Study of the relation between torsional shear stress and transverse torsion angle of cable

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Abstract. The relation between torsional shear stress and transverse rotational angle of earphone cable was investigated due to hypothecated to play an important role in the cable entanglement. The cable was hung with a circular plate and attached to force sensor on top. The experiment was carried out by rotating the plate stepwise at 90 degrees each for 80 times reaching 7200 degrees in total. Experimental results exhibit the fluctuation of longitudinal force with period almost exactly equals to a complete circle of transverse rotational displacement. It is also found that average longitudinal force tends to increase with counter clockwise rotation while decreasing in clockwise direction. We then conclude that the relationship between torsional shear stress and transverse torsion of the cable can be described by trigonometric function with linear changing of average amplitude.

1. Introduction
The problem that most wired-earphone users have usually been affected is the tangling and messiness of cable. We hypothesize that one of the reason of such entanglement is the longitudinal force caused by transverse torsion or the so called ‘torsional shear stress’. There have been existed an explicit explanation on the relation between torsional shear stress and rotational angle but at limited angular displacement [1]. This study empirically investigates such relation at much larger rotational displacement.

2. Equipment and Experiment
Samples of earphone cable were brought from the market to be used as specimen. Vernier Dual-Range force sensor was brought into the experiment to measure the longitudinal force. The stronger cable is being pulled to the ground, the more positive longitudinal pulling force will be displayed by force sensor. In order to varying the transverse rotational displacement, circular plate with degree scale was hung with the cable and attached to the force sensor on top. Such experimental setup enables us to record the longitudinal force continuously all along the whole experiment.

After setting up the experiment, we rotated the plate counter clockwise at 90 degrees each and observed the force that was shown on the force sensor. The experiment carried on by increasing rotational angle stepwise, 90 degrees each, for 80 times to complete 20 full circle or succeeded 7200 degrees in total. The experiment was performed twice then changing the direction of rotation to clockwise and repeat all steps again.
3. Results
Graph plots between longitudinal force and angular displacement shown in figures 1 and 2 are both the case of counter clockwise rotational experiment. The plots apparently show periodic fluctuation of longitudinal force with angular displacement. Moreover, there exists a tendency of increasing on average longitudinal force with higher rotation angle.

![Figure 1](image1.png)
**Figure 1.** The plot between longitudinal force and angular displacement on counter clockwise rotation in the first experiment.

![Figure 2](image2.png)
**Figure 2.** The plot between longitudinal force and angular displacement on counter clockwise rotation in the second experiment.

After the direction of rotation was changed as shown in figures 3 and 4, the plots between longitudinal force and angular displacement still exhibit periodic fluctuation behaviour similar to the counter clockwise ones. In contrast, the trend lines of average force in both experiments appear to goes down which make the slope negative.

![Figure 3](image3.png)
**Figure 3.** The plot between longitudinal force and angular displacement on clockwise rotation in the third experiment.

![Figure 4](image4.png)
**Figure 4.** The plot between longitudinal force and angular displacement on clockwise rotation in the fourth experiment.

4. Discussion and conclusion
The graphs plotted between longitudinal force and angular displacement of rotation apparently suggest us the periodic fluctuation with linear changing of average force. The counter clockwise rotation gives us the increasing trend line of average force. On the other hand, the clockwise experiment exhibits decreasing average longitudinal force. According to these experimental results, we estimate the relationship between longitudinal force ($F$) and angular displacement of rotation ($\theta$) following the known trigonometric function [2]. Then, it could be written as:

$$ F = A\theta \sin\theta + B\theta $$

(1)

$$ F = A\theta \cos\theta + B\theta $$

(2)

where $F$, $\theta$, $A$ and $B$ are the longitudinal force, angular displacement, amplitude coefficient and trend coefficient respectively.
According to the fact that the experiment was performed by using a single cable along the way, it might be affected by considerably fatigue that leads to an uncertainty in restoring force which inherently connected to the longitudinal force. However, McDiarmid [3] mentioned that the predicted life of the thin cylinder is approximately $10^4$-$10^6$ cycles. In addition, Triana [4] figures out that the internal force that occurs when the cable is rotated is not strong enough to break the elastic band. Therefore, it could probably be claimed that our concern of fatigue would not affect the results that much. Consequently, the deterioration of the wire might not significantly contribute to the amplitude coefficient ($A$) but it would be rather the cumulative longitudinal force collected when the cable is repeatedly rotated that plays dominated role in $A$.

As mention above, the difference between the slopes of average longitudinal force in counter clockwise and clockwise rotations is their positively and negatively changing with accumulated angle. We postulate that such behaviour of longitudinal force might be a consequence of spiral- or spring-like internal structure of the cable. When the spring is rotated in the same direction as its spiral, it is contracted which consequently increases the pulling longitudinal force or being more ‘likely to be contracted’. Contrarily, when it is rotated in the direction opposite to its spiral, the spring is being stretched which consequently increases the pushing force or increases its ‘stiffness’. With this assumption, when we first rotated the cable in counter clockwise direction, it seems that the cable was rotated in the same direction with spiral and consequently increased the pulling force. As long as the rotation was carried on, the pulling force was being accumulated and subsequently increased an average longitudinal force. Then, after rotated in opposite direction, the spring-like cable was rotated in opposite direction to its spiral. This made it increased stiffness and resulted in pushing the internal structure apart. Such behaviour occurred decreasing longitudinal force. According to equations (1) and (2), they are presumable to be the case when we rotate the cable in the same direction as its spiral. On the other hand, their opposite sign $F = - (A \theta \sin(\theta) + B \theta)$ and $F = - (A \theta \cos(\theta) + B \theta)$ might responsible for the case when we rotate it counter turn of its spiral.

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