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NOTES ON THE ROTHENBERG MASK

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Abstract

The aim of this study was to assess the limitations of the Rothenberg mask for flow measurements at high frequencies. Both the flow response of the mask and the possible distortion of radiated speech recorded outside the mask were investigated. It was found that the flow amplitude response is consistent up to 1 kHz. A pronounced zero at about 1.5 kHz restricts the useful range to well below this frequency. The speech signal radiated through the mask was not distorted for frequencies below 1 kHz. Above this frequency an overall attenuation of the amplitude was found in combination with a slight peak at about 1.3 kHz and a slight valley between 2 and 2.5 kHz.

To conclude, the Rothenberg mask is a useful device for measurements of air flow up to 1 kHz. For higher frequencies a sound pressure recording should be used. If this recording is done simultaneously with a mask recording, the distortions introduced by the mask need to be taken into account.

INTRODUCTION

In many studies of source characteristics the flow measured at the lips is of great interest. One way to measure this flow is to use a "circumferentially vented pneumotachograph mask" as designed by Rothenberg in 1973. This device has been used to obtain the flow in many experiments (see for example Badin, 1989; Gobl & Ní Chasaide, 1988; Hertegård, 1989; Holmberg, Hillman, & Perkell, 1988; Karlsson, 1985; 1988). The aim of this study was to assess the limitations of such a device, concentrating on frequencies above 100 Hz, with respect to both the flow response of the mask, and a possible distortion of the radiated speech sounds.

The principle of a pneumotachograph mask is to measure the pressure drop across a fine metallic or nylon wire screen of known acoustic resistance through which the unknown flow is directed. The Rothenberg mask consists of a face-mask in which a number of holes are drilled (Rothenberg, 1973). The holes are covered with a steel wire screen. The edge of the mask is equipped with a rubber joint to avoid leakage. A differential microphone with one input close to the wire screen inside the mask, and the other input close to the wire screen outside the mask provides a measure of the pressure drop across the acoustic resistance, and thus an estimation of the flow.

In the first section of the paper, tries are made to estimate the upper frequency limit of the flow response of the mask, which has not been studied thoroughly so far. The upper frequency limit is determined by the acoustics of the mask proper and by the properties of the wire screen, as well as by the characteristics and location of the differential microphone. The second section deals with the purely acoustic influence of the mask enclosure upon the radiation of the sound from the speaker's lips and nostrils. In the last section the consequences of these limitations on inverse filtering are discussed.

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1. SWEEP-TONE ANALYSIS OF THE FLOW RESPONSE OF THE MASK

This section reports our attempts to determine the limits of the flow response of the mask, i.e. the frequency transfer characteristics between a "flow excitation" and the mask response. The frequency transfer characteristics are determined by means of sweep-tone analysis.

In order to measure the frequency transfer characteristics of the system, the mask was excited by a loudspeaker driven by a frequency sweep of constant amplitude produced by a BK Heterodyne analyzer type 2010. The loudspeaker provided a sinusoidal flow with an amplitude that decreased with a constant slope of 6 dB/octave between at least 150 Hz and 1.5 kHz. The output voltage of the mask electronics was recorded on a BK graphic level recorder type 2307. The connection between mask and loudspeaker was realized through the ceramic adaptor provided by Glottal Enterprise, the maker of the Rothenberg mask.

1.1 Effects of the built-in filter

As a first step the characteristics of the output low-pass filter provided with the mask electronics were estimated. Using the peak amplitude at 160 Hz as a reference the amplitude of the filtered output is 2, 3, 5, 7, and 11 dB lower than the direct output respectively at 1, 2, 3, 4, and 5 kHz as can be seen in Fig. 1: this is a clear low-pass filtering effect. The valley at about 1.5 kHz is attenuated more than expected.

