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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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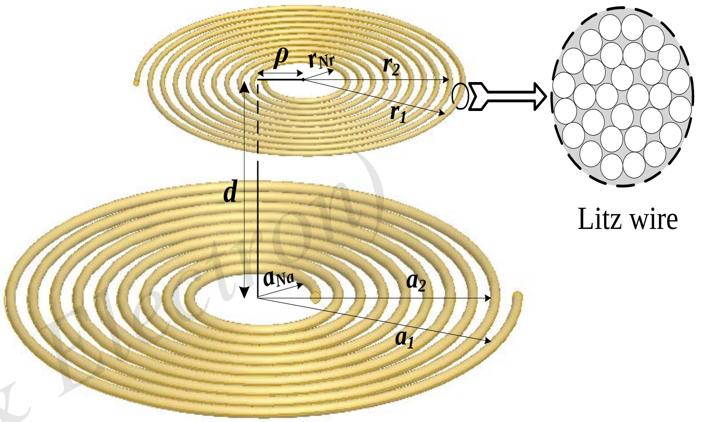
# Introduction

- 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)

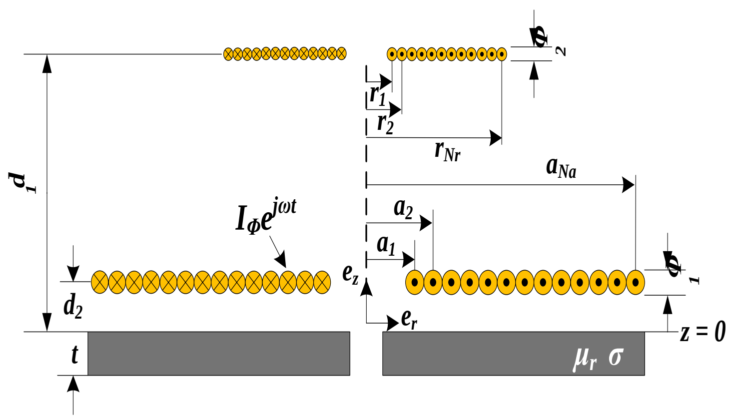
Air-cored structure:




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

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

Primary-substrate structure




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

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

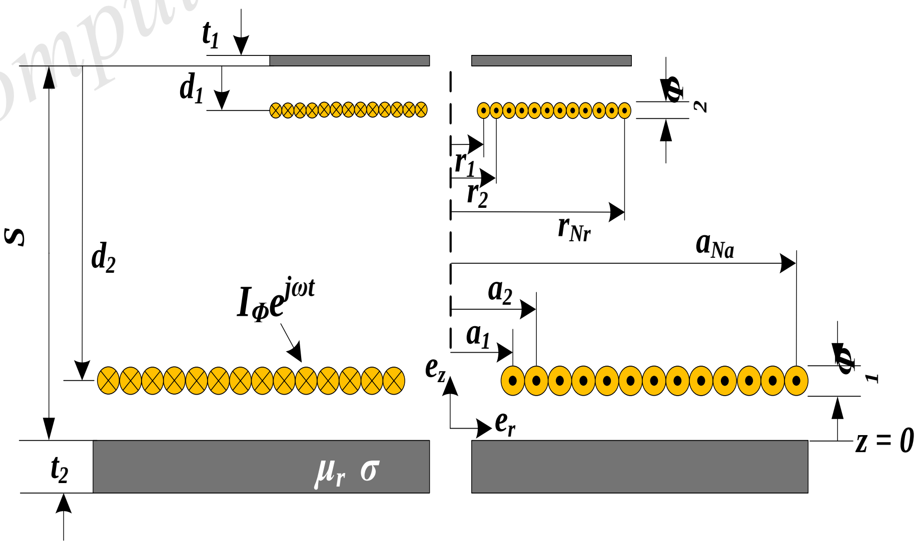
$$Z_t = R_s + j\omega\Delta M = j\omega\mu_0\pi$$

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

# Design method (I)

Sandwich structure

$$Z_{\mathrm{sw}} = R_{\mathrm{s}} + \mathrm{j}\omega\Delta M = \mathrm{j}\omega\mu_0\pi \cdot \sum_{i=1}^{N_r}\sum_{j=1}^{N_a} r_i a_j \int_0^{\infty} J_1(kr_i)J_1(ka_j)\left[f(\lambda)+g(\lambda)\right]\mathrm{d}k$$

