LETTERS TO THE EDITOR

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Compensating for miter bends in cylindrical tubing (L)

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Miter bends in cylindrical tubing perturb wave propagation in a way that may alter the desired resonance properties in musical instruments. The nature of the perturbations and several methods of compensating for them at low frequencies are described. © *2007 Acoustical Society of America.* [DOI: 10.1121/1.2713669]

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I. INTRODUCTION

The air columns of many wind instruments, and some pedal organ pipes, are folded to shorten the instrument. The folds are usually formed by toroidal bends. Nederveen[1] has analyzed the effects of such bends and shown how to compensate them. Toroidal bends are difficult to produce. Amateur wind instrument makers can much more easily make mitered bends, where the tubing is cut at 45 deg and reassembled to make a 90-deg bend. Dequand *et al.*[2] have calculated and measured the reflection coefficients of such bends, but have provided no information on how they may be compensated. The present letter presents methods for compensating miter bends in cylindrical tubing.

II. MITER BEND EFFECTS

A miter bend section is defined by the two planes perpendicular to the axes and intersecting at the inside inner corner of the bend. The physical length of the section is measured along the centerlines and is equal, for a 90-deg bend, to the tubing ID, its inner diameter. The volume, and therefore the compliance, of a mitered section is unchanged from that of a straight section of the same length. Vibratory motion, however, takes a shortcut around the bend, the flow lines being more concentrated toward the inside corner. Thus the inertance is reduced, and the characteristic impedance of the section is altered. When such a bend is located at a pressure maximum in a resonant tube, there is no effect, but if it is located at a pressure minimum the section appears acoustically shortened. The measurements of Dequand *et al.*[2] on a 90-deg bend correspond to a shortening at low frequencies by a factor of 0.61—this is consistent with my own measurements. The technique I used to measure the effects of compensation was to compare resonance frequencies of tubes in which the bend was located close to a pressure maximum with those in which the bend was located near a pressure minimum. These techniques are described in detail by Coltman.[3] Experiments were done with plastic tubes, though the results are applicable to metal.

III. COMPENSATION

Compensation to restore the characteristic impedance to that of the straight tube can be obtained either by increasing the inertance to match the compliance, decreasing the compliance to match the inertance, or both. The acoustic length of the section may thereby be shortened, which must be accounted for in the instrument design.

In Fig. 1(a), the first method, the inertance has been increased by making a saw cut of depth h at 45 deg in the inner corner and inserting a thin card (in the experiment a plastic card of thickness 0.04 ID was used) and cementing it

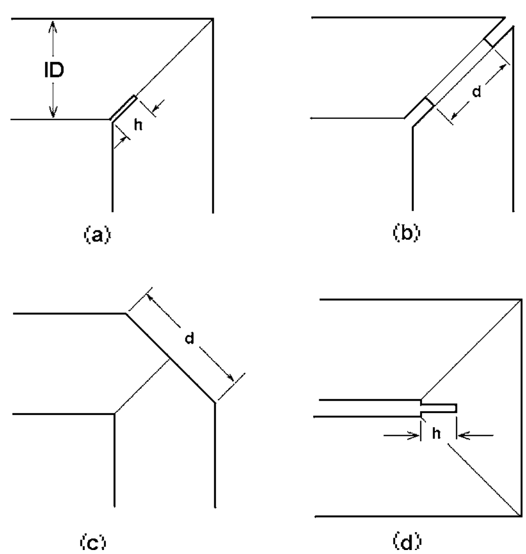

FIG. 1. Methods to compensate miter bends. Only inside dimensions shown.

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in place. The proper value to achieve zero reflection is $h = 0.35$ ID. The edge of the card is preferably rounded to reduce turbulence. The acoustical length of the section is essentially equal to the physical length.

An alternative method is shown in Fig. 1(b). Here a disk of thickness 0.1 ID contains a round hole of diameter $d = 0.87$ ID and is cemented between the tubes as they are joined. Rounding of the edges to reduce turbulence is recommended. The compensation will depend somewhat on the thickness of the disk, but since the hole is not far in diameter from that of the tubing, the effect will not be large; a variation from 0.05 to 0.15 ID probably would not change things much. The acoustic length of this section is close to the distance measured along the centerlines.

In Fig. 1(c), the compliance has been reduced, and the inertance somewhat increased, by beveling the miter and closing the hole with a plate. The dimension d is that of the long axis of the near-elliptical hole created by beveling the miter; its proper value is $d = 1.26$ ID. The acoustical distance around the bend is shortened by 0.32 ID.

A 180-deg bend or fold can be produced by two successive 90-deg bends, the tightest fold being that when the outside walls of the tubes are in contact, as shown in Fig. 1(d). I found that the acoustic shortening due to this assembly was not much different than the sum for two distant 90-deg bends, so wall thickness of a tight bend can be ignored as a variable. Here compensation can be provided by a segment of a disk inserted into the center of the bridging tube. The proper segment was found to have a height that depended on its thickness t, the proper value being $h = 0.49\ \mathrm{ID} - 0.5t$. The acoustic length of this assembly will be shortened by about $0.4t$.

Finally, the double bend can be compensated by beveling each miter as was done in Fig. 1(c). This is probably the most esthetically pleasing arrangement for a fold. Because of the interaction of the close bends, the proper value for d is not the same as in Fig. 1(b). I found it to be $d = 1.33$ ID, and the acoustic shortening of the assembly to be 0.69 ID.

IV. CONCLUSION

Compensation of miter bends can be readily accomplished. The numbers given here are estimated to be applicable for practical purposes to wavelengths greater than four times the inside diameter of the tubing.

[1] C. J. Nederveen, "Influence of a toroidal bend on wind instrument tuning," J. Acoust. Soc. Am. **104**(3), 1616–1620 (1998).

[2] S. Dequand, S. J. Hulshoff, A. Ayregan, J. Huijnene, R. ter Riet, L. J. van Lier, and A. Hirschberg, "Acoustics of 90 degree sharp bends. Part 1: Low-frequency response," Acta Acust. **89**, 1025–1037 (2003).

[3] J. W. Coltman, "Acoustic properties of miter bends," http://ccrma.stanford.edu/marl/Coltman/Papers.html, item 1.44, December 2006, 188kB, PDF (archived), viewed 4/6/2007.