FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

VIBRATION AND IDLING NOISE IN COMMERCIAL CIRCULAR SAWS

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This article presents the outcomes of a theoretical and experimental research on vibration and idling noise developed in a set of thirteen circular saws commercially available. The logical difficulty associated to the testing of these two generating sources of noise separately led to the experimentation of these two sources simultaneusly. Due to the fact that it was not easy to find out enough commercially circular saws that allowed the covering and testing of a wide range of variables affecting the generation of noise, modifications in workshop in the geometry of some of them were carried out. It was determined that the natural frequencies increased according to the teeth highness for saws with equal diameter and identical thickness. Furthermore, the natural frequency came out directly proportional to the dimensions of the fixing collar. During the rotation it could be noticed that the natural frequency is divided in two resonance frequencies linearly increased with the angular frequency of rotation. It was observed that the sound pressure level generated by these circular saws varied proportional to the peripherical velocity of rotation.

INTRODUCTION

Studies related to circular saws have been continously published since almost five decades ago up to now (1).

From these studies, a source of information has arisen which permits to wait for better operational and work conditions in sawmills and industries where these working tools are present.

At present there exist answers for those vibration problems in a rotation circular saw. They can be prevented by means of an appropriate and high quality manufacture besides a proper maintenance and assembling, where critical rotation velocities are avoided and well built big collars are used.

In the case of idling noise produced by a circular saw, two radiation mechanism have been explicitly described. One of them due to a forced or resonant answer of the saw and the other caused by the interaction of the turbulent air and the peripheral area of the saw.

In many occassions, it is spoken about aerodynamic noise to refer exclusively to the noise associated to an idling saw, that is, rotating freely in its own plane, excluding the resonant answer (2).

The sound of pure tone radiated by a resonating saw has been directly associated to the natural vibrating modes of the saw. This relationship can be illustrated when comparing a vibration spectrum and a noise one for a resonating idling saw.

The aerodynamic noise is characterized in its frequency spectrum by a relatively wide peak with a central frequency that increases when the rotating velocity goes up. Finally, something important to observe in almost the majority of these studies is that their hypothesis have been tested in circular disks with peripheral cuts, artificial saws with spiring form contour and using a variety of teeth models and big thicknesses of saws. However these outcomes may not become applicable to any real saw. Furthermore, as in our case, where circular saws are not manufactured in Chile but they are all imported, any possibility of modifying some aspects of saws is discarded from the begining. Hence as users and not as manufacturers, a research was done in order to study the sources of noise that produce acoustic pollution in commercial circular saws available in the local market. Experiments on vibration and noise were developped in an anechoic chamber designed and built exclusively for this work, over a set of thirteen saws classified in groups according to their diameter, thickness, number, height and area of teeth.

MEASUREMENT OF VIBRATION AND NOISE. LAW OF SOUND PRESSURE LEVEL. NOISE SPECTRUM. RADIATION PATTERNS.

In the existing literature about this topic it has been stated that the model of aerodynamic source of noise is dipendable of an exponent of the peripheral velocity of the saw. The Sound Pressure Level, Lp, should increase theoretically 18 dB per each twofold of the rotation velocity. The idealized model of noise source depends on the design of the saw including the teeth geometry. The deviation of the theoretical law of 18 dB per each twofold, has to do with the specification of the source of noise and the receiver. That is if the size of the source is small or big, compared with the length of the sound wave itself.

If it is small, it is significant to imagine that the sound comes from a source and to consider the source characteristics. But, if the source region is not small compared with the wavelength, there is a possibility that diffraction effects which determine that the coupling of the source to the radiated sound, were so important for them to dominate the problem. It is likely to be the case, in fundamental aspects of the noise of circular saws. The exponents of peripheral velocity reported in literature are shown in Table I.

Reference No.	n exponent
3	4.9 - 6
4	5.6
2	5.25
5	4.9 - 5.5
6	5.37
7	4.9 - 5.6
8	4.65 - 6
9	5.0 - 5.6

Table I. Variation of the n exponent of the peripheral velocity.