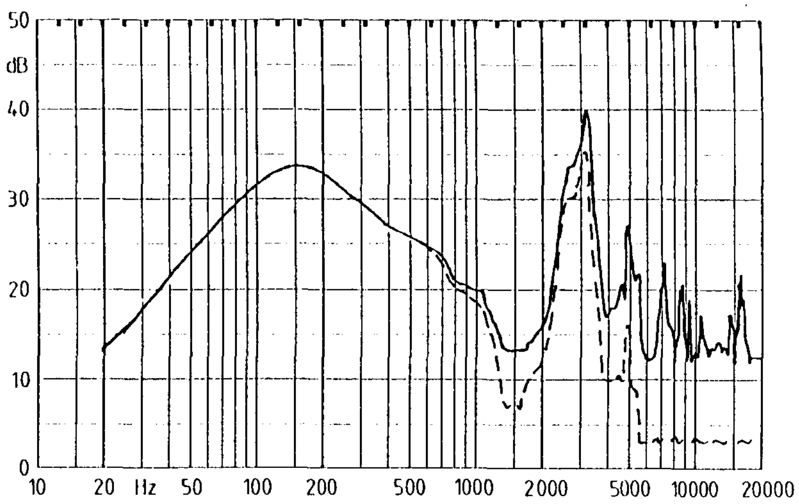

Fig. 1. *Flow responses for the direct output and the low-pass filtered output. Solid line: direct output; dashed line: low-pass filtered output. (Loudspeaker excitation, ceramic adaptor, no extra damping material).*

1.2 Effects of different damping conditions of the differential microphone

The flow frequency response of the mask can be modified by inserting extra damping material in either or both inner and outer inputs of the differential microphone. The damping material consisted of polyesther foam in this study. The effects of the additional damping was evaluated by measuring the flow response for different conditions. The results given in Fig. 2 show that:

(1) extra foam in the inner microphone input attenuates the peaks at 2.6 kHz and 3.2 kHz by respectively 5 and 15 dB; the dip at 1.7 kHz is moved toward 1.8 kHz;
(2) extra foam in the outer microphone input has almost no effect on the peaks at 2.6 and 3.2 kHz; the dip is moved toward 1.5 kHz;
(3) extra foam in both outer and inner microphone inputs attenuates the peaks at 2.6 kHz and 3.2 kHz by respectively 7 and 18 dB; the dip at 1.7 kHz is moved to about 2 kHz and the frequencies around 1.2 kHz are lifted approximately 7 dB.

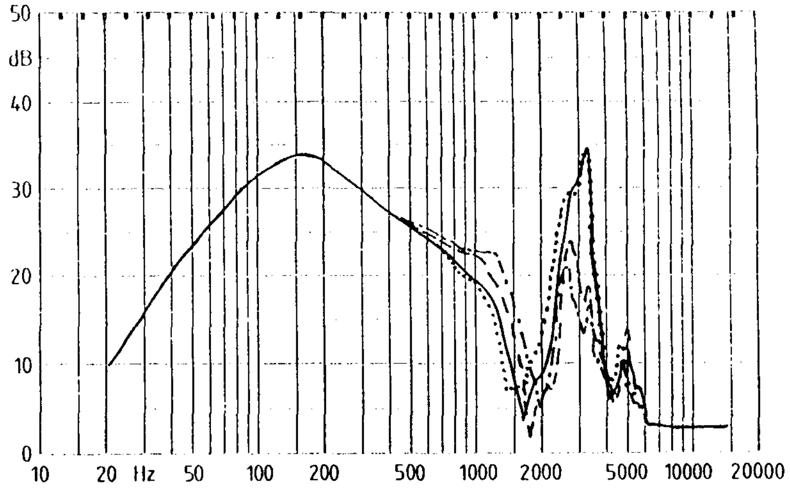

Fig. 2. *Flow responses for different foam settings. Solid line: original foam; dashed line: extra foam in the inner microphone input; dotted line: extra foam in the outer microphone input; dotted-dashed line: extra foam in both inner and outer microphone inputs. (Loudspeaker excitation, ceramic adaptor, low-pass filtered output.)*

The frequency response variations are within 3 dB below about 1 kHz. These results show that the mask response for higher frequencies is affected fairly much by the different damping conditions that were tried out. These changes are difficult to reproduce in a consistent way though: slight differences in the manner of compressing the foam in the microphone inputs can have fairly large consequences.

