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FRICTIONAL EFFECT IN PACEMAKER LEAD CABLE DUE TO COUPLED CONTACT MODE

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ABSTRACT

A Pacemaker is a device which conducts electrical impulses from pulse generator to heart muscle when the heart beat is abnormal. This electrical impulse are conducted to heart muscle by means of lead cables which numbers one to three to treat the heart problem. The lead cables are considered as multi-layered cable assembly with 1+6+12 helical wires and a straight cylindrical core. These assemblies can be made by three modes of contact in a simple straight strand. The first mode is a core-wire contact where the wires in the layer are in contact with the core only. In the second mode, the wires in the layer are in contact among themselves and not with the core. In the third mode, there is a coupled contact among the core and all the wires. There is no literature handled the lead cable assembly with either the core-wire contact or the wire-wire contact or the coupled contact. An attempt is made in this paper, to model the lead cable strand with a coupled core-wire and wire-wire contact and deduce its equations of equilibrium. The numerical analyses of cable strand force, twisting moment, strand stiffness, contact force, and contact stress are carried out based on the theory of thin rods.

Keywords: pacemaker lead cable, contact stress, friction, cable mechanics.

1. INTRODUCTION

The lead cable plays an important role in the pacemaker for the transmission of electrical impulses from pulse generator to heart muscle. Stranded cable geometry may be core-wire contact or wire-wire contact or coupled core-wire and wire-wire contacts. The contact modes may change from one to other depending on the loads and the deformation of the core and wires. None of the literature analyzes the lead cable with either the core-wire contact or the wire-wire contact or the coupled contacts of core-wire and wire-wire.

The analysis of the lead cable in a coupled core-wire and wire-wire contact is essential to understand the importance of the interfacial loads and their effects. Furthermore, the effect of friction at the interfaces are considered, which lead to a wider variation in the results. The effect of tangential distributed forces and normal distributed forces are considered wire-wire contact and the normal distributed forces are considered on core-wire contact [1]. The mathematical model is developed for a 1+7+12 cable strand by considering the effect of friction between core and wire and the theoretical model is compared with the experimental results [2, 3]. The response of a cable strand due to axial forces is investigated by considering the effect of friction between core and wire [4]. The analytical expression for the maximum contact stress induced at the core-wire interface is obtained [7]. A mathematical model to represent the effect of tangential and normal distributed forces in a coupled contact is formulated [10]

The aim of the present work is to represent the lead cable by means of mathematical model and finding out the response of the lead cable strand by considering all the forces in a coupled contact with fixed end conditions.

2. MODELING

In this work, lead cable is considered as the strand. Figure-1 indicates the cross section and the developed geometry of a 1+6+12 wire strand in the coupled contact. The forces and moments in the helical wires act along normal, bi-normal, and tangential directions, as shown in Figure-2. The components of the resultant force acting on the wire are denoted by *T*, *N*, *N'* and the components of moment acting on the wire are denoted by *H, G, G'*. The components of the distributed force per unit length of the wire are *X*, *Y*, and *Z* and the components of the distributed moment per unit length of the wire are *K*, *K'* and Θ. The normal distributed force *U* and the tangential distributed forces *V* and *W* exist along any line of contact between the helical wires.

The normal distributed force *S* and the tangential distributed forces *P* and *Q* act along the line of contact between the core and helical wire. The above interfacial forces can be related to the forces and moments in the wire as under

$$X = -2U\cos\beta - S, Y = 2V\cos\beta \pm P, Z = Q \quad (1)$$

$$K = 2WR_w\sin\beta,\ K' = QR_w, Q = 2VR_w \pm PR_w \quad (2)$$

where R_w is the radius of the wire and β is the contact angle, which locates the lines of action of the line contact loads *U* on a wire due to its neighbors.

The equations of equilibrium of all the forces and the moments acting on an infinitesimal element of the wire are obtained from the theory of slender curved rods. Since the strand is considered long, all the derivatives of resultant stress and moments with respect to the arc length of the wire are neglected. Since the helical wire is wound on a straight cylindrical core, the normal curvature and the