In the present work, logical difficulty associated to the making of experimental comparisons with more than one parameter in circular saws, commercially available, guided to the selection of a group of thirteen different typical circular saws of commercial use. Three of them were modified in their geometry in workshop so as to be able to get a wider set of saws and in this way to experimentally evaluate major design alternatives. The saw in normal operation will vibrate by all means and that vibration is important at the moment to establish the Level and character of the sound. That was the reason why none of the test saws used was damped.

The study of vibrations was done with the purpose of measuring the natural frequencies in stationary saws and the resonating frequencies in rotating saws. With them there was the intention of being able to establish relations between the geometrical and operating parameters.

Summing up, in Table II and III the geometrical characteristics of each of the saws and groups of the study are shown.

Saw	Diameter mm	Thickness mm	No. of teeth	Height of teeth mm	Area of teeth x10^{-5} mm^2
A	350	1.8	80	8.4	4.5
B	200	1.75	72	7.3	2.8
C	307	2.75	80	6.8	3.4
D	184	1.35	200	1.9	0.2
E	184	1.35	150	2.2	0.3
F	184	1.35	150	1.8	0.3
G	184	1.35	40	8.5	6.1
H	229	2	28	7	8.4
I	229	2.75	28	5.2	9.6
J	229	2	28	12	15.8
K	235	2.75	16	4.8	16.8
L	235	2.75	30	4.8	10
M	235	1.25	100	4.8	1.5

Tabla II. Geometrical characteristics of the circular saws.

Group	Saws	Characteristic in common
1	A, B, C	Teeth geometry
2	D, E, F, G	Diameter
3	H, I, J	No. of teeth
4	K, L, M	Height of teeth

Tabla III. Classification by saw groups.

The rotational velocity that was tried with the saws, varied between 1000 and 3000 rpm. This corresponds to a range of border peripheral velocity of 10 to 52 m/s, depending on the saw diameter. In this way, the evaluation was done in a range of operating velocities found during the practice. The dimensions of the anechoic chamber used to measure the sound directly from the sources of sound are 2.5 m x 3 m x 2.2 m. The poliuritanum flexible foam stakes used to cover the walls, floor and ceiling of the chamber eliminated the reverberating sound over a cut frequency of 160 Hz, approximately. A frequency converter connected to an electric motor allowed to vary the motor velocity in the determined range. The conducting motor was placed out of the anechoic chamber to minimize its contibution to the noise inside the chamber.

The saw vibrations were measured with a non contact displacement transducer, and the noise levels were got by placing a measuring microphone with a 12.7 mm diameter (B&K) in the several positions inside the chamber. The signal captured by the microphone was incorporated to a Sound Level Meter (B&K). The vibration and noise signals were digitalized by a converse A/D card and processed by a DSP card installed in a personal computer.

RESULTS

The experimental results of the values of natural frequencies show that the geometrical parameters, diameters, teeth height and teeth area, condition the modes of vibrating and its natural frequencies. The saws with bigger diameters were excited up to the twentieth mode approximately (saws A and M). In smaller saws, the exciting did not overcome the eleventh mode (saws B, D, E, F, G). The natural frequencies became strongly related to the corresponding diameter. A strong inverse dependence between the natural frequencies of the saws and the diameters was noticed, that is to say, as the diameter increased, the values of the frequencies decreased. In the saws D, E, F, and G, the values of the natural frequencies showed an increase proportional to the height of teeth. In the saws K, L, and M the values of natural frequencies showed an increase proportional to the thickness. If we compare only the saws K and L the values of the natural frequencies turned to be independent from the number of teeth up to the three first modes.

