Chapter 6

Torsion in Multistrand Cables

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6.1 The Problem

Multistrand cables are used widely in industry. Overhead electrical conductors, wire ropes and suspension cables in mine hoists are typical examples. The simplest construction involves a straight core wire surrounded by concentric layers of strands, while more complex cables involve a stranded core. (See Figure 6.1.) All strands in a given layer remain twisted about the cable axis at a fixed angle known as the layer angle, as in Figure 6.2. Adjacent layers remain twisted in opposite directions to one another, clockwise or anticlockwise in order to minimize torsion when the cable is loaded axially. Such a construction involves interaction between strands in contact.

A simple model, developed recently by Lanteigne and Akhtar [1], predicts the maximum failing load and torsion of the cable using data on the wire strands as the input parameters. That model has made the simplifying assumption that no frictional interaction occurs between adjacent strands. Experiments carried out by Akhtar and Lanteigne [2], are in excellent agreement with the predictions of the model for multistrand conductors made with aluminum alloy strands and for the measured values of true tensile stress for all cables. However, the model predicts torsion values for cables containing galvanized steel strands that deviate substantially from those measured experimentally. It has been concluded [2] that interstrand and frictional interaction does not occur between strands

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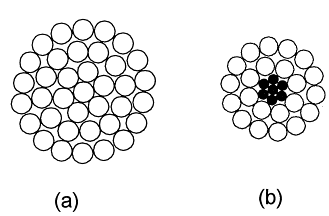

Figure 6.1: Cross-section of a multistrand cable

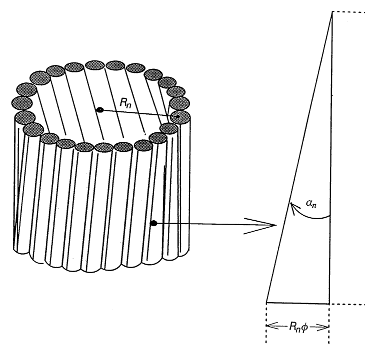

Figure 6.2: Single layer and angle of strands

made of aluminum and aluminum alloys and that frictional interaction occurs when galvanized steel strands are used for the construction of the multistrand cable.

Proposed objective for the PIMS Workshop 98: *Modify the existing model [1] or develop an alternative model to predict torsion in multistrand cable involving interstrand friction.*

Dr. Akhtar made the programme “conse” used in the calculation of [1] available to us as well as data for various sample cables in [3].

6.2 Solution Strategy

The initial discussion focussed on the consideration of possible frictional forces that must occur between the layers. Newton’s Third Law however says that these will occur in equal and opposite pairs and both the resultant force and resultant moment of such pairs will be zero.

More subtle effects of the frictional forces will be the redistribution of the forces and moments on the ends of the cable where the boundary conditions are those of fixed displacement. A simple thought experiment for the case of wires of different materials suggested that load would be shifted from the stiffer to the less stiff material by the friction. A naive adjustment based on this idea was made for the programme “corse” and the result checked for one of the examples. A change of the correct sort occurred but clearly any further effort in this direction would require more detailed work and would not solve the problem in the case of materials of the same kind such as all steel cables. This idea was left for possible later consideration.

The method which was finally used amounted to the introduction and distribution of “body couples” between the layers. These body couples were taken to be proportional to the normal force between layers with a coefficient of friction as the constant of proportionality. The coefficient of friction μ was assumed to depend only on the materials in the two adjacent layers; that is, aluminum–aluminum, aluminum–steel, or steel–steel. The values of these coefficients of friction became free parameters in our numerical experiments. Because the theory and experiment agreed in the all aluminum cable we made $\mu = 0$ in this case.

The formula and its derivation are given in Section 6.3. An adjustment was made to the programme “conse” and numerical experiments were carried out .

First we treated the all steel cable so that only one free parameter was available. A value was calculated to fit one set of data and the same parameter was used with other data sets. This method was repeated for the aluminum–steel wire “Peace.” Results of these numerical experiments are given in Section 6.4.

6.3 Changes in the Theoretical Model

In [1], Lanteigne and Akhtar obtain the following formulae for the incremental changes δF, δT in the axial force and the torque due to the incremental change $\delta\left(\frac{u}{l}\right)$ in the strain (these are adjusted here to the special case when there is no external twist)

$$\delta F = (AE)\delta\left(\frac{u}{l}\right) \tag{3.1}$$

$$\delta T = C\delta\left(\frac{u}{l}\right) \tag{3.2}$$

where

$$AE = \sum_{n=0}^{N} K_n A_n \cos^3\alpha_n \left(\frac{d\sigma_n}{d\varepsilon_n}\right) \tag{3.3}$$

$$C = \sum_{n=0}^{N} K_n A_n R_n \sin\alpha_n \cos^2\alpha_n \left(\frac{d\sigma_n}{d\varepsilon_n}\right). \tag{3.4}$$

In these formulae, K_n is the number of strands in the layer n, A_n is the cross sectional area of a strand in layer n, R_n is the radius of the helix for a strand in layer n, α_n is the lay angle for layer n and $\frac{d\sigma_n}{d\varepsilon_n}$ is the slope of a specified stress strain curve at the current value of the strain $\varepsilon_n = \left(\frac{u}{l}\right)\cos^2\alpha_n$. The increment of the force f_n along the axis of the helix is $df_n = A_n\left(\frac{d\sigma_n}{d\varepsilon_n}\right)d\varepsilon_n$. To account for the observed discrepancies between theory and experiment the value of C should be increased.

