Impedance analogy

The impedance analogy is a method of representing a mechanical system by an analogous electrical system . The advantage of doing this is that there is a large body of theory and analysis techniques concerning complex electrical systems , especially in the field of filters . By converting to an electrical representation , these tools in the electrical domain can be directly applied to a mechanical system without modification . A further advantage occurs in electromechanical systems : Converting the mechanical part of such a system into the electrical domain allows the entire system to be analysed as a unified whole .

The mathematical behaviour of the simulated electrical system is identical to the mathematical behaviour of the represented mechanical system . Each element in the electrical domain has a corresponding element in the mechanical domain with an analogous constitutive equation . Every law of circuit analysis , such as Kirchhoff 's laws , that apply in the electrical domain also applies to the mechanical impedance analogy .

The impedance analogy is one of the two main mechanical @-@ electrical analogies used for representing mechanical systems in the electrical domain , the other being the mobility analogy . The roles of voltage and current are reversed in these two methods , and the electrical representations produced are the dual circuits of each other . The impedance analogy preserves the analogy between electrical impedance and mechanical impedance whereas the mobility analogy does not . On the other hand , the mobility analogy preserves the topology of the mechanical system when transferred to the electrical domain whereas the impedance analogy does not .

Applications

The impedance analogy is widely used to model the behaviour of mechanical filters . These are filters that are intended for use in an electronic circuit , but work entirely by mechanical vibrational waves . Transducers are provided at the input and output of the filter to convert between the electrical and mechanical domains .

Another very common use is in the field of audio equipment , such as loudspeakers . Loudspeakers consist of a transducer and mechanical moving parts . Acoustic waves themselves are waves of mechanical motion : of air molecules or some other fluid medium . A very early application of this type was to make significant improvements to the abysmal audio performance of phonographs . In 1929 Edward Norton designed the mechanical parts of a phonograph to behave as a maximally flat filter , thus anticipating the electronic Butterworth filter .

Elements

Before an electrical analogy can be developed for a mechanical system , it must first be described as an abstract mechanical network . The mechanical system is broken down into a number of ideal elements each of which can then be paired with an electrical analogue . The symbols used for these mechanical elements on network diagrams are shown in the following sections on each individual element .

The mechanical analogies of lumped electrical elements are also lumped elements , that is , it is assumed that the mechanical component possessing the element is small enough that the time taken by mechanical waves to propagate from one end of the component to the other can be neglected . Analogies can also be developed for distributed elements such as transmission lines but the greatest benefits are with lumped element circuits . Mechanical analogies are required for the three passive electrical elements , namely , resistance , inductance and capacitance . What these analogies are is determined by what mechanical property is chosen to represent ' ' effort ' ' , the analogy of voltage , and the property chosen to represent ' ' flow ' ' , the analogy of current . In the impedance analogy the effort variable is force and the flow variable is velocity .

Resistance

The mechanical analogy of electrical resistance is the loss of energy of a moving system through such processes as friction . A mechanical component analogous to a resistor is a shock absorber and the property analogous to resistance is damping . A resistor is governed by the constitutive equation of Ohm 's law ,

<formula>

The analogous equation in the mechanical domain is ,

<formula>

where ,

R is resistance

v is voltage

i is current

Rm is mechanical resistance , or damping

F is force

u is velocity induced by the force .

Electrical resistance represents the real part of electrical impedance . Likewise , mechanical resistance is the real part of mechanical impedance .

= = = Inductance = = =

The mechanical analogy of inductance in the impedance analogy is mass . A mechanical component analogous to an inductor is a large , rigid weight . An inductor is governed by the constitutive equation ,

<formula>

The analogous equation in the mechanical domain is Newton 's second law of motion ,

<formula>

where ,

L is inductance

t is time

M is mass

The impedance of an inductor is purely imaginary and is given by ,

<formula>

The analogous mechanical impedance is given by ,

<formula>

where ,

Z is electrical impedance

j is the imaginary unit

? is angular frequency

Zm is mechanical impedance .

= = = Capacitance = = =

The mechanical analogy of capacitance in the impedance analogy is compliance . It is more common in mechanics to discuss stiffness , the inverse of compliance . The analogy of stiffness in the electrical domain is the less commonly used elastance , the inverse of capacitance . A mechanical component analogous to a capacitor is a spring . A capacitor is governed by the constitutive equation ,

<formula>

The analogous equation in the mechanical domain is a form of Hooke 's law ,

<formula>

where ,