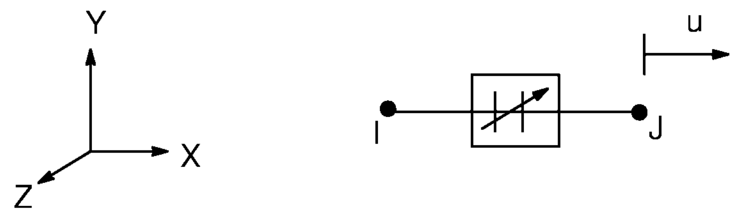
14.126 TRANS126 — Electromechanical Transducer for MEMS



The electromechanical transducer element, TRANS126, realizes strong coupling between distributed and lumped mechanical and electrostatic systems. For details abouts its theory see Gyimesi and Ostergaard(248). TRANS126 is especially suitable for the analysis of Micro Electromechanical Systems (MEMS): accelerometers, pressure sensors, micro actuators, gyroscopes, torsional actuators, filters, HF switches, etc.

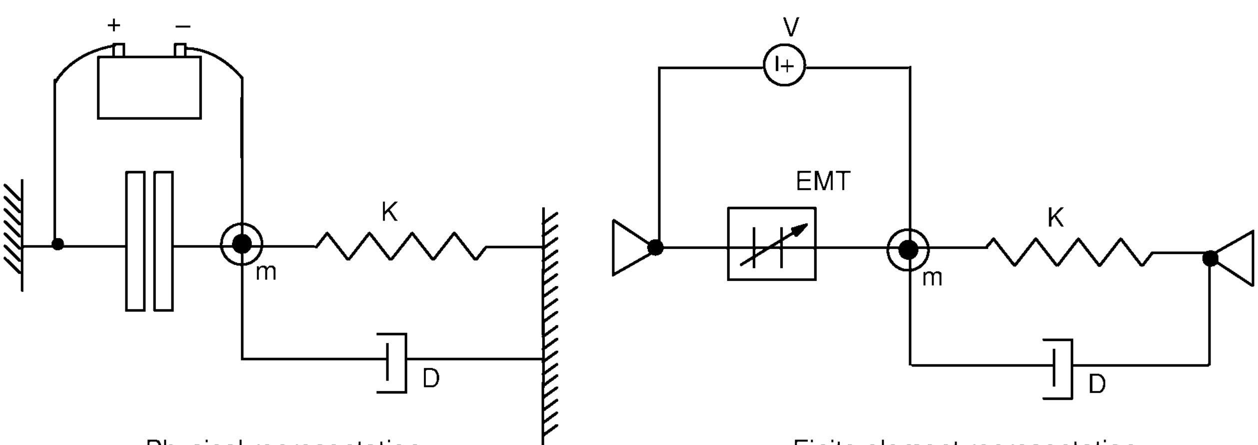


Figure 14.126–1 Electromechanical Transducer

See, for example, Figure 14.126–1 with a damped spring mass resonator driven by a parallel plate capacitor fed by a voltage generator constituting an electromechanical system. The left side shows the physical layout of the transducer connected to the mechanical system, the right side shows the equivalent electromechanical transducer element connected to the mechanical system.

TRANS126 is a 2 noded element each node having a structural (UX, UY or UZ) and an electrical (VOLT) DOFs. The force between the plates is attractive:

$$F = \frac{1}{2} \frac{dC}{dx} V^2 \tag{14.126–1}$$

where:
- F = force
- C = capacitance
- x = gap size
- V = voltage between capacitor electrodes

The capacitance can be obtained by ANSYS from a static FEM analysis using the **CMATRIX** macro. For the theory of computing the capacitance matrix see section 5.10.

The current is

$$I = C \frac{dV}{dt} + \frac{dC}{dx} v V \tag{14.126–2}$$

where:
- I = current
- t = time
- v = velocity of gap opening $\left(= \frac{dx}{dt}\right)$

The first term is the usual capacitive current due to voltage change; the second term is the motion induced current.

For small signal analysis:

$$F = F_0 + D_{xv} v + D_{xv} \frac{dV}{dt} + K_{xx} \Delta x + K_{xv} \Delta V \tag{14.126–3}$$

$$I = I_0 + D_{vx} v + D_{vv} \frac{dV}{dt} + K_{vx} \Delta x + K_{vv} \Delta V \tag{14.126–4}$$

where:
- F_0 = force at the operating point
- I_0 = current at the operating point
- [D] = linearized damping matrices
- [K] = linearized stiffness matrices
- Δx = gap change between the operating point and the actual solution
- ΔV = voltage change between the operating point and the actual solution

The stiffness and damping matrices charaterize the transducer for small signal prestressed harmonic, modal and transient analyses.

For large signal static and transient analyses, the Newton–Raphson algorithm is applied with F_0 and I_0 constituting the Newton–Raphson restoring force and [K] and [D] the tangent stiffness and damping matrices.

$$K_{xx} = \frac{dF}{dx} = \frac{1}{2} C'' V^2 \qquad (14.126\text{–}5)$$

where:

K_{xx} = electrostatic stiffness (output as ESTIF)
F = electrostatic force between capacitor plates
V = voltage between capacitor electrodes
C'' = second derivative of capacitance with respect to gap displacement

$$K_{vv} = \frac{dI}{dV} = C' v \qquad (14.126\text{–}6)$$

where:

K_{vv} = motion conductivity (output as CONDUCT)
I = current
C' = first derivative of capacitance with respect to gap displacement
v = velocity of gap opening

Definitions of additional post items for the electromechanical transducer are as follows:

$$P_m = F v \qquad (14.126\text{–}7)$$

where:

P_m = mechanical power (output as MECHPOWER)
F = force between capacitor plates
v = velocity of gap opening

$$P_c = V I \qquad (14.126\text{–}8)$$

where:

P_e = electrical power (output as ELECPOWER)
V = voltage between capacitor electrodes
I = current

$$W_c = \frac{1}{2} C V^2 \qquad (14.126\text{–}9)$$

where:

W_c = electrostatic energy of capacitor (output as CENERGY)
V = voltage between capacitor electrodes
C = capacitance

$$F = \frac{1}{2} \frac{dC}{dx} V^2 \qquad (14.126\text{–}10)$$

where:

F = electrostatic force between capacitor plates (output as EFORCE)

C = capacitance

x = gap size

$\frac{dC}{dx}$ = first derivative of capacitance with regard to gap

V = voltage between capacitor electrodes

$\frac{dV}{dt}$ = voltage rate (output as DVDT)