To verify that the previous results did not depend on the type of excitation chosen, i.e., the particular loudspeaker, these sweep-tone measurements were replicated using a mouth simulator as flow source. The BK mouth simulator type 4215 is a loudspeaker that is driven by a feedback loop so that the pressure measured by a microphone mounted at the centre of the device is kept constant during the frequency sweep. In the experiments described in this paper the flow created by the mouth simulator can be expected to show a constant slope between 200 and 1800 Hz. The mask was fitted to the mouth simulator using the ceramic adaptor. The results obtained led to the same conclusions as before about the effects of the extra foam conditions, the differences between the curves being due to the loudspeaker characteristics.

1.3 Effects of different adaptors

To make sure that the observed resonances are related to the mask itself rather than to the *ceramic adaptor*, experiments were made using also another type of adaptor, a *foam adaptor*, consisting of a thick ring of polyesther foam pressed between the edge of the mask and the mouth simulator to prevent acoustic leakage.

Since the sound pressure at the centre of the mask is kept constant, the driving voltage of the loudspeaker is directly related to the acoustic load on the loudspeaker, and thus to the acoustic resonances of the mask itself.

In this experiment the input voltage to the artificial mouth was measured for different load conditions: (A) no load, (B) air flow through the ceramic adaptor, (C) air flow directed through ceramic adaptor and mask, and (D) air flow through foam adaptor and mask. A clear peak can be seen at about 4.0 kHz for the two curves corresponding to the ceramic adaptor in Fig. 3: this may be related to the 3 cm long tube of the ceramic adaptor. This peak disappears for the foam adaptor.

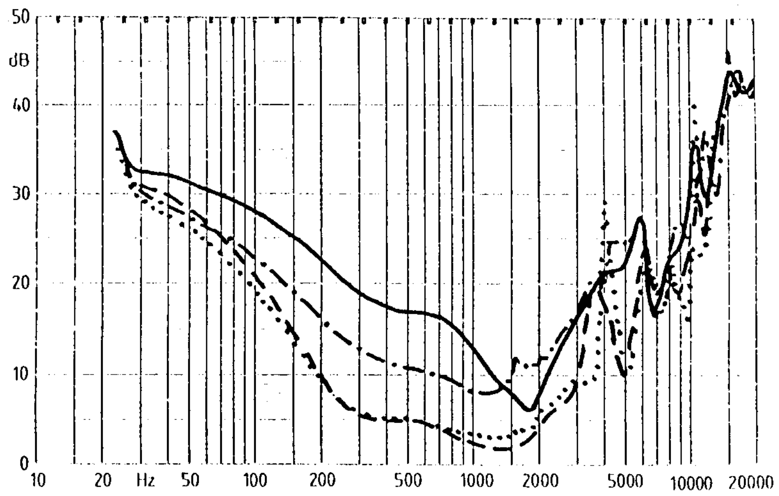

Fig. 3. *Input voltage to the mouth simulator with different acoustic loads. Solid line: no load; dashed line: ceramic adaptor; dotted line: ceramic adaptor + mask; dotted-dashed line: foam adaptor + mask.*

1.4 Conclusions

The experiments described above show that the flow amplitude response of the mask is consistently valid up to about 1 kHz, whatever the damping conditions of the differential microphone are. This is related to the presence of a pronounced zero around 1.5 kHz. We have not been able to determine the phase response of the flow, as it would be a very intricate process. Moreover, we assume that the response at very low frequencies, down to zero, is valid, since an approximately linear response was measured for static flows (Rothenberg, 1977).