ARPN Journal of Engineering and Applied Sciences

corresponding normal bending moment of the wire are zero. Hence, the equations of equilibrium are written as:

$$-N'\tau + T\kappa' + X = 0 \tag{3}$$

$$N\tau + Y = 0 \tag{4}$$

$$-N\kappa + Z = 0 \tag{5}$$

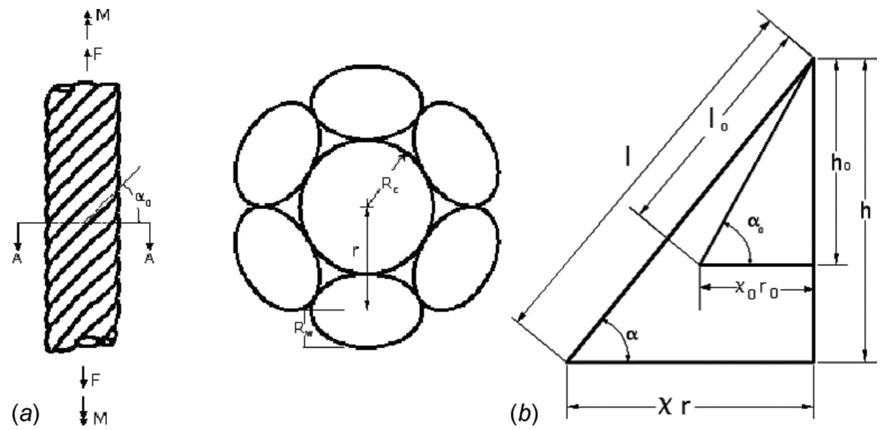

Figure-1. Strand geometry.

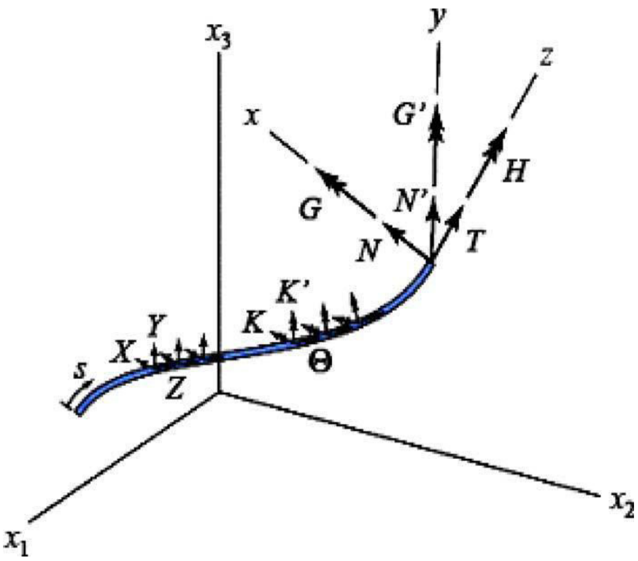

Figure-2. Forces and moments produced on a helical wire.

$$-G'\tau + H\kappa' - N + K = 0 \tag{6}$$

$$N + K' = 0 \tag{7}$$

$$\Theta = 0 \tag{8}$$

where "κ' " is the bi-normal curvature and "τ" is the twist of the wire. When the slipping between helical wires during the extension of the strand is considered, the tangential distributed forces between the core-wire and the wire-wire are given by

$$V = \mu U\,; W = \mu U\,; P = \mu S\,; Q = \mu S \tag{9}$$

where "μ" is the coefficient of friction between the core wire and the helical wire.

On substitution and rearranging, the following equations are obtained:

$$N' = \frac{-G'(R_w\tau^2 + R_w\tau\kappa' + \tau) + H(R_w\kappa' + R_w\tau\kappa' + \kappa') - T(R_w\kappa' sin\beta)}{(\mu R_w \tau sin\beta) + (R_w\tau) + (R_w\kappa') + 1} \tag{10}$$

The resultant axial force and axial twisting moment acting on the outer layer of the strand is given by

$$\mathrm{F_w = m(Tsin\alpha + N'cos\alpha)} \tag{11}$$

$$F_w = m\left[\left\{\left(sin\alpha - \frac{i}{j}cos\alpha\right)AE.a - \frac{g}{j}cos\alpha \mathrm{EI.c} + \frac{h}{j}cos\alpha\frac{\mathrm{E}}{2(1+\nu)}\mathrm{J.e}\right\}\varepsilon + \left\{\left(sin\alpha - \frac{i}{j}cos\alpha\right)AE.b - \frac{g}{j}cos\alpha \mathrm{EI.d} + \frac{h}{j}cos\alpha\frac{\mathrm{E}}{2(1+\nu)}\mathrm{J.f}\right\}\gamma\right] \tag{12}$$

$$\mathrm{M_w = m[Hsin\alpha + G'cos\alpha + T.rcos\alpha - N'.rcos\alpha]} \tag{13}$$

$$M_w = m\left[\left\{\left(rcos\alpha + \frac{i}{j}.rsin\alpha\right)AE.a + \left(cos\alpha + \frac{g}{j}.rsin\alpha\right)\mathrm{EI.c} + \left(sin\alpha - \frac{h}{j}.rsin\alpha\right)\frac{\mathrm{E}}{2(1+\nu)}\mathrm{J.e}\right\}\varepsilon + \left\{\left(rcos\alpha + \frac{i}{j}.rsin\alpha\right)AE.b + \left(cos\alpha + \frac{g}{j}.rsin\alpha\right)\mathrm{EI.d} + \left(sin\alpha - \frac{h}{j}.rsin\alpha\right)\frac{\mathrm{E}}{2(1+\nu)}\mathrm{J.f}\right\}\gamma\right] \tag{14}$$

where "m" is the number of wires in that layer.

