1014 | 1012    | 2924 |         |
| 1080 |         | 2994 |         |
| 1364 | 1360    | 3048 |         |
| 1396 | 1396    | 3080 |         |
| 1458 |         | 3174 |         |
| 1580 |         |      | 4192    |
| 1734 |         |      |         |

#### 6. Summary

Designed and built measuring stand has the following advantages:

- more precise frequency setting from previously used equipment, thanks to the DDS generator,
- greater tested frequencies range than in previously used equipment, thanks to special construction elec-

- tromagnetic actuator controlled by high-speed power amplifier,
- the possibility of long-term operation without overheating the excitation electromagnet.

The measuring stand has the following disadvantages:

- it cannot be used in industrial conditions where many vibration and noise sources are present,
- registration of Chladni figures with use of digital camera and manual evaluation of vibration modes.

## References

1. Chladni E.F., *Entdeckung über die Theorie des Klanges*, Leipzig 1787.
2. Idzikowski I., *Częstotliwości i postacie drgań własnych płaskich pił tarczowych do skrawania drewna*, master's thesis, 2003.
3. Lister P.F., Schajer G.S., *The effectiveness of the light-gap and frequency measurement methods for evaluating saw tensioning*, Proceedings of 10<sup>th</sup> Wood Machining Seminar, University of California, Forest Products Laboratory, Richmond, USA, 21–23 October 1991.
4. Münz U.V., *Means of testing and designing circular saw blades*, Proceedings of the 13<sup>th</sup> International Wood Machining Seminar, 17–20 June 1997, Vancouver, Canada, 105–116.
5. Rhemrev J., Trinchera L., *Improving the stability of thin circular saws through applied research*, 32<sup>nd</sup> Annual Meeting the Forest Products Research Society, Atlanta, GA, USA, 1978.
6. Schajer G.S., *CSAW 4.0 Computer software for optimizing circular saw design*, Wood Machining Institute, Berkeley, CA USA, 2007.
7. Schajer G.S., Mote C.D., *Analysis of optimal roll tensioning for circular saw stability*, Proc. of the 7<sup>th</sup> Wood Machining Seminar, University of California Forest Products Laboratory, Richmond, USA, 18–20 October 1982.
8. Schajer G.S., Mote C.D., *Analysis of roll tensioning and its influence on circular saw stability*, "Wood Science & Technology", 1983.
9. Schajer G.S., Mote C.D., *Analysis of optimal roll tensioning for circular saw stability*, "Wood & Fiber Science", 1984.
10. Szymani R., Mote C.D., *Circular saw stiffness as a measure of tension*, "Forest Products Journal", 1977.
11. Schajer G.S., Ekevad M., Grönlund A., *Practical Measurement of Circular Saw Vibration Mode Shapes*, Proceedings of 20<sup>th</sup> International Wood Machining Seminar, Skelleftea, Sweden, 2011.
12. Turner J., *What tension works and matching that to other saws*, Teach Talk, California Cedar Products Company (CCPC), Stockton, CA, USA.
13. Folder of Circular Saw Innovations, California Cedar Products Company, Stockton CA, USA.
14. [www.woodmachining.com/electric.html] – Wood Machining Institute (January 2013).

## Stanowisko do pomiaru częstotliwości i postaci drgań własnych pił tarczowych

**Streszczenie:** W artykule przedstawiono problematykę związaną z pomiarem częstotliwości rezonansowych pił tarczowych. Następnie opisano stanowisko pomiarowe do obserwacji figur Chladniego powstających na piłach tarczowych. Stanowisko to składa się z precyzyjnego generatora sygnału DDS, szybkiego wzmacniacza mocy, siłownika elektromagnetycznego, rozdrobnionego proszku i aparatu cyfrowego. Dzięki temu stanowisku można uzyskać obrazy Chladniego dla częstotliwości rezonansowych pił do 5 kHz. Koncowa część artykułu zawiera wyniki pomiaru częstotliwości rezonansowych oraz obrazy Chladniego dla zużytej płyty tarczowej.

**Słowa kluczowe:** piła tarczowa, częstotliwość drgań własnych, postacie drgań, figury Chladniego

### Marcin Chciuk, MSc

Assistant at the Institute of Education Technology and Computer Science, Faculty of Mechanical Engineering, University of Zielona Góra. Interests: mechatronics and control systems.  
e-mail: M.Chciuk@eti.uz.zgora.pl



### Paweł Bachman, MSc

Assistant at the Institute of Education Technology and Computer Science, Faculty of Mechanical Engineering, University of Zielona Góra. Interests: mechatronics and control systems. Scholarship in Sub-measure 8.2.2 "Regional Innovation Strategies", Measure 8.2 "Transfer of Knowledge", Priority VIII "HR Regional Economy" Operational Programme Human Resources co-funded by the European Social Fund, the European Union and the state budget.  
e-mail: P.Bachman@eti.uz.zgora.pl



### Bolesław Porankiewicz, PhD

Retired and habilitated in 2004 at the Agricultural University of Poznań, Faculty of Wood Technology, where he received his Doctor of Technical Science and MSc degrees in 1973 and 1968, respectively. In 2008–2011 he was employed as the contract professor at the University of Zielona Góra, Faculty of Mechanical Engineering. Research interests: wood cutting forces, cutting accuracy, wearing of wood cutting tools, construction and exploitation of wood cutting tools and woodworking machinery.  
e-mail: B.Porankiewicz@eti.uz.zgora.pl

