ARTICULATORY MEASUREMENTS BY MAGNETIC METHODS

GEORGIOS PANAGOS HANS WERNER STRUBE

Drittes Physikalisches Institut, Universität Göttingen,
Bürgerstr. 42-44, D-3400 Göttingen, Fed. Rep. of Germany

ABSTRACT

We present two methods, which use alternating magnetic fields, for measuring articulatory activities. The first method uses homogeneous magnetic fields and as induction coils a flat flexible rectangular coil and a magnetic potentiometer. The second method uses inhomogeneous magnetic fields and small dipole receiver coils. Some examples of comparative measurements of various articulatory movements during speech production are presented here in order to demonstrate the applicability of the system.

INTRODUCTION

One of the most important problems in the phonetic sciences is the measurement and theoretical modelling of the articulatory motions and their relation to the acoustic speech signal.

For the direct registration and measurement of the articulatory motions several methods have been developed in the past. However, most of them are very expensive or/and have some undesirable bioeffects [2]. Some other techniques, based on pulsed-echo ultrasound [3], are not tissue invasive but disturb the articulation a little, and they are not suitable for measuring all the articulatory parameters.

We developed two magnetic methods, by which we are able to measure the tongue and jaw movements. These methods hardly disturb the speech production, are biologically safe and not expensive. We also present here some comparative investigations between various quantities related to the articulatory movements.

METHODS

Homogeneous fields

The first magnetic method uses homogeneous fields, generated by three orthogonal Helmholtz-coil pairs with different frequencies (15, 17.5 and 20 kHz) surrounding the head of the subject. One of the coil pairs is not quite "Helmholtz", but serves only for correcting purposes. The homogeneous fields do not allow to measure absolute positions, but vectorial distances can be measured more exactly. We used two types of receiver coils: a magnetic potentiometer (MPM) and a flat flexible coil (FC).

By the MPM, i.e. a long, thin and flexible coil, we can measure the vectorial distance between its ends with the help of the voltages induced by the three fields in the coil. These voltages depend only on the position of the MPM's ends (Fig. 1). We place and fix the coil's ends on the upper and lower incisors. Thus we can measure the distance of the upper to the lower jaw in the midsagittal plane.

The FC (with one or two rectangular windings, which are embedded between two flexible plastic sheets) is attached to the tongue surface in order to measure the tongue "curvature" and the angle of the tongue tangent relative to the Frankfort horizontal line in the midsagittal plane. By the induction of the same homogeneous fields as above, a two dimensional vectorial distance of the short edges can be measured (Fig. 2), which can be interpreted as the curvature and the tangential direction of a tongue surface element. An outline of the vocal tract with the positions of the coils is shown in Fig. 3.

A longer flat coil allows us to measure the distance palate-tongue, if one edge of the FC is attached to the immoveable palate and the other to the tongue. Thus we had the possibility to obtain measurements relative to the head of the subject. But this technique may be too disturbing during speech production.

Dipole fields

The second method uses four dipole transmitter coils placed on the edges of a square in the median plane of the subject's head (Fig. 4). The opposite coils are driven at the same frequency but opposite phase, so that the field strength equals zero at the centre of the square. Each coil has 22 cm distance from this centre. Another pair of transmitter coils with their axes perpendicular to the median plane are used for correcting purposes. This (circular) coil pair generates a nearly homogeneous field about the centre of the above-mentioned square, which is approximated with a 4th-order polynomial [4]. These coils correct the induced amplitude for a possible deviation of the receiver-coil axes from the normal of the median plane. The receiver coils attached to the tongue surface are about 1 mm thick and 3 mm long, with a ferrite core and about 400 windings. With such miniaturized dimensions of the coils no disturbance during speech is given (they are smaller than the pellets in [2]). They are pasted on a plastic strip, which is then attached to the tongue. This facilitates obtaining the proper orientation and position of the coils, protects the coil's leads and enhances reproducibility. Another receiver coil is placed on a immoveable point of the head (e.g. upper incisor) used as reference point. Since we use synchronous demodulators for the detection of the receiver signals, we can distinguish the sign of the field strenghts, unlike [1]. The field strengths are converted into Cartesian coordinates by a zero-detection iterative technique. The calibration constants can also be estimated by a similar iterative technique.

