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The STL Ionophone sound source

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IV. MUSICAL ACOUSTICS

A. THE S.T.L. IONOPHONE SOUND SOURCE*

F. Fransson

The Speech Transmission Laboratory has developed a sound source on the principle of a modulated ionized air-gap. This sound source is useful for acoustical measurements and especially for studies of musical wind-instruments on account of a diminutive size, great frequency range, amplitude stability, and high impedance.

In the early part of this century F.W. Peek at the General Electric Co. studied Corona phenomena and found that sound of a pitch twice that of the supply frequency, was produced. It was presumed that the sound generation was solely due to a thermal effect in the Corona discharge, but it was later shown that there exists an air-pressure change, the Corona wind, related to the mobility of ionized particles. A loudspeaker of this principle, the Ionophone or Ionovac, was invented by the Frenchman S. Klein about 1946 and a similar instrument, the Corona Wind loudspeaker with an ingenious modulation system was developed by the Englishman D.M. Tombs about 1955.

The general principle of our device is shown in Fig. IV-A-1. The condenser C is charged from the DC-source E of 2000-3000 V. The condenser discharges over the resistance R_i, the Corona electrodes at U and the series modulator M. The resistance R_i is of importance for a stable Corona production without sparking or spluttering tendencies. The ionophone anode consists of a piece of wire with a length of about 3 mm and a diameter $\leqq 0.05$ mm. The cathode is a blunt electrode with a diameter of about 0.5 mm. The length of the air-gap is 1-5 mm. The Corona at the anode is a small violet cone and at the cathode a minute blue-white spot.

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The ionophone resistance decreases with increased current and the sound generation is proportional to the DC-current, AC-current, and ionophone resistance. The ionophone can be treated as a volume current source with high internal impedance of the volume velocity.

$$U = k \cdot \ell \cdot (I_0 + I_1)^2, \text{ (Fig. IV-A-1)}$$

The modulation degree should not be too high if a low distortion is wanted.

Measurements on flutes (Fig. IV-A-2)

The spectrum of the produced tone P_f is a product of the source spectrum S_f and the transmission function T_f.

$$|P_f| = |S_f| \cdot |T_f|$$

Besides the transmission function, the inimpedance of the instrument is significant for tone production. It is found that overblowing is possible in a frequency range in which the input impedance, measured at the resonant frequencies, rises with the frequency.

The transmission function and inimpedance for flutes are:

$$H_{(j\omega)} = \frac{P_t}{U_i} = \frac{Z \cdot \sinh \Gamma_e \cdot \sinh \Gamma_t}{\sinh(\Gamma + \Gamma_e + \Gamma_t)} \qquad (1)$$

$$Z_i = \frac{P_e}{U_i} = \frac{Z \cdot \sinh(\Gamma + \Gamma_t) \cdot \sinh \cdot \Gamma_e}{\sinh(\Gamma + \Gamma_e + \Gamma_t)} \qquad (2)$$

Z = the characteristic impedance

Γ = the complex propagation constant = $\alpha\ell + j \cdot \beta\ell$,

$\Gamma_e = \operatorname{arctanh} \frac{Z_e}{Z}$, and

$\Gamma_t = \operatorname{arctanh} \frac{Z_t}{Z}$, where Z_e is the embouchure impedance and Z_t the effective termination impedance.

These equations are valid for consecutive fingering.