From the spectrum obtained during the experimentation with rotatory saws paires of resonance frequencies could be appreciated, this means, two peak frequencies very close together, corresponding to the different modes of vibrating. It was interesting to observe the separation of one from the other in the pairs of resonance frequencies due to the rotation velocity. When those frequencies inpairs were compared with the values of the corresponding natural frequencies, it was found that these under a determined mode of vibrating came apart uniformously, increasing and decreasing in relation to the values of the natural frequencies. These pairs of resonace frequencies showed a linear behaviour with the rotation velocity. One of the components of the pair increased proportionally with velocity, while the other behaved inversely. According to the results and to current literature, those frequencies would correspond to the frequencies of two waves generated by rotation which would move in directions following the rotation and opposing it. Figure 1 shows these results for saw I.

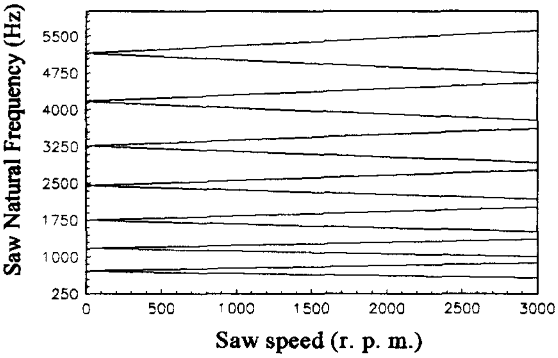


Figure 1. Effect of the increase of the rotation velocity (rpm) over the natural frequencies (stationary) of vibration corresponding to saw I.

On the basis of sound measurement it could be established that the rotation velocity is the parameter which mostly affects sound radiation. The parameters of the design of the saw such as the number of teeth, teeth height, teeth area and diameter are directly related to the values of fluctuating sound pressure.

However, its contribution to the total noise was not so meaningful as the increase in the Sound Pressure Level, Lp, due to the duplication of the rotation velocity (rpm). The variation of the Lp in dB, (ref. $2x10^{-5}$ N/m^2) according to an exponent of the peripheral velocity, U, fluctuated between 4.04 and 5.52 approximately. This produced increases of 12.2 dB to 16.6 dB in the Lp, due to the duplication of peripheral velocity, U. Figure 2 show these results for the different saws in groups. In Figure 3 (a), we can observe that in the case of saws with equal teeth geometry, but different diameters, Lp increases as the diameter increases. In Figure 3 (b), we can see the effect of the increase of the area of the saws over Lp. This group of saws of equal diameter, in which saws D, E, F had teeth with very small areas compared to saw G, shows a clear increase of the Level of saw G over the others. In Figure 4 (a), it is possible to observe the influence of the height of teeth over the Sound Pressure Level Lp. In the case of saws H, I, J with equal diameter and equal number of teeth it can be observed that as height increases, Lp increases too. The effect of the increase of the number of teeth over Lp is clearly seen in Figure 4 (b). In it, we can observe the increase of the Level as the number of teeth increases. The saws K, L, M had equal diameter and equal height of teeth. The spectrum of the sound radiated by the saws tended to be narrow over a characteristic frequency peak. Figure 5 exemplifies this for saw I. Experimentally it could be verified that the peak frequency resulted numerically equal to a constant times the rotational velocity of the saw in revolution per minute (rpm). For the saws B, C, G, I, J, K and L, these constants resulted in B = 0.72; C = 0.7; G = 0.85; I = 0.34; J = 0.95; K = 0.8; and L = 0.58. This constant is directly proportional to the diameter and inversely proportional to the thickness. Figure 6 shows that in saws B and K the characteristic acoustic frequencies resulted proportional to the peripheral velocity and inversely proportional to the thickness.