The central core is under the action of axial forces, twisting moments, and lateral forces along the line of contacts. To evaluate the deformation of the central core, the line forces S on the curved surface of the core are replaced by a statically equivalent uniformly distributed lateral pressure with intensity. The formation of the strand, the constraint of central core always causes separation

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between helical wires. For all the models, analysis is done until the wires are not separated. The strand force, strand stiffness, and contact stress are higher in the present model com-pared with other models because all the wire forces are considered along with the effect of friction. In a line contact, the stress distribution is complex. The effect of stress concentration is considered and contact stress is determined theoretically using the Hertz solution. Along these lines of con-tact, the movement of the wires occur depending on the resisting the friction force that is developed at the interface.

3. RESULTS AND DISCUSSIONS

Using the numerical data of the strand given above, the results of strand force, strand twisting moment, strand stiffness, contact force, and contact stress are obtained for the fixed end condition. In the fixed end condition, there is no rotational strain on the strand. The models are worked with the above cable data and the results are compared with the present model. With the change in orientation of helix angle which is always assumed to be constant, is made as 82.53°/-75.62°, 73.29°/62.36° and 62.24°/-71.02°. This change in orientation has made the better comparison of the mechanical properties of the lead cable used in cardiac pacemaker.

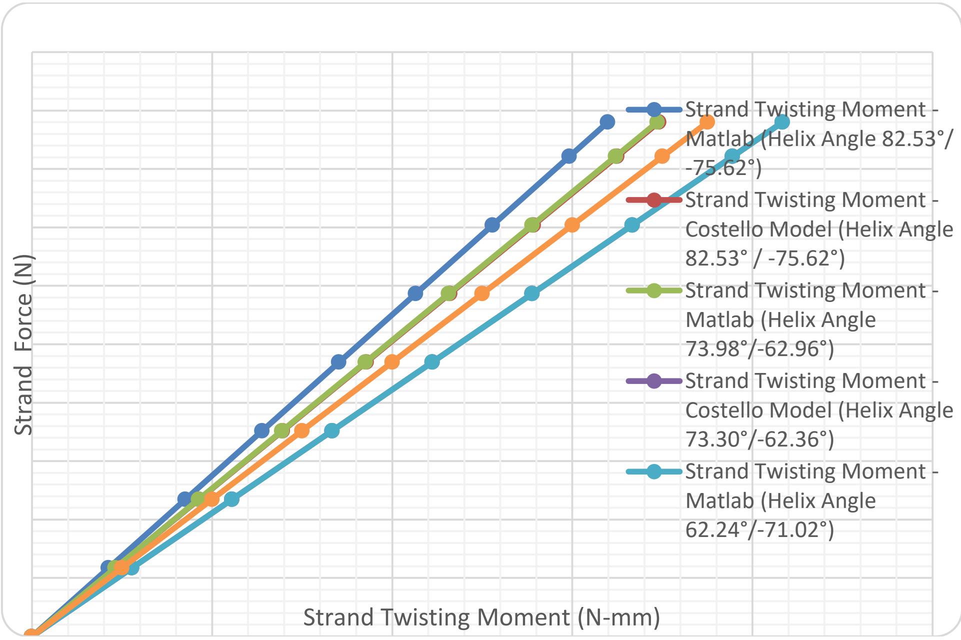

Figure-3. Strand force vs strand twisting moment.