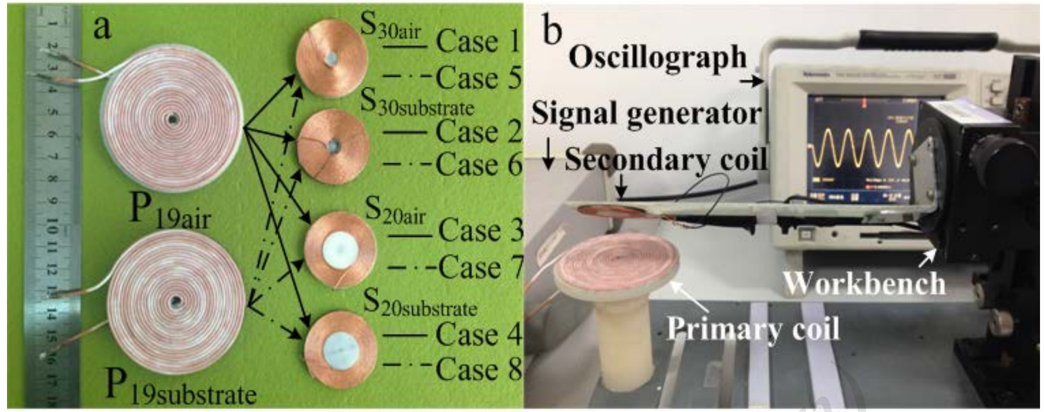


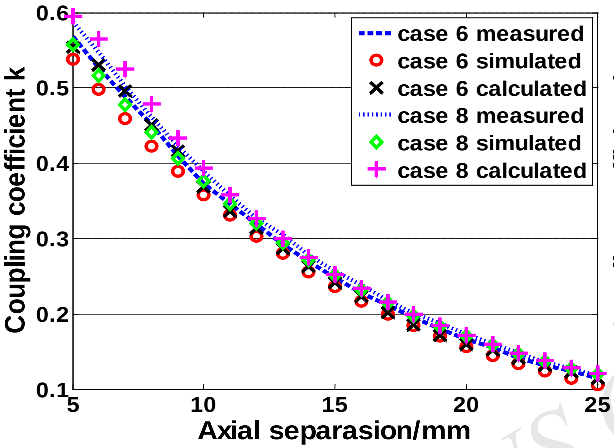
# Design method (II)

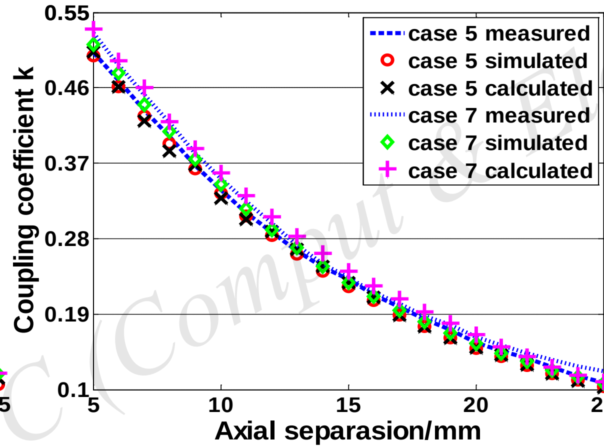
| | P19 | S20 | S30 | Notes |
|---|---|---|---|---|
| N | 19 | 20 | 30 | Number of turns |
| n0 | 120 | 24 | 24 | Number of strands |
| Rin | 3.5 | 8.5 | 3.0 | Coil inner radius, mm |
| Rout | 32 | 17.5 | 17.5 | Coil external radius, mm |
| Φc | 0.06 | 0.06 | 0.06 | Diameter of strand, mm |
| Φo | 1.5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

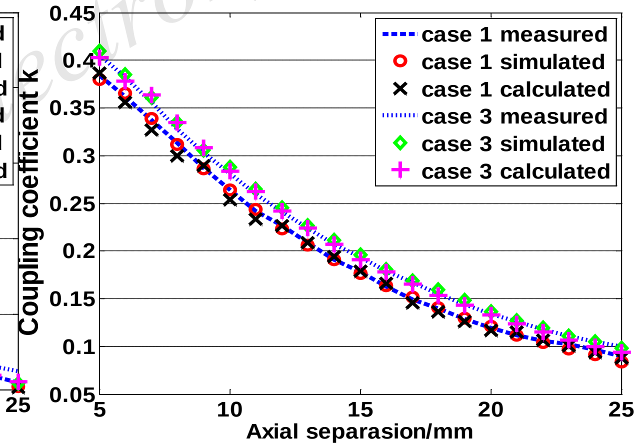
| | Primary | Secondary | Notes |
|---|---|---|---|
| t | 5 | 1 | Ferrite substrate thickness, mm |
| Rin | 2.5 | 2.5 | Inner radius, mm |
| Rout | 32 | 17.5 | External radius, mm |
| μr | 2500 | 2500 | Relative permeability |
| σ | 0.01 | 0.01 | Conductivity, (Ωm)-1 |
| | | | |

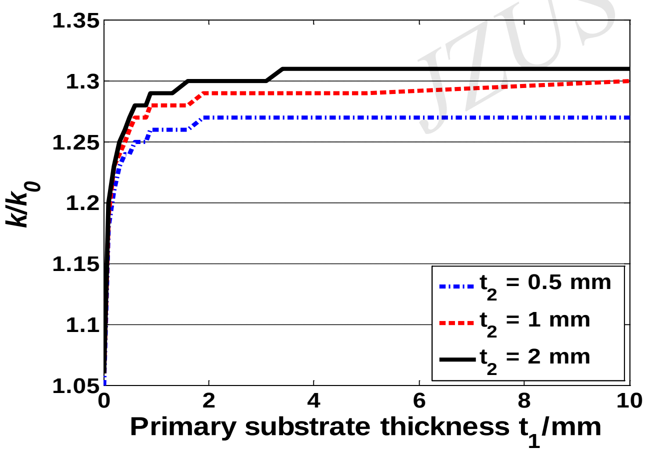
# Major results

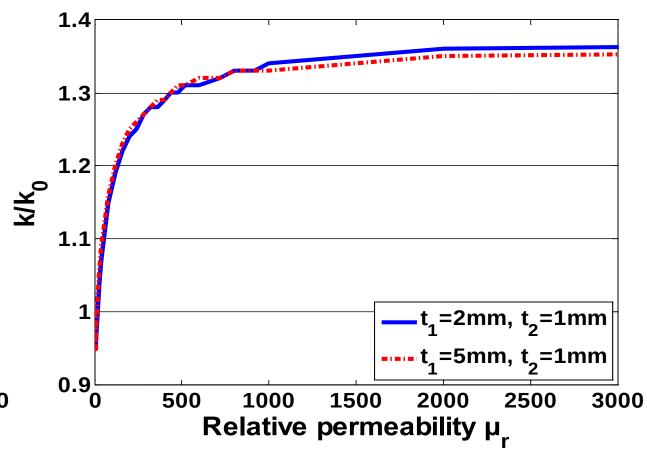


# Conclusions

- 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