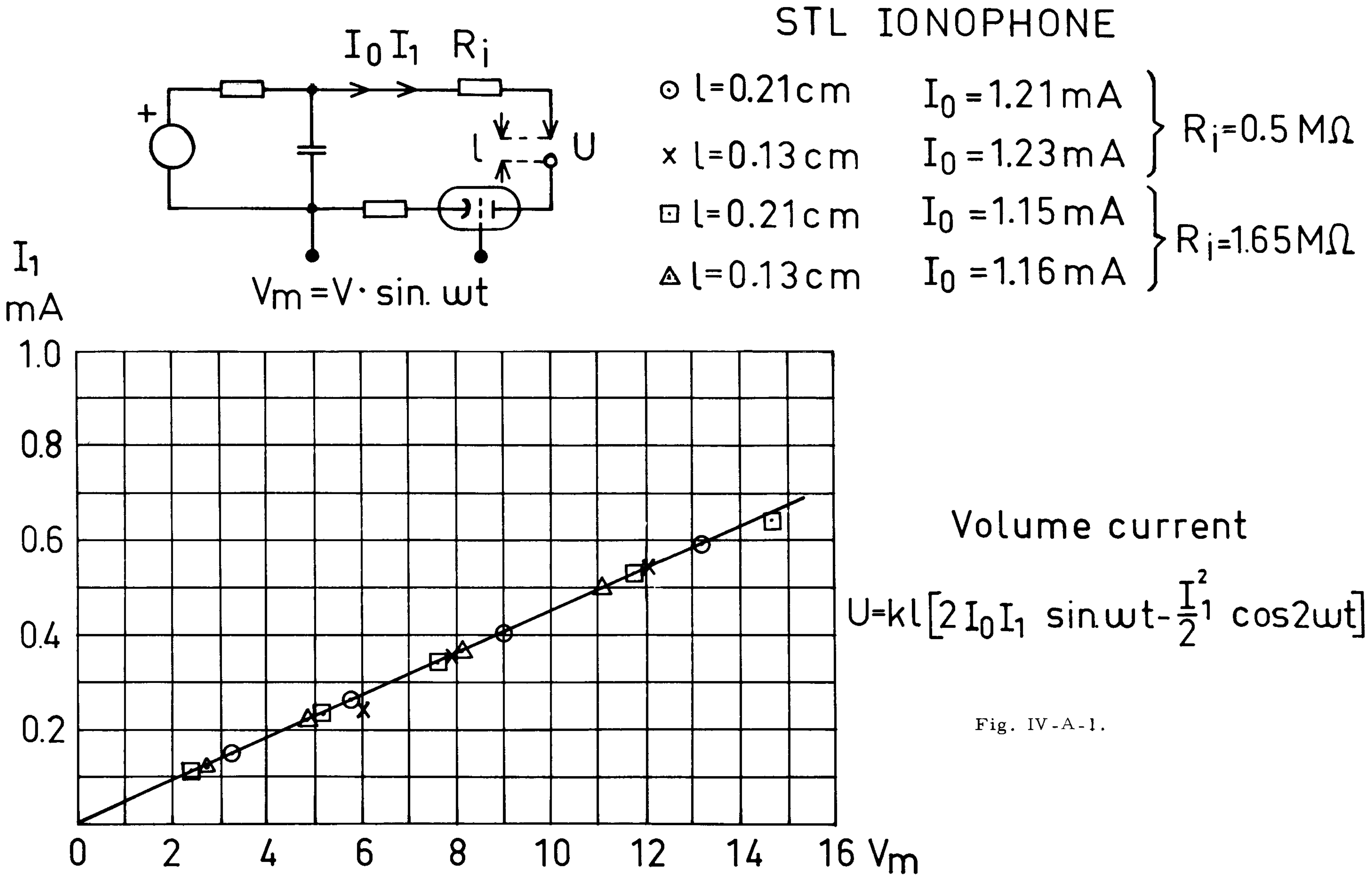
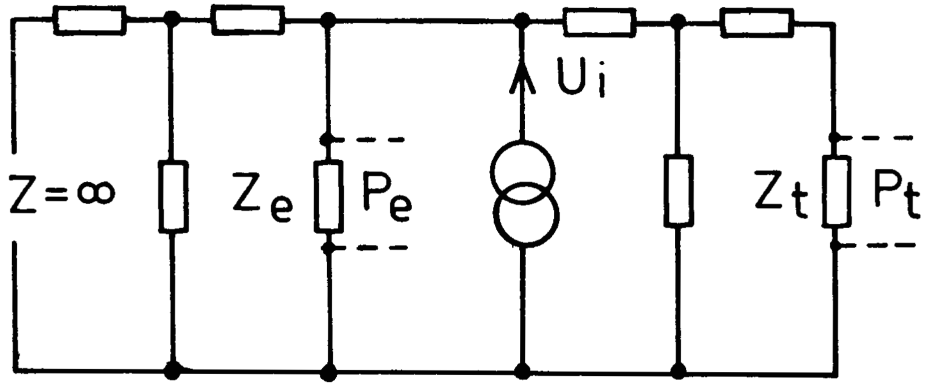