The electronic section of the apparatus consists of a transmitter (three sinewave oscillators) and a receiver lock-in amplifier, which separates the three induction voltages of the receiver coils by a synchronous demodulator and three 4th-order Bessel filters. The advantage of the lock-in circuit is that it keeps the disturbing voltages to a minimum and allows the distinction of the sign of the induced voltage.

The errors of both methods are below 1 mm. Simultaneously with the motions of the coils the speech signal is picked up by a Sennheiser microphone (MKH 105), in order to compare the signal with the articulatory parameters. For preventing any acoustical disturbances all the measurements have been done in an echo-free chamber. All the signals (speech and those from the lock-in amplifier) are digitized and fed into a laboratory computer.

MEASUREMENTS - DISCUSSION

With the homogeneous-field apparatus tongue and jaw movements have been measured in VCVCV utterances. Comparative investigations have been done of the time which is required from the start of the

movements until the onset of phonation and the maximal velocity or the maximal amplitude of the movement; between the latter two quantities we found a roughly linear dependence of the data (Fig. 5). We measured the coordination between the jaw and tongue movements. Specifically, we did some investigations about the repetitive production of /d/, /t/, /p/, combined with /a/, /u/, /o/ and /au/. In the comparisons of tongue and jaw movement we found a positive correlation (an example is shown in Fig. 6). Jaw and tongue measurement examples by the dipole-field method will be presented at the Congress.

These methods have the following advantages: negligible disturbance during speech, they are inexpensive, and they are biologically safe. The disadvantage of the homogeneous-field method is that it is impossible to registrate parallel displacements of the coils (thus no absolute positions can be measured). This disadvantage is avoided by the second method (the inhomogeneous fields). Unlike the first method, we can thereby measure absolute positions in the mouth, with the transmitter coils, having fixed positions about the head of the subject, as reference frame. In further development of these methods we combine them with optical methods (measurements of the lip opening area [5]) and collect a large amount of data for application in articulatory and speech modelling.

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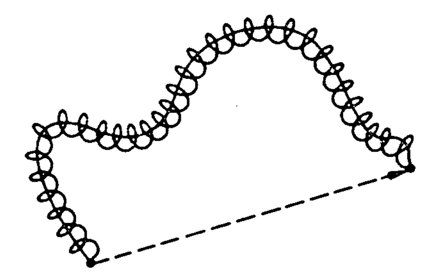

Fig. 1: Schematic of the magnetic potentiometer; dashed line indicates the vectorial distance between MPM's ends.

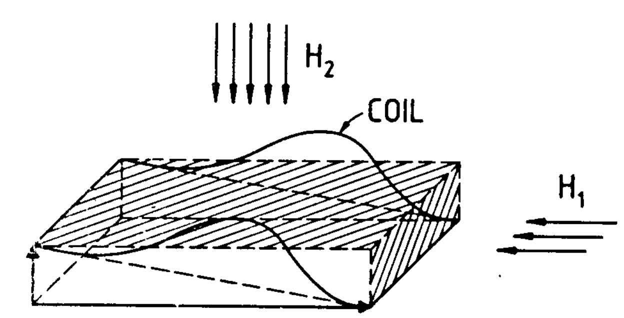

Fig. 2: Schematic of the flexible flat coil. The hatched planes indicate the projections normal to the fields. The dashed line indicates the measured vectorial distance.

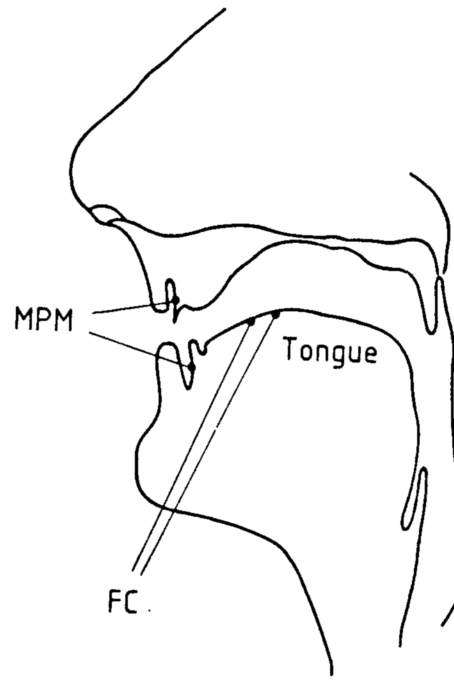

Fig. 3: Positions of the flat coil and the magnetic potentiometer in the vocal tract.