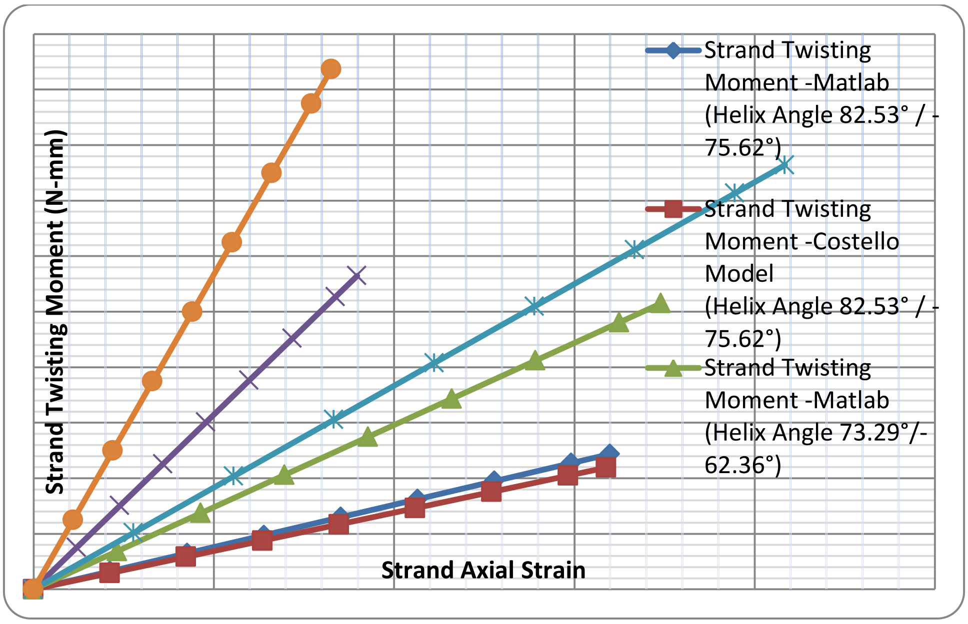

Figure-4. Strand twisting moment vs strand axial strain.

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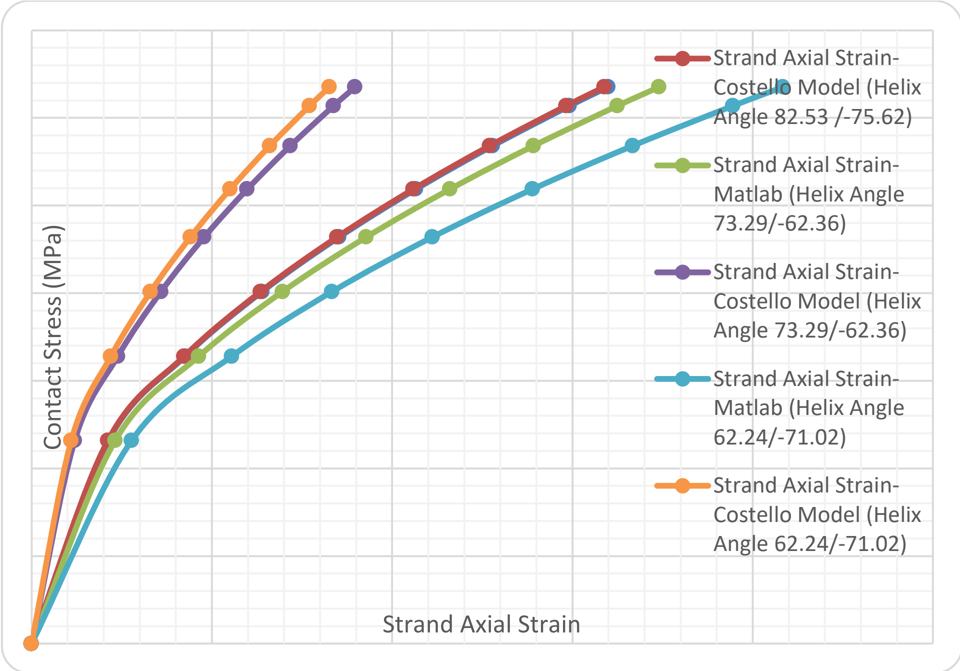

Figure-5. Contact stress vs strand axial strain.

The variations in the above results are shown as a function of strand strain. It is found that the coupled contact mode exists only in the initial stage of loading, i.e., up to a strain level of 0.0018 and thereafter turns into core wire contact. The figures are plotted only up to the range where coupled contact exists.

4. CONCLUSIONS

In a helical wired strand, the nature of the contact between the wires and the core play a significant role in predicting the behavior of the strand. A strand with a core-wire and wire-wire coupled contact is analyzed. During the initial stages of loading, the coupled contact persists, thereby; all the interface contact loads influence the strand stiffness. Hence, a higher stiffness is predicted. During further extension of the strand, the deformation in the wires causes separation between the wires leaving the strand under the core-wire contact mode only. Although the coupled core-wire and the wire-wire contact mode exist during the initial stages of loading, its significance is relevant to predict the strand behavior in this stage. It is hoped that this influence will be noted by the design engineer in order to design the cable geometry suitably.

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