Note that α_n the lay angle is positive when the helix is anticlockwise and negative when it is clockwise. This means that the value of C is positive when the outer layer is anticlockwise and negative when it is clockwise.

To find the normal force per unit length between layers we use the normal component of the force due to a tension for the helix. This is $\kappa_n f_n$ directed toward the central axis of the helix where κ_n is the curvature. In terms of the lay angle α_n and the radius R_n of the helix the curvature is given by $\frac{1}{R_n}\sin^2\alpha_n$, thus the normal force is $\frac{f_n \sin^2\alpha_n}{R_n}$ per unit length.

This force would represent the normal force due to the n^{th} layer on the $n-1^{st}$. If we denote the outer layer as the N^{th} then the total normal force between the $n+1^{st}$ and n^{th} layers is $\sum_{k=n+1}^{N} \frac{f_k \sin^2\alpha_k}{R_k} = G_n$. (Equivalently, $G_{n-1} = G_n + \kappa_n f_n$, with $G_N = 0$).

We now consider a strand in the n^{th} layer, as shown in Figure 6.3. It is assumed that the normal forces G_n give rise to frictional forces $F_n = \mu_n G_n$ as shown. The contribution of these forces to the total torque is estimated as follows.

The resultant tangential force is taken to act at the centre of the layer and its moment is then

$$(F_{n-1} - F_n)R_n = (\mu_{n-1}G_{n-1} - \mu_n G_n)R_n.$$

The contribution to the torque for the whole layer is thus $(\mu_{n-1}G_{n-1} - \mu_n G_n)K_n R_n$. These contributions are summed over all layers to give the total torque.

The incremental change in the torque is then related to the incremental change in strain $\delta\left(\frac{u}{l}\right)$ by $\delta T = (C + C')\delta\left(\frac{u}{l}\right)$ where C is the constant defined in Equation 3.4

$$C'\delta\left(\frac{u}{l}\right) = \sum_{n=1}^{N}(\mu_{n-1}\delta G_{n-1} - \mu_n \delta G_n)K_n R_n$$

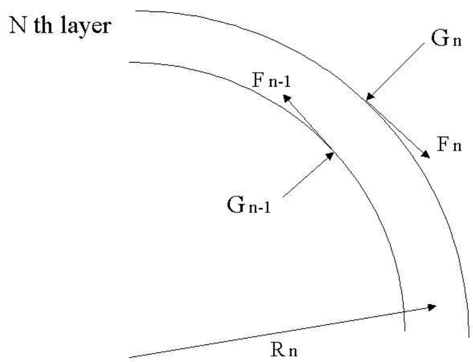

Figure 6.3: Single layer of strands

and

$$\delta G_n = \sum_{k=n+1}^{N} \frac{\sin^2 \alpha_k A_k}{R_k} \left(\frac{d\sigma_k}{d\varepsilon_k}\right) \cos^2 \alpha_k \delta \left(\frac{u}{l}\right).$$

The friction coefficients μ_n are parameters which depend on the nature of the n and $n+1^{st}$ layers.

For all aluminum cables all μ_n are taken to be zero, as the results for such cables seem to be satisfactory. For the other examples μ_n is given one value for all steel cables and another for steel aluminum interfaces. The values are chosen to give a good fit for one set of data and these values are used in other sets of data to examine the credibility of the model.

This model is equivalent to the introduction of resultant body couples of magnitude $\mu_{n-1}G_{n-1}(K_nR_n - K_{n-1}R_{n-1})$ at the n^{th} interface (n^{th} interface between layers $n-1$ and n) since

$$\sum_{n-1}^{N} K_nR_n(\mu_{n-1}G_{n-1} - \mu_nG_n) = \sum_{n=1}^{N} \mu_{n-1}G_{n-1}(K_nR_n - K_{n-1}R_{n-1}).$$

Note $G_N = 0$, $R_0 = 0$ so that $\sum_{n=1}^{N} K_nR_n\mu_nG_n = \sum_{n=0}^{N-1} K_nR_n\mu_nG_n = \sum_{n=1}^{N} K_{n-1}R_{n-1}\mu_{n-1}G_{n-1}$. The second form of the correction shows clearly that $C' > 0$ as the experiments in [2] suggest.

6.4 Numerical experiments

These were carried out using the data from 5/8 Ground wire, "gwire18" (all steel), Curlew (steel-core, aluminum) and Peace (steel core-aluminum) [3]. For the ground wire the friction μ_G coefficient was chosen to fit the data for the three layer wire and then tested against the two layer case.