STL IONOPHONE
$I_0 I_1$
R_i
+
l
U
$V_m = V \cdot \sin. \omega t$
⊙ l=0.21cm I_0 = 1.21 mA
× l=0.13cm I_0 = 1.23 mA
R_i=0.5 MΩ
⊡ l=0.21cm I_0 = 1.15 mA
⚠ l=0.13cm I_0 = 1.16 mA
R_i=1.65 MΩ
I_1
mA
1.0
0.8
0.6
0.4
0.2
0
2
4
6
8
10
12
14
16 V_m
Volume current
$U = kl\left[2 I_0 I_1 \sin.\omega t - \frac{I_1^2}{2} \cos 2\omega t\right]$

Fig. IV-A-1.



Acoustic Analog for the Flute

Fig. IV-A-2.

The ionophone electrodes are applied in the embouchure and three series of measurements with gliding sine-wave modulation are executed.

1. The flute is completely closed, i.e. Z_e and $Z_t = \infty$. The sound pressure at the end is measured with a sond microphone:

$$H_{(j\omega)} = \frac{P_t}{U_i} = \frac{Z}{\sinh\Gamma} \qquad (3), \text{ (Fig. IV-A-3)}$$

2. The embouchure is kept closed (i.e. $Z_e = \infty$), the end and keys or holes are successively opened according to the tone in question and a microphone is placed above the open hole or key nearest the embouchure.

$$H_{(j\omega)} = \frac{P_t}{U_i} = \frac{Z \cdot \sinh\Gamma}{\cosh(\Gamma + \Gamma_t)} \qquad (4), \text{ (Fig. IV-A-4)}$$

3. The embouchure is opened and the transmission function and impedance for each tone according to eqs. (1) and (2) are measured, Figs. IV-A-5 and IV-A-6.

Information about the most significant characteristics of the flute is now obtained. Of basic interest is the relation between the resonance frequencies and the pitch of the blown tone. If this relation is known, a greater accuracy for determining the temperament deviation than the usual performance test is possible. A number of tests with musicians playing different flutes indicated that undesirable corrections were made, especially in the middle register, also when playing according to scores with difficult intervals. We found however that a more true relation could be obtained if the flutist was required to perform after a staff with a signaling lamp for each tone. The sequence of the switching was chosen at random and a lamp indicating a certain note was lighted when the performer pressed a foot switch. Mean values from five flutes, representative for different periods from the beginning of last century up to now are shown in Fig. IV-A-7.

In order to determine by simulation the effective covering of the embouchure by the mouth, a series of measurements were made with the ionophone as a source and successively reduced embouchure opening. Comparisons between the pitch of a blown tone