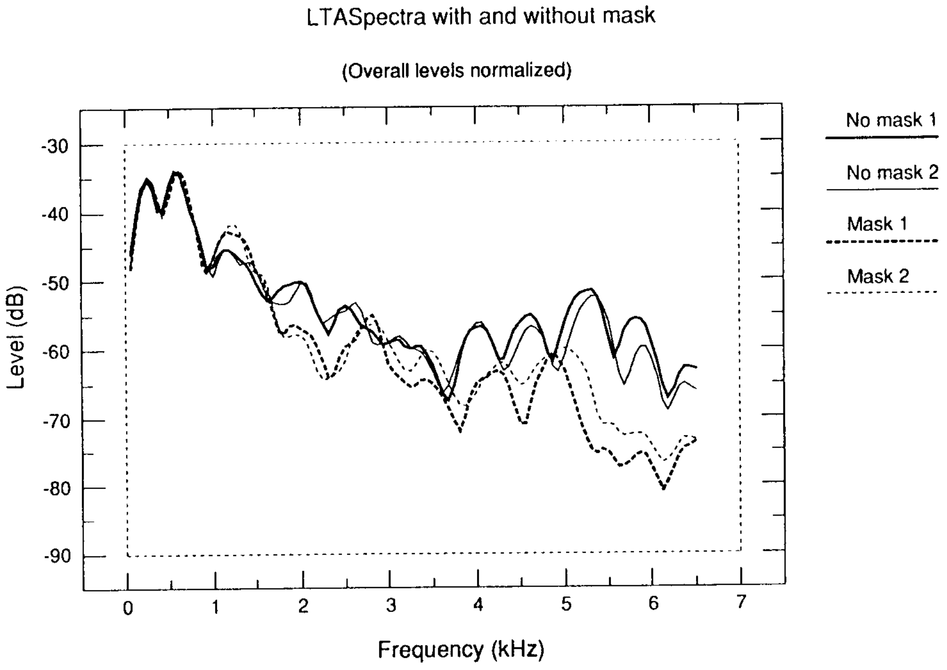

Fig. 4. *LTAS for the speech material. (Analysis bandwidth Bw = 250 Hz). Solid lines: recordings of the same fragment without mask. Dashed lines: recordings with mask.*

2. LTAS AND SWEEP-TONE DETERMINATION OF THE ACOUSTIC TRANSMISSION CHARACTERISTICS OF THE MASK

In order to evaluate the spectral distortion of the speech sound pressure radiated through the mask, i.e., the acoustic transmission characteristics of the mask, a 10 sec sentence was recorded with a BK condenser microphone placed at about 1 meter from a female subject. The recordings were done under two experimental conditions: subject (1) not wearing the mask and (2) wearing the mask. Two recordings were made for each experimental condition. The Long Time Average Spectra of the radiated pressure signal measured by the microphone for both conditions were computed and compared. Fig. 4 shows these spectra, computed with an analysis bandwidth of 250 Hz, normalized to each other with respect to overall relative Sound Pressure Level. For each experimental condition, the two recordings show spectra very similar to each other, which reconfirms the reliability of this method.

Fig. 5 shows the difference between the LTAS of the radiated sound pressure signals with and without mask. No noticeable distortion is introduced by the mask below 1 kHz. The distorted curve presents a 3 dB peak at about 1.3 kHz, and a 6 dB valley from 2 to 2.5 kHz. There is also a general tendency towards a weakening of the higher frequencies.

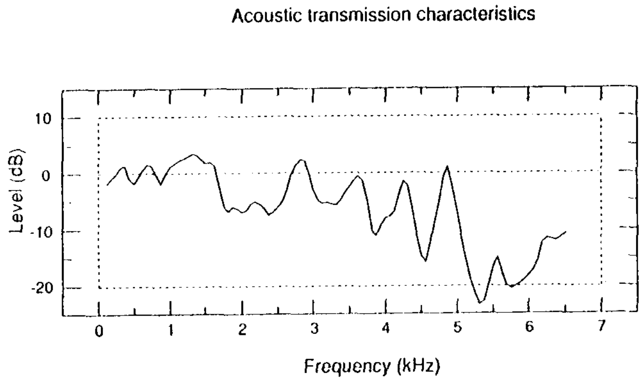

Fig. 5. Acoustic transmission characteristics of the mask (LTAS method). (Analysis bandwidth Bw = 250 Hz.)

These results should be compared with Rothenberg's measurements of the acoustic transmission characteristics of the mask (1973, Fig. 5, p. 1636). The general tendency for the lower frequencies is quite similar, with a peak at about 1.25 kHz, and a dip at about 2 kHz. Our results show less distortion, possibly due to the LTAS method, which could smooth out peaks and dips. The discrepancies could also be explained by the fact that our commercial version of the mask differs from the prototype described in Rothenberg (1973).