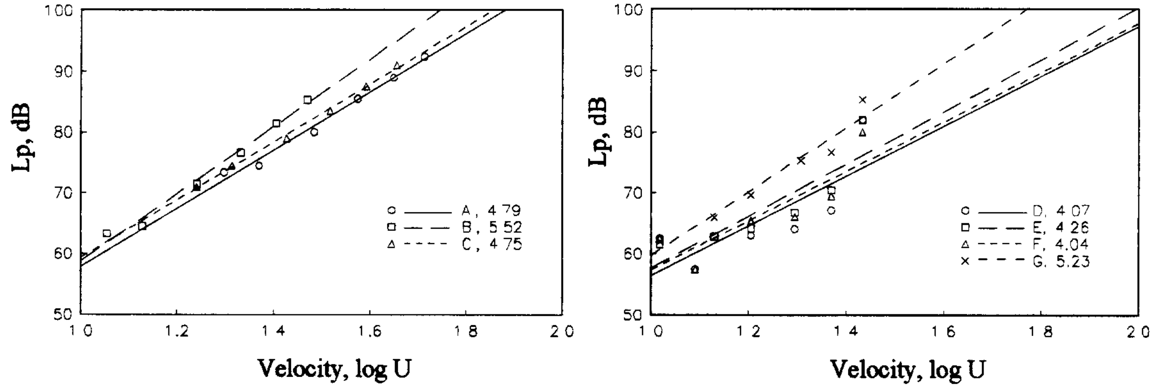
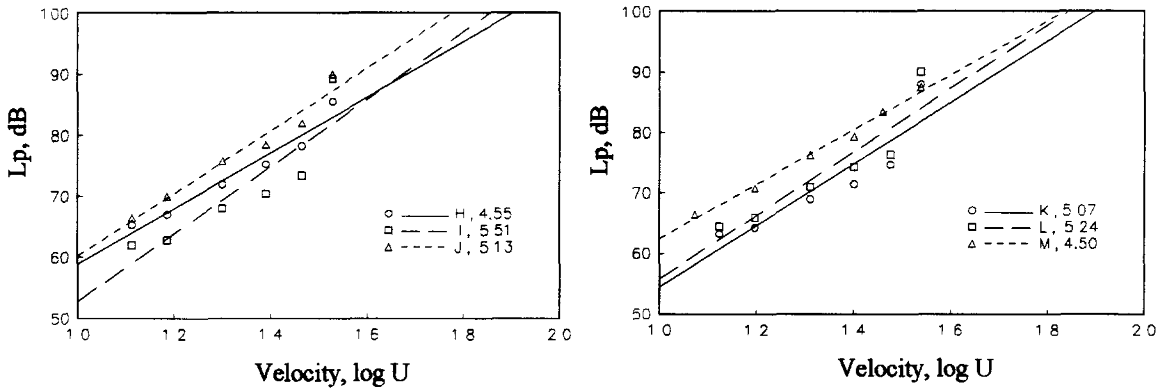


Figure 2. Sound Pressure Level, Lp, dB - Peripheral Velocity, U, (log U), for the diffrent saws in groups.



