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Coupling analysis of transcutaneous energy transfer coils with planar sandwich structure for a novel artificial anal sphincter

Key words: Transcutaneous energy transfer, Planar spiral inductance, Mutual inductance, Coupling coefficient, Artificial anal sphincter, Fecal incontinence

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Introduction

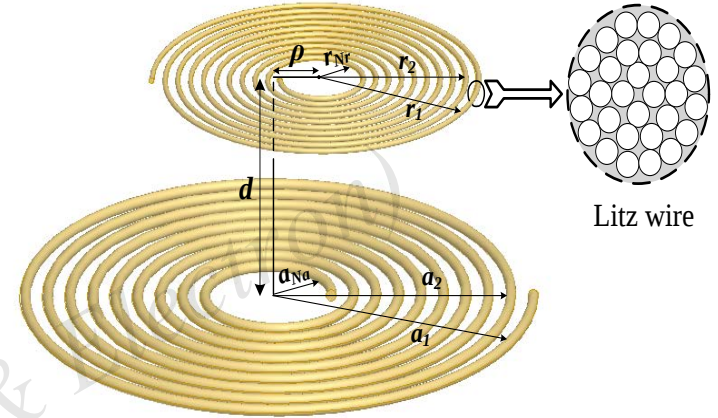
- To reduce the potential risk of infection associated with wires through the skin, inductive transcutaneous energy transfer (TET) technology was used to power the system without direct electrical connectivity
- To estimate the performance of a TET system, requires the prediction of the coupling coefficient k between the coils
- The inductance formulas presented in the literature do not account for reflections from the ferrite substrate structure underneath
- In this paper, the proposed model calculates the prediction based on the winding characteristics, substrate properties, geometric parameters of the planar coils, as well as the relative placement of the coils in the TET system

Design method (I)

Air-cored structure:

$$L = \sum_{i=1}^{N_a} \sum_{j=1}^{N_a} M_0(a_i, a_j, \rho = 0, d = 0)(1 - \delta_{ij}) + \sum_{i=1}^{N_a} L_0(a_i, R)$$

$$M = \sum_{i=1}^{N_a} \sum_{j=1}^{N_r} M_0(a_i, r_j, \rho, d)$$



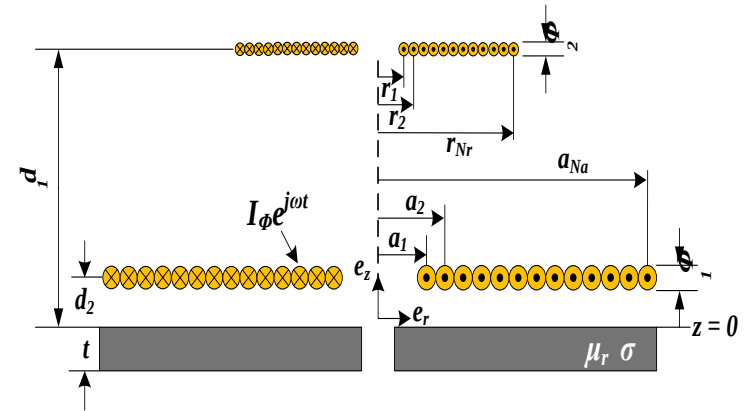
Primary-substrate structure

$$E_{\phi,i}(r, z) = -\frac{j\omega\mu_0 I_{\phi} a_i}{2} \int_0^{\infty} e^{-kd_2} [e^{kz} - \lambda(t)e^{-kz}] J_1(kr) J_1(ka_i) dk$$

$$L_t = L + \Delta L \quad \Delta L = \pi\mu_0 \int_0^{\infty} \text{real}[\lambda(t)] T(k) e^{-2kd_2} dk$$

$$Z_t = R_s + j\omega\Delta M = j\omega\mu_0\pi$$

$$\cdot \sum_{i=1}^{N_r} \sum_{j=1}^{N_a} r_i a_j \int_0^{\infty} J_1(kr_i) J_1(ka_j) \lambda(t) e^{-k(d_1+d_2)} dk$$