A conclusion from these results is that the radiated pressure recordings are reliable up to 1 kHz, but should be used with caution above that frequency limit. This reconfirms the results from the previous section.

3. CONSEQUENCES ON INVERSE FILTERED FLOW AND RADIATED PRESSURE

At the recording session for this experiment two different signals were recorded simultaneously. The Rothenberg mask and the flow microphone attached to it were used to record the flow and a BK condenser microphone placed one meter from the speaker recorded the speech pressure wave (i.e., differentiated flow). Both signals were registered on a DAT recorder with a bandwidth from 10 Hz to 20 kHz and no phase distortion. From these recordings the vowels /i/ and /a/ from the word /tiza/ were selected for inverse filtering. The inverse filtering was done using a computer program. The filter coefficients were determined from the sound pressure curve and the same settings were used for both flow and sound pressure signals. After inverse filtering the signal bandwidth was 25-2500 kHz.

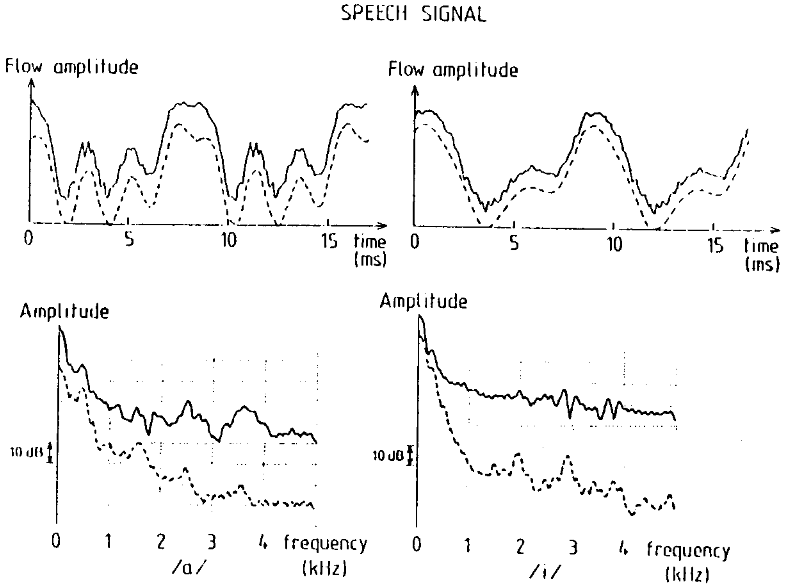

Fig. 6. ***Waveforms and spectra of flow and pressure signals for /a/ and /i/. Solid line: flow signal; dashed line: integrated radiated pressure signal. The curves are transposed in the amplitude domains to make comparisons easier.***

The time wave and the spectra for a few voice pulses from each vowel are shown in Fig. 6 and the same voice pulses after inverse filtering can be seen in Fig. 7. To make a comparison easier the pressure wave was integrated using a real pole at 1 Hz. The flow signal from the mask is rather noisy, which explains the high amplitude at higher frequencies of the flow spectra. In the vowel /a/ the second formant, at about 1.6 kHz, is not visible in the flow signal, Fig. 6. This is presumably due to the zero we have seen earlier in the sweep tone measurements.

For /a/ the frequency response for the mask and the microphone recordings seem to be similar up to nearly 1 kHz, while for /i/ the upper frequency limit is lower. The discrepancies between the registrations could in part be explained by the very noisy mask recording.