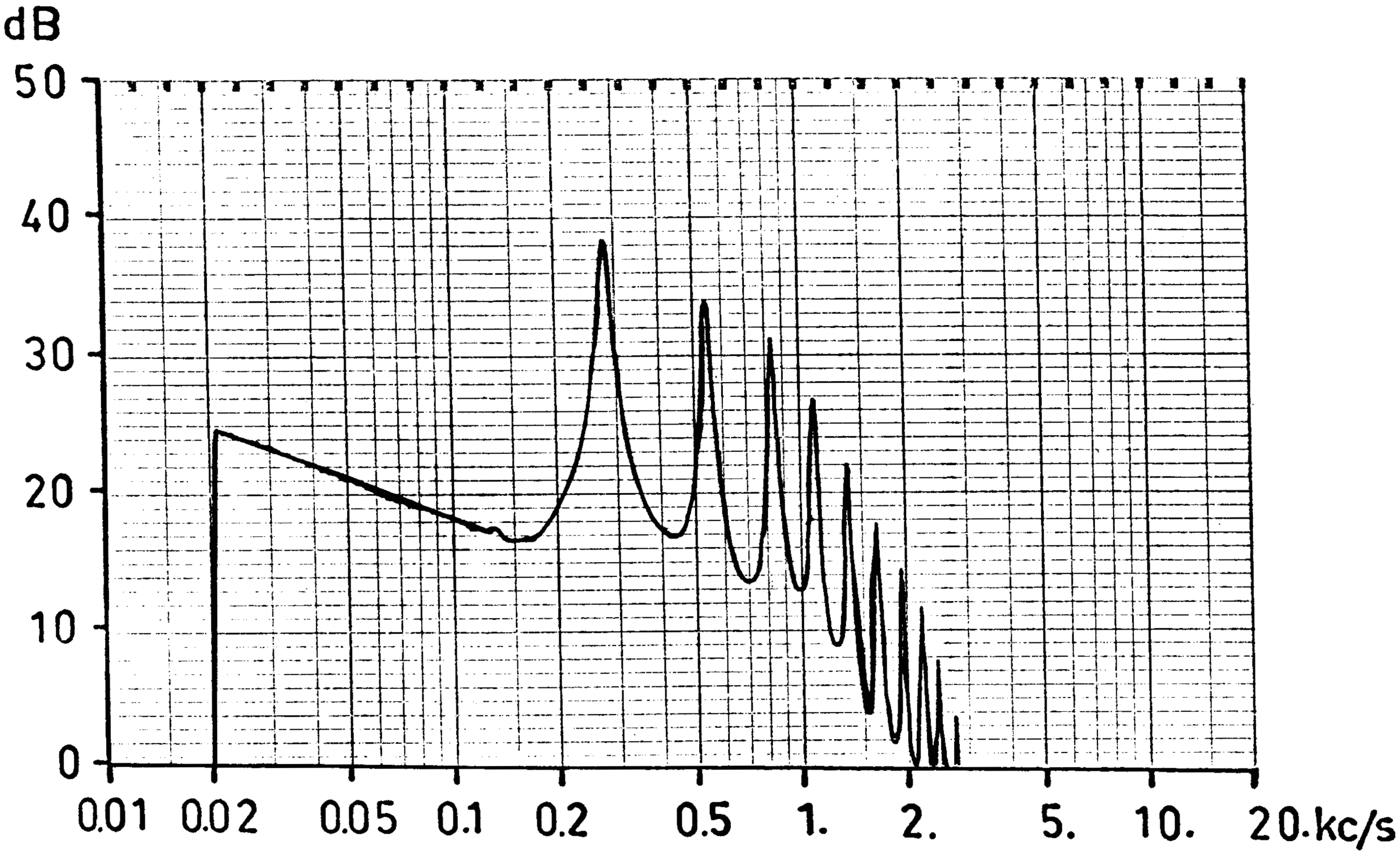


Fig. IV-A-3. Transmission function for closed flute.

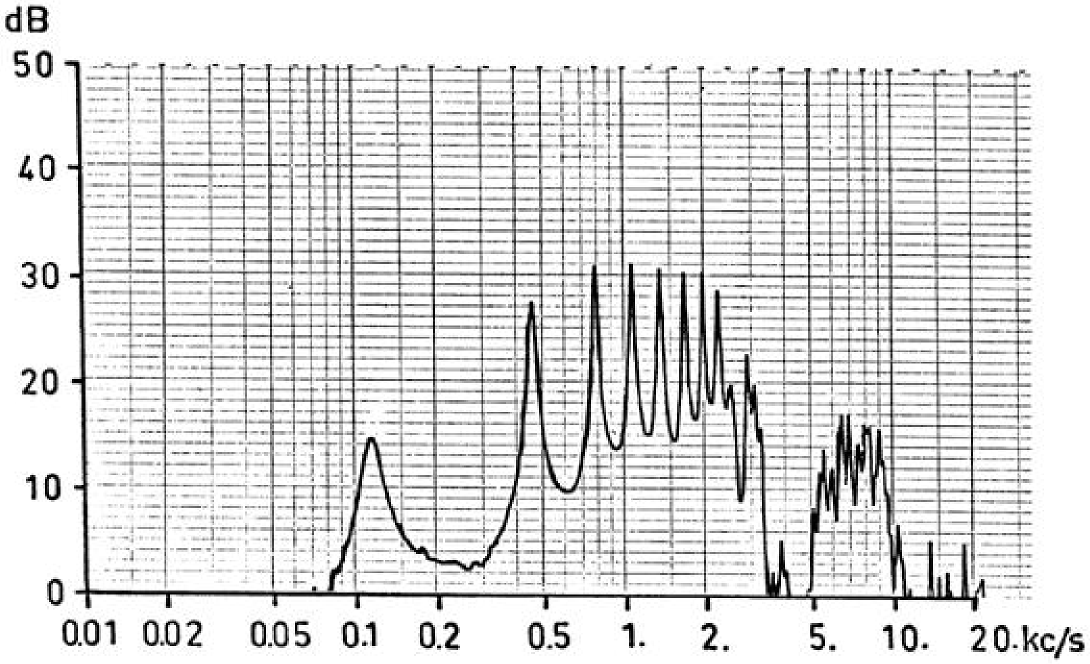


Fig. IV-A-4. Transmission function for D_4. Embouchure closed.