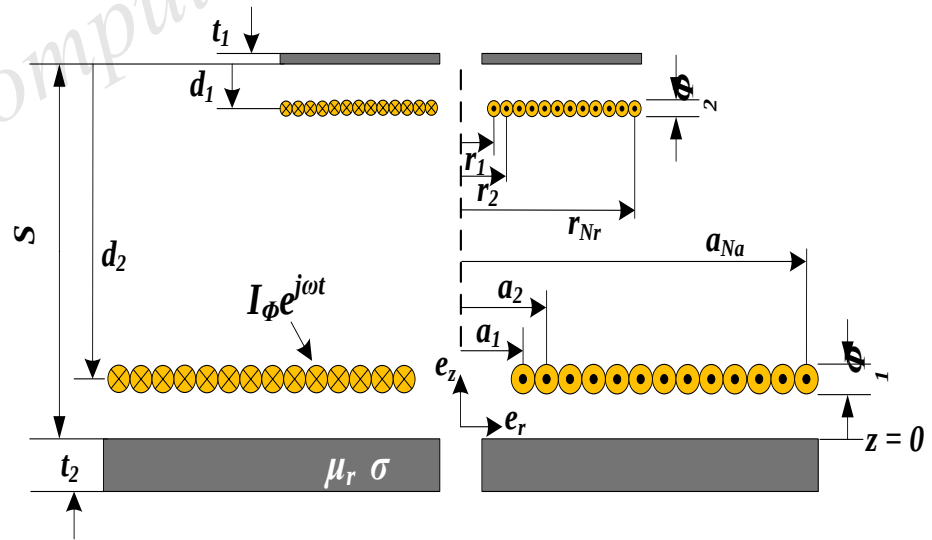


Design method (I)

Sandwich structure

$$Z_{sw} = R_s + j\omega\Delta M = j\omega\mu_0\pi$$

$$\cdot \sum_{i=1}^{N_r} \sum_{j=1}^{N_a} r_i a_j \int_0^\infty J_1(kr_i) J_1(ka_j) [f(\lambda) + g(\lambda)] dk$$

