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The Concept of Impedance

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The concept of impedance is ubiquitous in science. It implies an obstruction, restraint, or holding back of something that would otherwise flow or move easily. For a most general definition, impedance can be thought of as the ratio of a stimulus to a response. The stimulus can be a force, a pressure, a command, or an enticement. The response is the corresponding motion, flow, action, or reaction. In my classroom teaching, I often informally measure the impedance between me and the students in my class. If the students respond readily to my explanations, either with displayed understanding or multiple questions, impedance between us is low. If they stare at me with a stupor of thought and say nothing, impedance is high.

Impedance is neither good nor bad. It is sometimes maximized and sometimes minimized. The dam of a reservoir, or a shut-off valve, is designed to offer infinite impedance to water flow, whereas a large diameter pipe with smooth walls is designed to offer low impedance to water flow. In both cases, the stimulus is water pressure, and the response is water flow. In an electric circuit, the stimulus is an applied voltage and the response is the electric current in the circuit. In economics, the stimulus can be the infusion of an extra supply of money and the response is the corresponding economic growth.

When the response is immediate, without delay or anticipation, impedance is known as resistance. This special case of impedance can be described with a real number (no imaginary component). For example, in electric circuit theory, a resistance R describes the relation between the voltage V and current I simply as $V/I = R$, where R is a single rational or irrational number. Likewise, in a pipe carrying a fluid flow U driven by a pressure P, the relation $P/U = R$ defines the flow resistance. The glottis between the vocal folds in the larynx offers a flow resistance. Here the transglottal pressure ΔP is the stimulus, Ug is the response, and Rg is the chosen symbol for glottal resistance, $Rg = \Delta P/Ug$. This quantity has been measured in voice science and is on the order of 1–10 kPa per L/s of flow.[1]

There are many situations for which the response is either anticipatory (advanced) or not immediate (delayed) with respect to the stimulus. In such cases, a resistance alone does not describe the stimulus/response relation. Here the impedance has two independent components, a resistance R and a reactance X. If we assign the symbol Z to the impedance, then we can write

$$Z = R + i\,X, \quad (1)$$

where $i = (-1)^{1/2}$, which is not a real number. The two terms on the right side of the equation can never be combined into a single real number; thus, there are always two components to the impedance, the resistance and the reactance. An example in voice science is the input impedance of the vocal tract, which would be the pressure/flow ratio directly above the vocal folds. Equation (1) applies for vocal tract input impedances, both for steady and oscillatory airflow. If the flow into the vocal tract is not oscillating (not moving back and forth at some frequency), the reactance X is zero and the vocal tract impedance becomes the vocal tract resistance for steady flow, which for an open mouth is much lower than the glottal resistance. For acoustic flow, however, which is always oscillatory, the reactance X becomes the dominant component at most frequencies. This reactance can vary not only in magnitude, but also in polarity. Positive reactance is known as *inertive* reactance (delayed response) while negative reactance is known as *compliant* reactance (advanced response). It has been shown that inertive supraglottal reactance is favorable to vocal fold vibration, while compliant supraglottal reactive hinders vocal fold vibration.[2]

Reactance grows rapidly in magnitude with frequency of oscillation. To better compare low-frequency and high-frequency effects on source-airway interaction, it is customary to divide the reactance by the angular (radian) frequency $\omega = 2 \pi f$, where f is the cyclic frequency. If the reactance is positive, this division defines the *inertance* I of the vocal tract.

$$I = X / (2 \pi f) \quad (2)$$

For much of today's scientifically-based vocal pedagogy, an inertagram would be helpful in understanding the relation between the source of sound in the larynx and the resonance options that the airway provides.[3] It is more of an internal view of what a spectrogram reveals from the acoustic output signal. However, it requires detailed information about the airway shape and an impedance computation, neither of which is easily available for general pedagogical applications. I suspect that some apps will become available in the near future.

NOTES

1. R. Konnai, R. C. Scherer, A. Peplinski, and K. Ryan, "Whisper and Phonation: Aerodynamic Comparisons Across Adduction and Loudness," *Journal of Voice* 31, no. 6 (November 2017): 773.e11–773.e20.
2. I. R. Titze, "The Physics of Small Amplitude Oscillation of the Vocal Folds," *Journal of the Acoustical Society of America* 83, no. 4 (May 1988): 1536.
3. I. R. Titze and K. Abbott Verdolini, *Vocology: The Science and Practice of Voice Habilitation* (Salt Lake City: National Center for Voice and Speech, 2012).