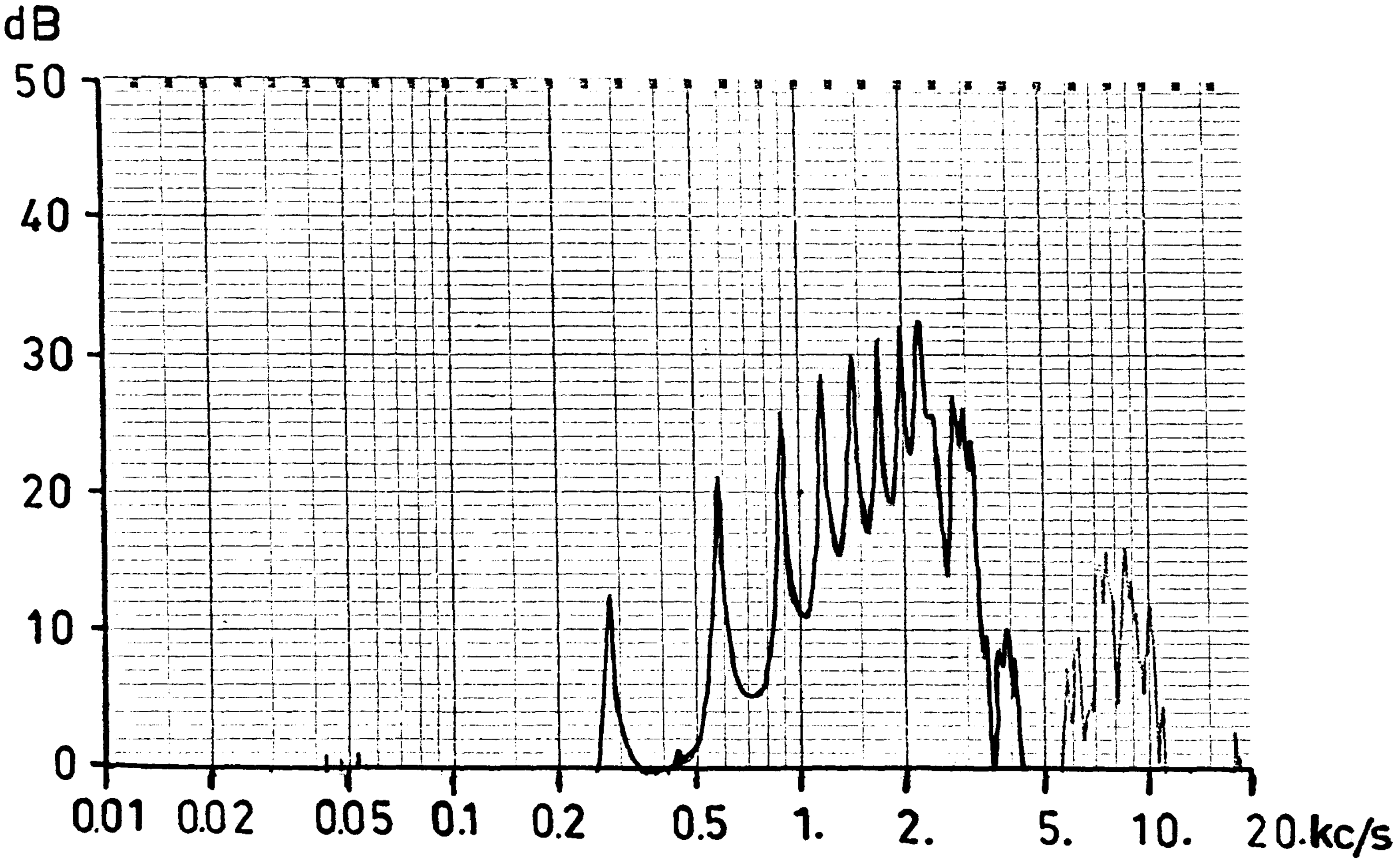


Fig. IV-A-5. Transmission function for D_4. Embouchure open.