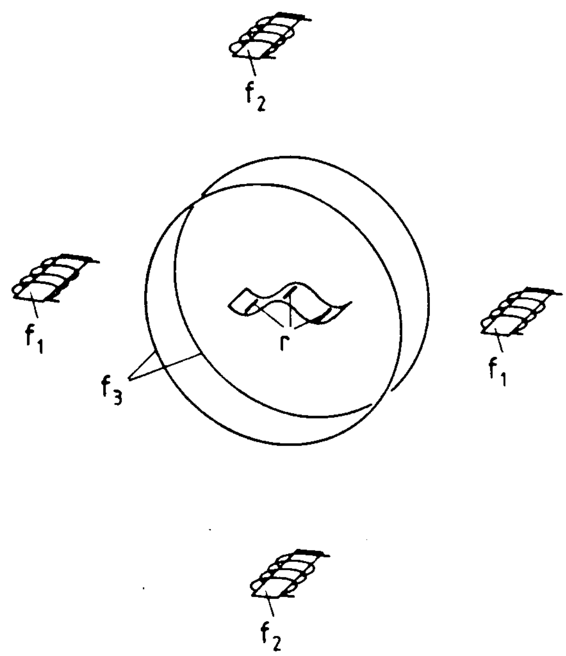

Fig. 4: The dipole coil system. Transmitter coil pairs with frequencies f1, f2, f3; r: three receiver coils on a plastic strip in the middle of the system.

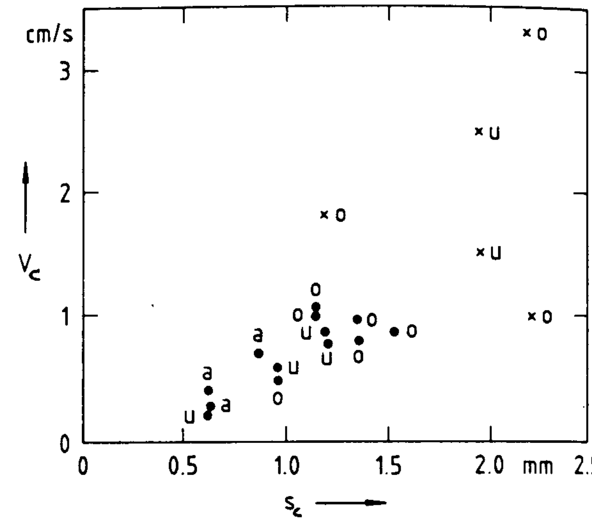

Fig. 5: Velocity v_c of tongue's "curvature" in dependence of the maximal amplitude s_c of the "curvature" of the vowels /a/, /o/ and /u/ combined with the consonant /d/; x, □ ,● : the measurement points of the three subjects.

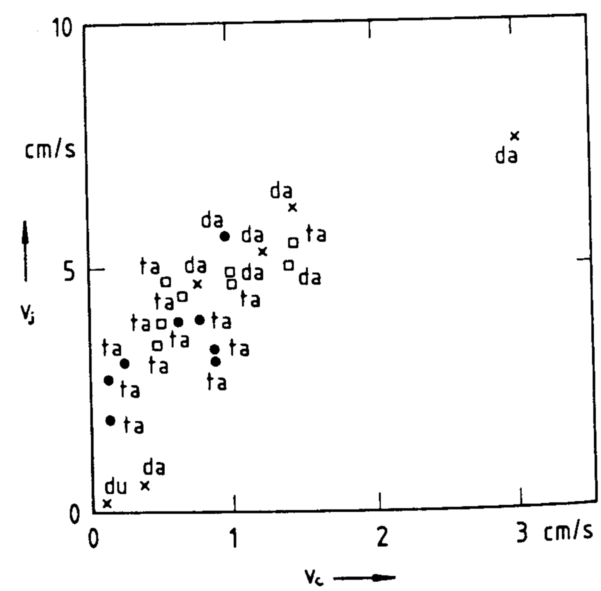

Fig. 6: Velocity v_j of the jaw movement in dependence of the velocity v_c of tongue's "curvature" (velocity: maximal velocity at the beginning of the vowel /a/); x, □, ●: the measurement points of the female and the two male subjects respectively.