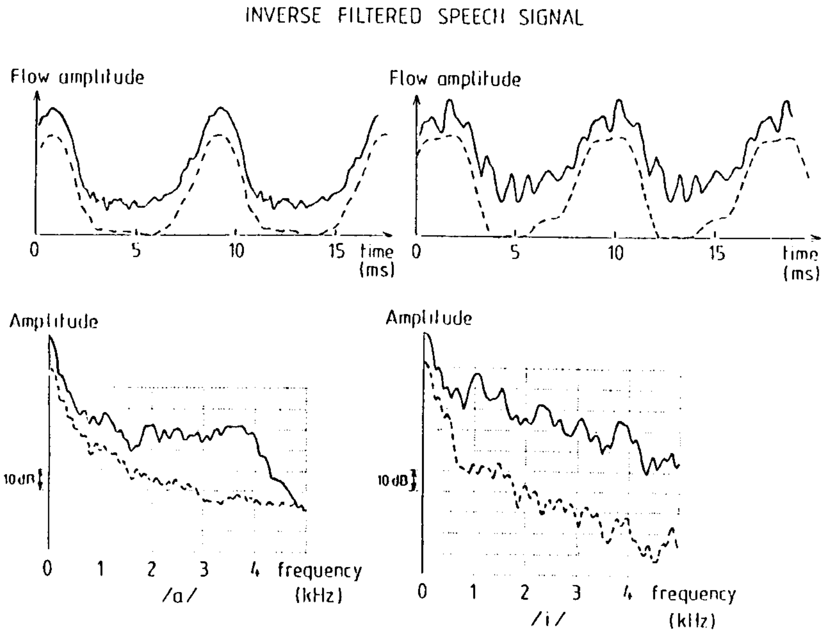

Fig. 7. ***Waveforms and spectra of inverse filtered signals for /a/ and /i/. Solid line: inverse filtered flow (same filter settings as for the pressure); dashed line: integrated inverse filtered radiated pressure. The curves are transposed in the amplitude domains to make comparisons easier.***

4. CONCLUSION

In this paper, the frequency properties of the circumferentially vented pneumotachograph proposed by Rothenberg (1973) have been analyzed. It has also been shown, in two different experiments, that the acoustic transmission characteristics of the mask is approximately flat up to 1 kHz. Finally, it has been verified that the same type of limitations apply when using the mask for inverse filtering purposes. The phase response of the flow could not be evaluated, but since the inverse filtering of flow and pressure led to quite similar waveforms, it can be assumed that the phase is linear enough not to affect these waveforms.

In order to get a more reliable flow response from the mask at frequencies higher than 1-1.5 kHz, a cancelling of the valley at 1.5 kHz by a complex pole filter (second order resonance filter) was tried. The attempt has not been successful, and supposedly the trough does not correspond to a single complex zero.In conclusion, the Rothenberg mask has a clear limitation of its valid frequency range, around 1 kHz, and should not be trusted above this frequency. This means that its use should be practically limited to cases where an estimation of the quasi static flow at the mouth is needed, and that classical microphone pressure recordings should be used in all cases where the details in the frequency domain above 1 kHz are of interest.

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References

Badin, P. (1989): "Acoustics of voiceless fricatives: production theory and data," STL-QPSR 3/1989, pp. 33-55.

Gobl, C. & Ní Chasaide, A. (1988): "The effects of adjacent voiced/voiceless consonants on the vowel voice source: a cross language study," STL-QPSR 2-3/1988, pp. 23-59.

Hertegård, S. (1989): "Insufficient vocal fold closure as studied by inverse filtering," Paper presented at the 6th Vocal Fold Physiology Conference, Stockholm, 1989; to be publ. in the Proceedings.

Holmberg, E.B., Hillman, R.E., & Perkell, J.S. (1988): "Glottal airflow and transglottal air pressure measurements for male and female speakers in soft, normal and loud voice," J.Acoust.Soc.Am. **84**(2), pp. 511-529.

Karlsson, I. (1985): "Glottal wave forms for normal female speakers," STL-QPSR 1/1985, pp. 31-36.

Karlsson, I. (1988): "Glottal waveform parameters for different speaker types," pp. 225-231 in *Proc. SPEECH '88, Book 1* (7th FASE-Symposium), Institute of Acoustics, Edinburgh.

Rothenberg, M. (1973): "A new inverse-filtering technique for deriving the glottal air flow waveform during voicing," J.Acoust.Soc.Am. **53**, pp. 1632-1645.

Rothenberg, M. (1977): "Measurements of air flow in speech," J. Speech & Hearing Res. **20**, pp. 155-176