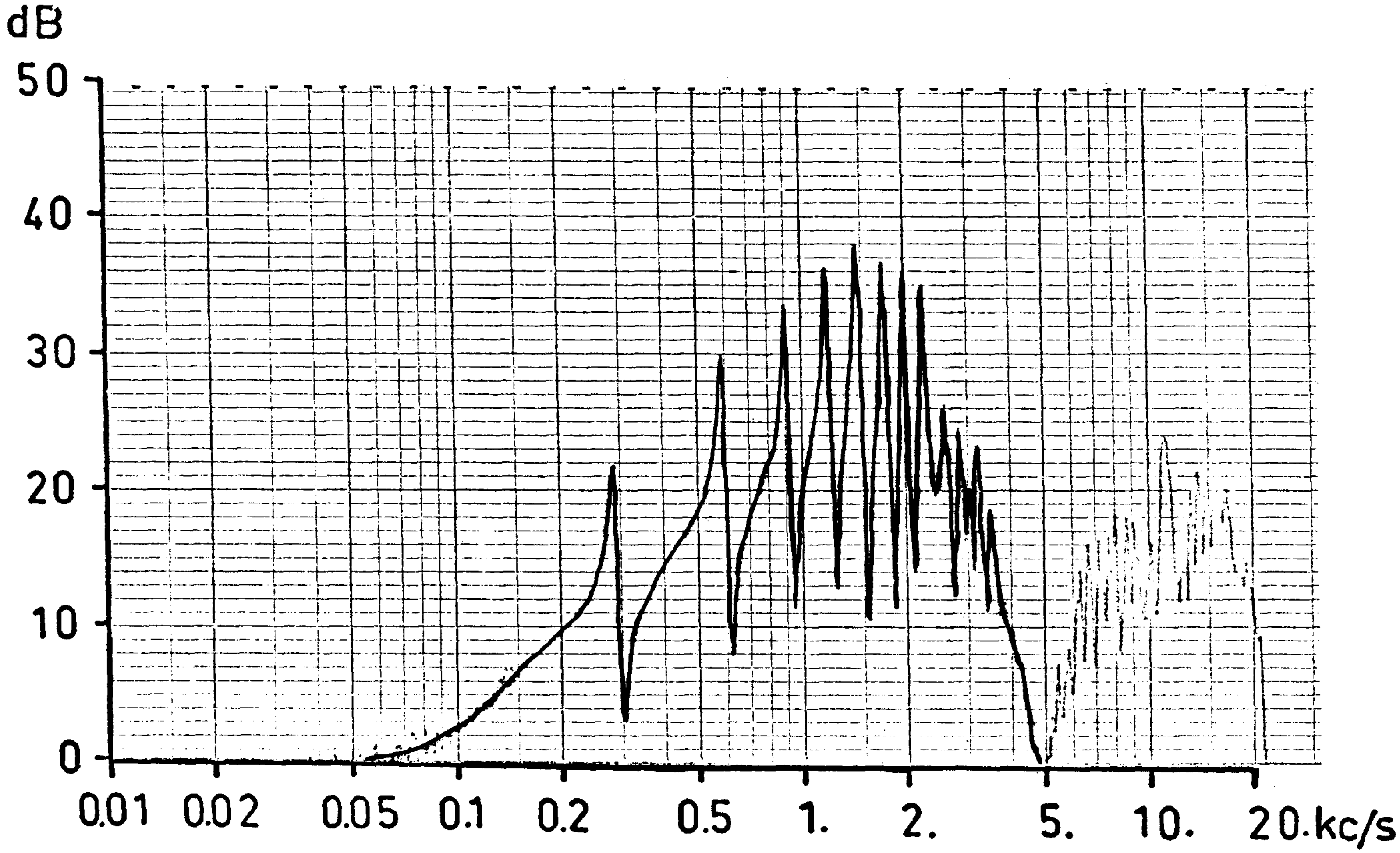


Fig. IV-A-6. Inimpedance for D_4. Embouchure open.

