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EFFECT OF LASER-CUT SLOTS ON THE RADIATED NOISE OF IDLING CIRCULAR SAW BLADES

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INTRODUCTION

Noise radiation from idling circular saw blades has been the focus of several investigations [1-8] where attempts have been made to identify noise generation mechanisms, to correlate measured noise, vibration and pressure fluctuations, and to determine the effect of blade kinematics. Recently Leu and Mote [7] concluded based on an experimental investigation that the vortices separating from the edges of the cutting teeth are the dominant source of surface pressure fluctuations and aerodynamic noise, and that the vortex shedding mechanism is controlled by blade geometry and teeth cascade.

The primary purpose of a radial edge slot is to allow thermal expansion during the cutting process without developing circumferential stresses. Often, in practice, a hole is also cut at the end of the slot in order to relieve radial stress introduced by the slot and to prevent propagation of a potential crack. Mote and Szymani [3] have reported that the effect of slots on noise and vibration are yet to be demonstrated conclusively as available literature contains conflicting reports. For instance, McKenzie [10] has shown that uniformly spaced narrow slots improve dynamic stability, and Malcolm [11] contends that the radial edge slots reduce "screaming" noise; conversely, Barz [12] states that such slots are ineffective and instead recommends annular slots near the hub.

OBJECTIVES

In general the saw blade industry [13] recognizes the importance of slots and therefore blades have been available with several radial, uniformly spaced milled slots. Moreover, at the end of each slot a hole has normally been cut which then is plugged with a copper insert as the general notion has been that this practice helps in reducing noise. In technical literature, however, we could not find any evidence to support this general idea.

Since the sponsors of this study have been manufacturing carbide tip saw blade bodies using a computer-aided laser machine, the idea of cutting patterns with lasers instead of milling slots obviously came up. Accordingly, we decided to conduct a comprehensive experimental study of the effect of radial slots on noise from idling circular saw blades. Also, a modal analysis experiment was conducted on a blade without any slots and on a blade with laser-cut slots in order to examine the problem from structural view point.

Overall 6 blades as listed in Table I have been evaluated. Only 4 equally spaced radial cuts, whether milled or laser cut, have been considered. Fig. I shows typical slots.

TABLE 1. Identification of Saw Blades Tested

Specification: Carbide saw body, zero hook on the teeth, teeth slant depth = 19mm, with carbide tip slots, outside diameter = 303.2mm, inside diameter = 15.87mm, clamp diameter = 44mm, blade thickness = 3.4mm and number of teeth = 80. (See Fig. 1)

Saw Blade No.	Description
B1	Saw blade - without any slots
C1	Saw blade with 4 radial, equally spaced milled slots (length L =19.05 mm) and open holes (see Fig. 1a)
C2	With 4 radial, equally spaced milled slots (L = 19.05mm) and holes plugged with copper inserts
D1	Saw blade with 4 radial, equally spaced laser cut slots (L =19.05mm) and milled, open holes
D2	With 4 radial, equally spaced laser cut slots (L =19.05mm) and holes plugged with copper inserts
D3	With 4 radial, equally spaced laser cut slots (L = 19.05mm), terminated in a spiral manner (see Fig. 1b).

MEASUREMENTS

Radiated Noise. All saw blades were run, without protective cover at the Dewalt Standard radial arm machine, at the rated speed of N = 3450 rpm. Free field sound pressure (L_p) was measured in the far field at r = 1.52 m. The following database was acquired; (i) octave band spectra and overall level L_{pA}, (ii) narrow band frequency spectra, L_p (unweighted) over 0-10 kHz with 25 Hz frequency resolution and (iii) directivty patterns.