The four layer curlew was fitted by using the previous value of μ_G for the steel–steel interface and choosing a new coefficient for the steel–aluminum interface. The aluminum–aluminum interface coefficient was taken to be zero because of the already excellent agreement obtained in [1, 2, 3] for all aluminum cables. These values were then used for a comparison with the three layer Peace results.

The approximate values for the torque in the two examples were

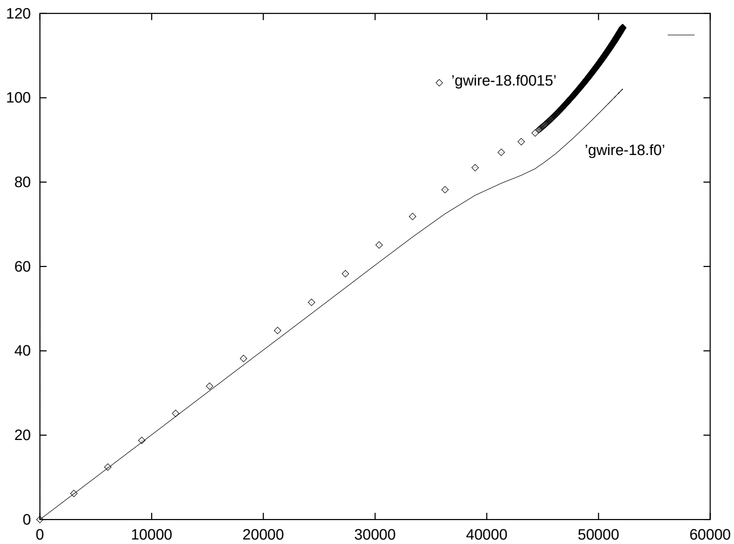

Figure 6.4: Torque vs Force in gwire 18

	Old Theory	New Theory	Exp.
5/8 cable, 2 layer	−76	−63	−53
Peace, 3 layer	−93	16	−70

Both results give corrections in the right direction. The first is not too bad, the second correction is perhaps a little to vigorous. Below we show graphs of Torque versus Force for the 5/8 cable, 2 layer ,"gwire 18" (Figure 6.4) and the "Peace" (Figure 6.5).

6.5 Conclusions

We were unable to devise a convincing new model and consequently resorted to numerical experiments with a feasible model allowing ourselves the luxury of choosing a parameter to fit a chosen set of data. To test whether the method was credible this choice was then used with other data.

The results were unconvincing and although they suggest that the changes were at least not in the wrong direction they are not recommended as a solution to the problem. A more detailed investigation of the changes might yield better results. For example our model did not take into account the number of contact points between two layers. The direction of the forces $\mu_n G_n$ is also rather arbitrarily specified and is perhaps not correct. These are matters which we hope to address in the future.

6.6 References

[1] J. Lanteigne and A. Akhtar, "Evaluation of Tensile Strength of Multistrand Conductors — Part I: Theoretical Basis", *ASME Journal of Engineering Materials and Technology*, Vol. 120, No. 1, 1998, pp. 33–38.

[2] 2 A. Akhtar and J. Lanteigne, "Evaluation of Tensile Strength of Multistrand Conductors — Part II: Experimental Results", *ASME Journal of Engineering Materials and Technology*, Vol. 120, No. 1, 1998, pp. 39–47

[3] 3 A. Akhtar and J. Lanteigne, "Tensile Strength of Stranded conductors in Relation to Properties of Constituent Wires", Report 84 J 637, December 1993.

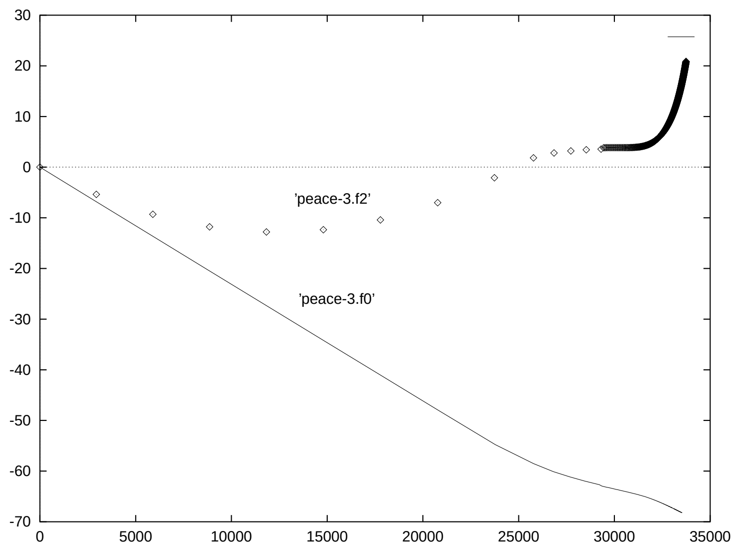

Figure 6.5: Torque vs Force in Peace