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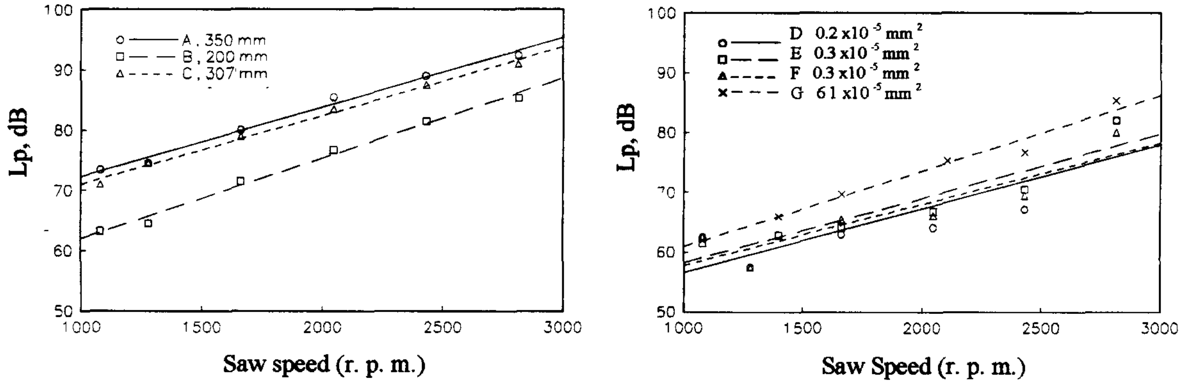
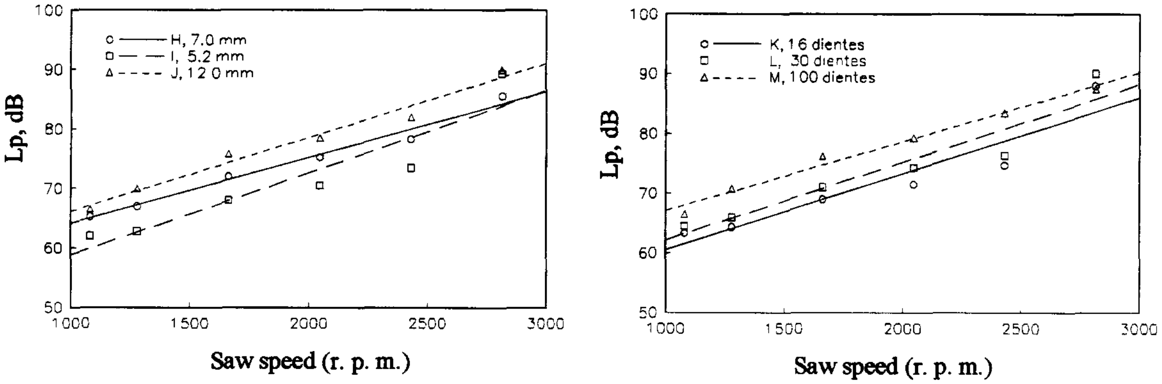


(a)

(b)

Figure 3. (a) Effect of the diameter over Sound Pressure Level Lp. (b) Effect of the area of the teeth over the Sound Pressure Level Lp.



(a)

(b)

Figure 4. (a) Effect of the height of the teeth over the Sound Pressure Level Lp. (b) Effect of the number of teeth over the Sound Pressure Level Lp.