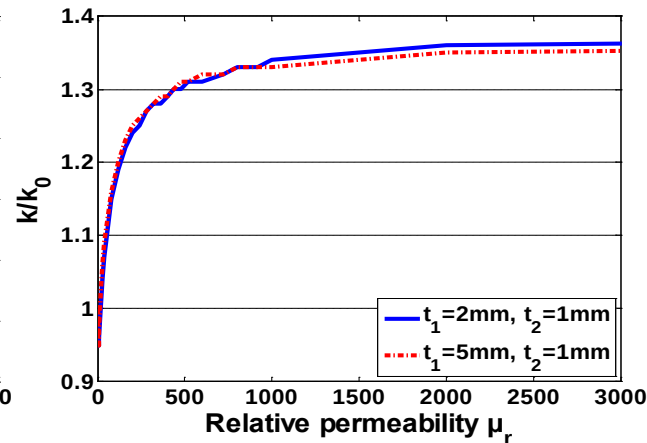
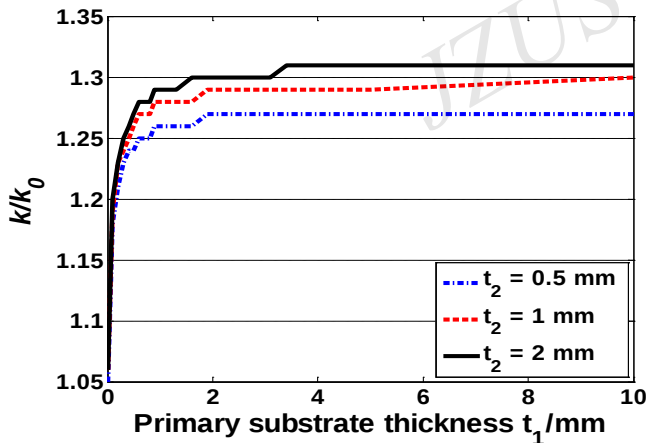
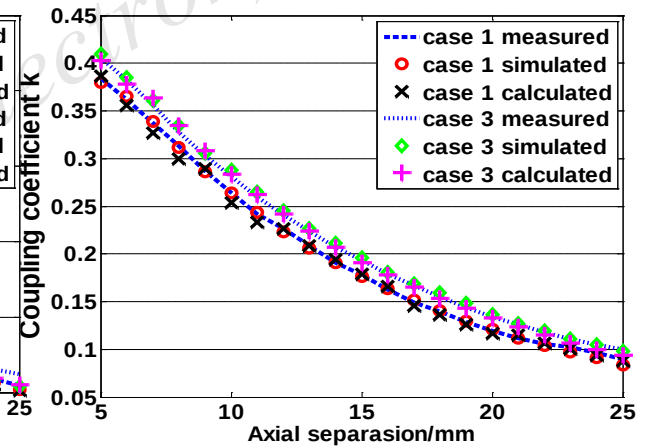
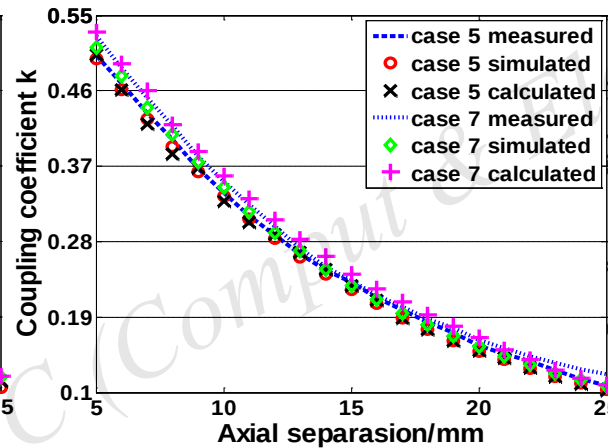
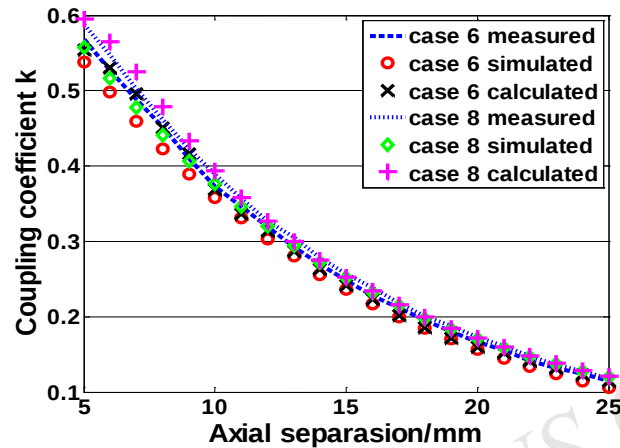
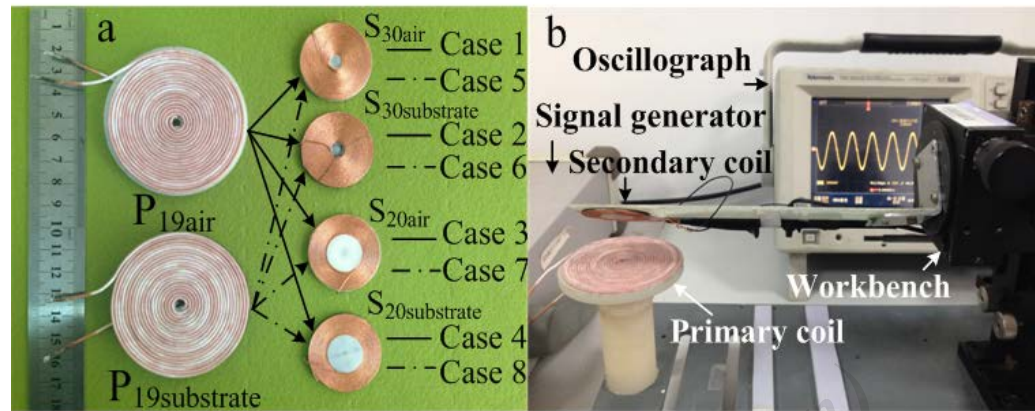


Design method (II)

	P19	S20	S30	Notes
N	19	20	30	Number of turns
n0	120	24	24	Number of strands
Rin	3.5	8.5	3.0	Coil inner radius, mm
Rout	32	17.5	17.5	Coil external radius, mm
Φ_c	0.06	0.06	0.06	Diameter of strand, mm
Φ_o	1.5	0.5	0.5	Diameter of bundle, mm
l	1	1	1	Number of the primary coil layers

	Primary	Secondary	Notes
t	5	1	Ferrite substrate thickness, mm
Rin	2.5	2.5	Inner radius, mm
Rout	32	17.5	External radius, mm
μ_r	2500	2500	Relative permeability
σ	0.01	0.01	Conductivity, $(\Omega m)^{-1}$

Major results



Conclusions

- The first focus of this paper was on the development of a novel elastic scaling artificial anal sphincter prosthesis composed of an annular elastic mechanism and a shrinkable actuator
- A series of formulas for two coaxial planar spiral windings with Litz wire in three kinds of structures were established and compared with FEA and practical measurements
- We found that these analytical models could be used to obtain the optimal value of magnetic coupling between the coils, critical values of the relative permeability, the thickness of the ferrite substrate for a given material, as well as the innermost radius of the coil for a fixed outermost radius