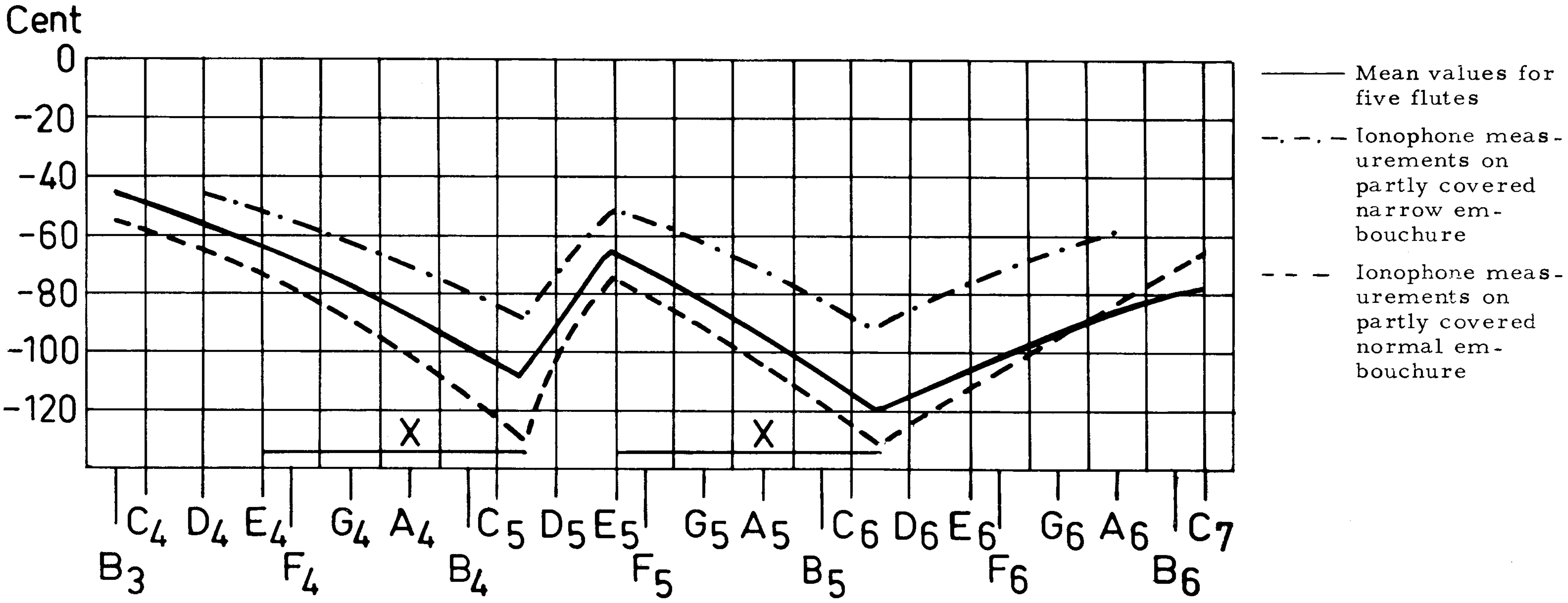


Fig. IV-A-7. Relation between resonance frequency and corresponding blown tone.

in the middle octave and the corresponding resonance frequency showed that the opening should be reduced to about one half in order to provide a frequency match. This relation was quite consistent over the whole register up to the high part of the third octave where the blown tone was slightly lower. Two flutes were tested, one with a normal and one with a narrow embouchure, i.e. an area difference of 23 per cent. The required area reduction was 60 per cent for the normal and 40 per cent for the narrow embouchure. The relative embouchure impedance is

$$\frac{Z_e}{Z} = \frac{R_e}{Z} + j\omega\frac{L_e}{Z} \;;$$

with reduced opening $\frac{L_e}{Z}$ increases to $\frac{L_e}{Z} + \Delta$

where Δ for the normal embouchure was found to be 47 per cent higher than Δ for the narrow embouchure. J.J. Quantz stated in his book: „Versuch, eine Anweisung die Flute Traversiere zu Spielen", Breslau 1789, that an area reduction of about 50 per cent was required for the production of a full tone, and it is known by flutists that a narrow embouchure should be covered less than a wide one.

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