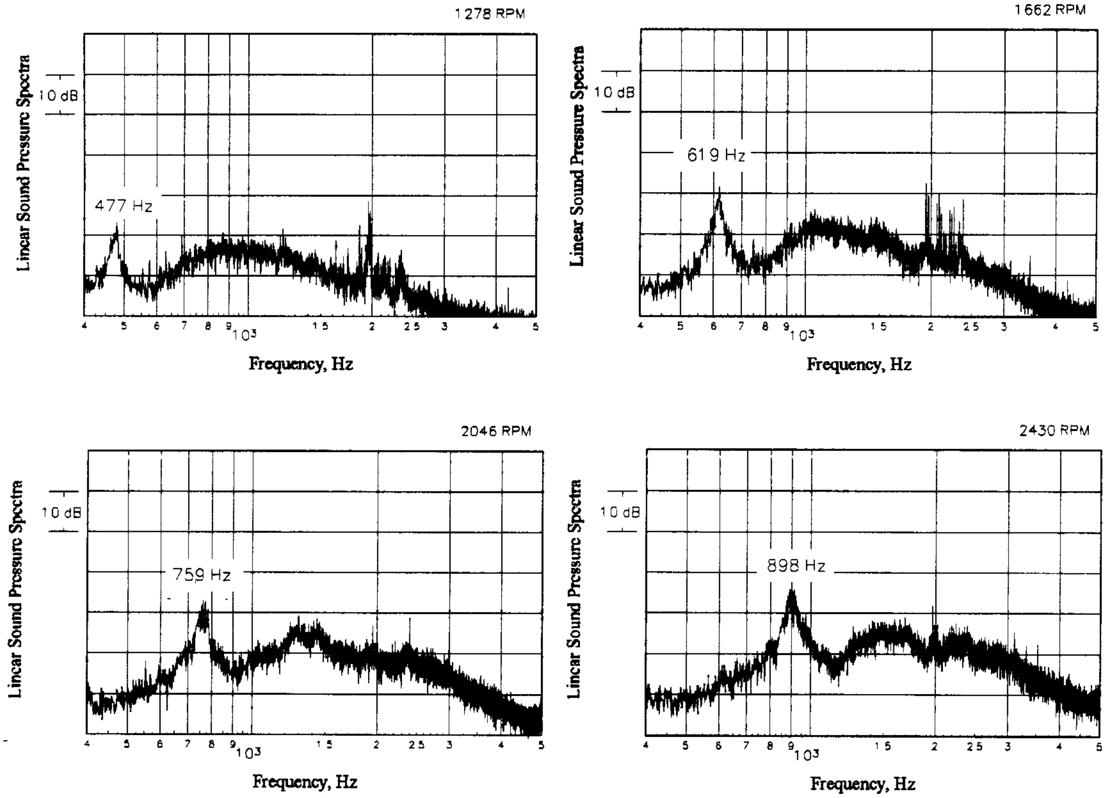


Figure 5. Spectral content of the sound field radiated by saw I.

The directional distribution of the acoustic field was measured at different velocity for all the saws. We observed minimums of Lp in the plane of rotation of the saw and maximums in the direction of the axe of the saw. No remarkable differences between the various saws were noticed, which demostrates that the directional distribution of the acoustic field is not dependant either on the size of the saw, the number of teeth, the area of the teeth or the height.

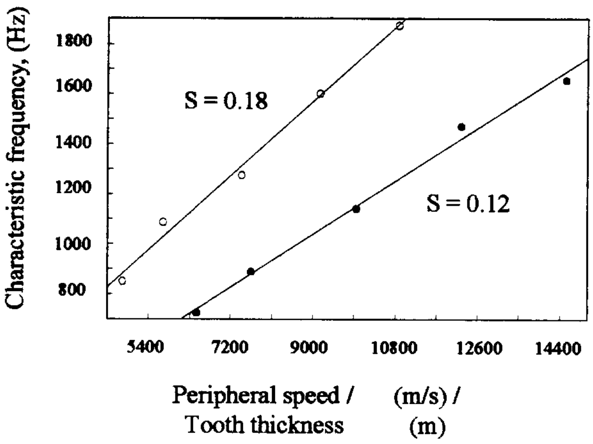


Figure 6. Characteristic acoustic frequencies of the spectrum radiated by saws B and K. For saw B, S = 0.12, and for saw K, S = 0.18. S is the constant for proportion, commonly refered to as Strouhal number.

CONCLUSIONS.

The main results of this research are:

1) The geometrical parameters, diameters, teeth height and teeth area, condition the modes of vibrating and its natural frequencies.
2) The rotation velocity of the saw affects the natural frequencies of vibration.
3) The rotation velocity of the saw is the parameter that mostly affects the radiation of sound.
4) The fluctuating sound pressure depends on the geometry of the teeth, the number of teeth, the height and the area of teeth. These experimental results confirm the type of model of theoretical source described by literature. The sound field is being generated by punctual dipolar pressure acoustics sources. The patterns of directivity, the dependance of the velocity and the linear spectrum suggest dipolar sound radiation.
5) The law of proportion characteristic of exponent 6 for the border peripheral velocity varied between the values 4.04 to 5.52. The angular dependance of the distribution of the acoustic field confirms a dipolar characteristic of sound radiation. The supposed linear relation between the characteristic peak frequency of the spectral content of the field sound and the velocity of the saw could be noticed very clearly. The value of these dipolar frequencies fluctuated between 0.08 and 0.18 (values of the Strouhal number for all the saws) times the reason between border peripheral velocity and thickness.
6) When the operating velocity is reduced to the half, a reduction of about 16 dB in Lp could be obtained. Among the others possible alternatives to reduce the Level of noise we can consider at the moment of selecting a saw diminishing the area and height of teeth, diminishing the number of teeth and the diameter of the saws.

ACKNOWLEDGEMENTS

The authors want to offer their thanks to FONDECYT 1951155, DID UACH F-95-15 and DID UACH F-96-09. The authors also thank Prof. Gloria Ramirez and Prof. Lidia Labra for their assistance with the manuscript.

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