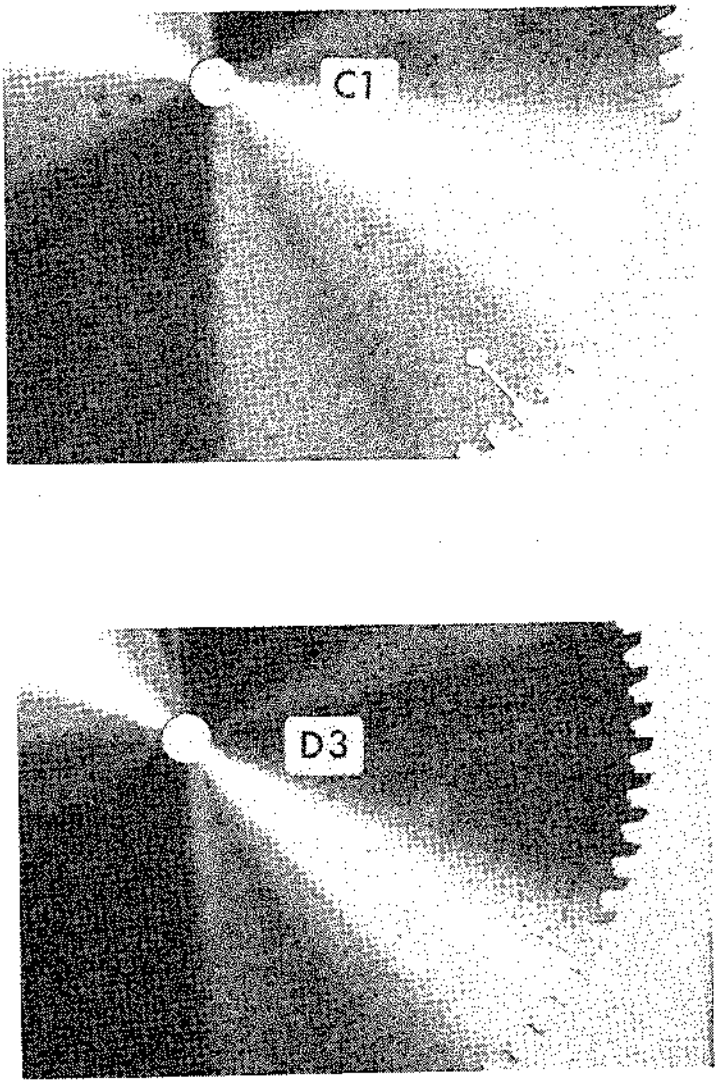

Fig. 1 Saw blade with radial slots. Overall there are 4 equally spaced slots, however, only one is shown here for clarity. a. milled slot, without copper plug (#C1). b. Laser cut slot (#D3). Refer to Table 1 for more details.

Structural Modal Analysis. Initially 40 measurement locations were chosen for Blade #B1 on the outer circumference in order to identify the circumferential mode, given by m number of nodal diameters. Then, a quarter segment of the blade was examined with 16 points described along an arc and a radial line in order to determine the radial pattern given by n number of nodal circles. The same experiment was repeated for Blade #D3. Over the frequency range of interst (0-4 kHz), natural frequencies, modal damping ratios (ζ) and modes (m,n) were determined.

RESULTS AND DISCUSSION

Vortex Shedding Fig. 2 shows the narrow band L_p spectrum for blade #B1. Here we note several dominant frequencies. To identify these we compute the vortex shedding excitation frequency f_e in Hz as: $f_e = \pi SdN/60t$ where d is the blade diameter, t is the thickness, N is the running speed in rpm and S is the Strouhal's number; for idling saw blades S = 0.1-0.2, depending on blade geometry and teeth cascading [1-7]. For our example case S is likely to be about 0.16-0.18 i.e. f_e is expected to be within 2572-2894 Hz range. Fig. 2 confirms it as we note 3 dominant frequencies which are all explained by the vortex shedding mechanism f_{e1} = 2825 Hz, f_{e2} = 2650 Hz, and $2f_{e1}$ = 5650 Hz. The directivity patterns associated with blade was measured to be dipole-like which confirms analysis by Mote and Zhu [8].

Radiated Noise Table 1 lists free field sound pressure levels for blades with and without equally spaced, four radial slots. The dominant octave bands for blades #B1 are 2 and 4 kHz which are also evident from narrow band spectrum shown in Fig. 2. These bands virtually contain all the energy level as indicated by circumferentially averaged overall $\overline{L}_{pA}$. The radiated noise from blade #B1 is whistling type, very loud and the main vortex shredding frequencies are within the sensitive range of the human ear. Thus the noise from this blade is extremely annoying and possibly damaging to the ear.

Table 1 also shows that the introduction of milled slots, especially holes plugged with copper inserts (#C2), helps in reducing noise drastically. Such lower levels are also achieved by blades #D1-3 which employ laser-cut slots. In fact the blade #D3 which contains only laser cut slots is as good, if not better, as any other slot geometry tested thus far.

Fig. 2 also compares narrow band data for blades #B1, C2, and D3. This figure shows that the slots essentially "dampen" the acoustic response excited by the vortex shedding mechanism.

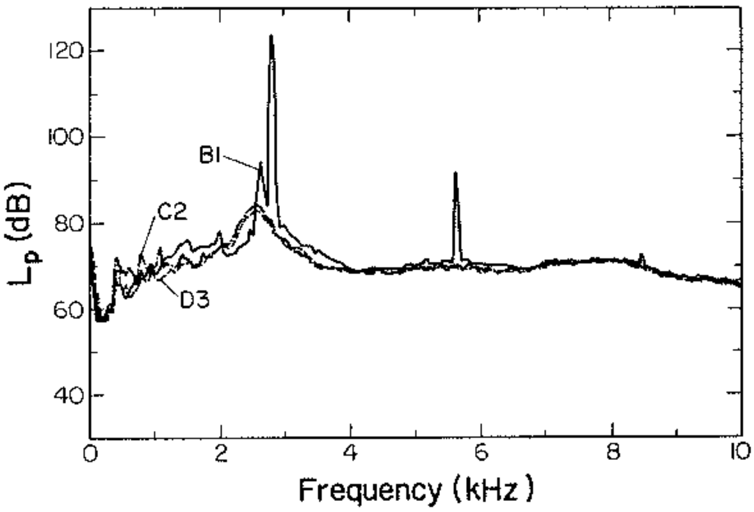

Fig. 2 Narrow band frequency spectra of free field sound pressure level L_p (unweighted) at $r = 1.52$m, $\theta = 30°$ where θ is measured from the plane of the blade.

a. Saw blade #B1 (without slots ——),

b. Saw blade #C2 (with milled slots and copper plugs — · —), and

c. Saw blade #D3 (with laser cut slots -----).

Modal Analysis Based on the coarse measurement grid certain trends and observations are evident. 1. The modes in the frequency range of interest (2500-2800 Hz) seem to be (7,0), (7,1), (8,0) and/or (8,1), i.e. there are 7 to 8 nodal diameters along with a possible nodal circle. 2. Natural frequencies are drastically altered by introducing radial slots. 3. Modal damping ratios as shown in Fig. 3 for blade #D3 are much higher than those measured for #B1. In fact, over the frequency range of interest the introduction of laser cut slots have increased damping by a factor of 7 to 10 times. Based on this alone one can predict that the resonant response should be lowered by at least 15-20 dB which is demonstrated by the radiated noise data of Fig. 2 and Table 2.

Table 2. Comparison of Saw Blades for Radiated Noise

Blade #	Averaged overall $\overline{L}_{pA}$	L_{pA}, dBA at r = 1.52 m octave band levels, at θ = 30° 1kHz	2kHz	4kHz
B1	107	67.5	103	104
C1	99	67.5	99	90
C2	78.5	61	78	72
D1	81	59.5	77	72
D2	79	50	78	72
D3	78	61	76	71

CONCLUDING REMARKS

This study has shown that radial edge slots can dampen vortex shedding controlled noise in idling circular saw blades. Further, it demonstrates that the slots can be completely cut with laser which obviously is a more efficient manufacturing solution. Currently work is in progress where alternative slot geometries, numbers, and arrangements are being examined. The intent is to optimize the saw blade for minimum noise and improved cutting stability.

ACKNOWLEDGEMENT

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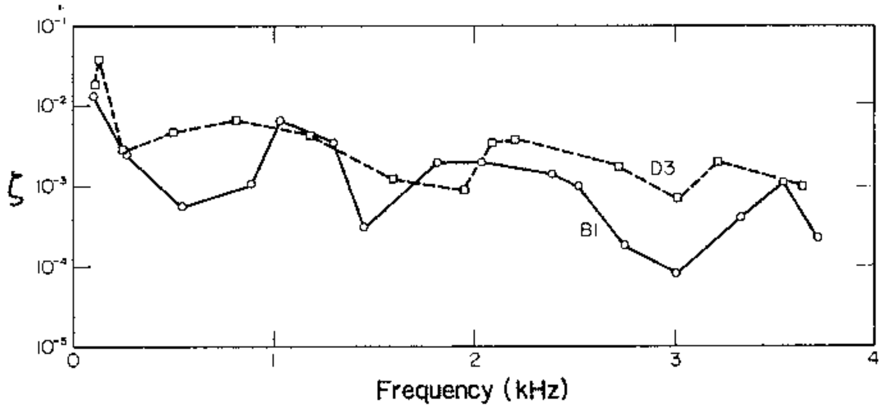

Fig. 3 Modal damping ratios of saw blade #B1 (without slots —o—) and #D3 (with laser cut slots ---□---).

REFERENCES

1. Dugdale, D.S., Journal of Sound and Vibration, Vol. 10, 296-304, 1969.

2. Reiter, W.F. and Keltie, R.F., Journal of Sound and Vibration, 44, 531-543, 1976.

3. Mote, C.D., Jr. and Szymani, R., Shock and Vibration Digest, 10 (6), 15-30, 1978.

4. Cho, H.S., and Mote, C.D., Jr., Journal of Acoustical Society of America, 65, 662-671, 1979.

5. Mote, C.D., Jr. and Leu, M.C., ASME Journal of Dynamic Systems, Measurement and Control, 102, 114-122, 1980.

6. Price, K. and Mote, C.D., Jr., Journal of Acoustical Society of America, 71, 748-750, 1982.

7. Leu, M.C. and Mote, C.D., Jr., ASME Journal of Vibration, Acoustics, Stress, and Reliability in Design, 106, 434-440, 1984.

8. C.D. Mote, Jr., and W.H. Zhu, ASME Journal of Vibration, Acoustics, Stress, and Reliability in Design, 106, 441-446, 1984.

9. Mote, C.D., Jr., ASME Journal of Dynamic Systems Measurements and Control , 94 (1), 64-70, 1972.

10. McKenzie, W.M., Wood Science, 5, (4), 304-311, 1973.

11. Malcolm, F.B., World Wood, 3, 10-11, 1972.

12. Barz, E., Holz RohWerkstoff, 23 (12), 484-491, 1965.

13. Personal conversations with the Peerless Saw Company personnel and their customers.