Bending Load Analysis of In-vehicle Multi-core Composite Cables

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We have developed a new analysis technology to accurately calculate the bending shape and bending load of multi-core composite cables installed in the undercarriage of automobiles. The multi-core composite cables are made by bundling multiple electric wires (core wires) and integrating them. They connect the electric parking brake, wheel speed sensor, etc. arranged in the wheel to the vehicle body-side unit, and are responsible for power supply and signal transmission. Demand for the cables is increasing with the electrification of automobiles and technical development of advanced driver-assistance systems (ADAS). The appealing point of the cable is the bending resistance, which prevents the conductor from breaking even when it is repeatedly bent due to the vertical movement of the wheel during traveling. In the past, the cable design was performed after determining the actual vehicle layout shape using CAD, but the calculation accuracy of the bending load was low, and the cable design had to be adjusted during prototyping and evaluation, causing the development period to be prolonged. With the newly developed analysis technology, the bending shape and bending load can be accurately calculated when both ends of the cable are fixed at a predetermined position and angle, thereby streamlining development.

Keywords: electrification, advanced driver-assistance system (ADAS), electric parking brake (EPB), CAD, CAE

1. Introduction

As the electrification of automobiles and technical development of advanced driver-assistance systems (ADAS) progress, more and more electric components and sensors such as electric parking brakes (EPB) and wheel speed sensors (WSS) are installed inside the wheels, which increases the demand for multi-core composite cables to connect to the electronic control units (ECU) on the vehicle body-side. A multi-core composite cable is made by bundling together a multiple of electric wires (core wires) that supply power to each component and sensor and transmit signals between them (Fig. 1).

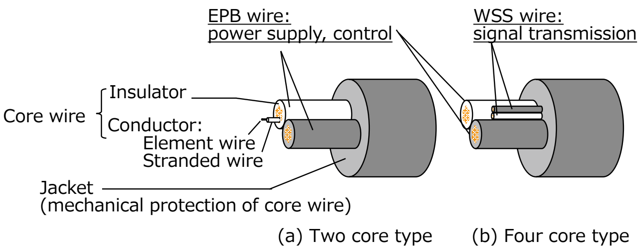


Fig. 1. Constructions of EPB cable (examples)

EPB is operated by electrical connection for the parking brake, which used to be mechanically connected to a handbrake lever on the driver's seat (Fig. 2).

EPB is becoming increasingly popular because it has the following advantage: it can be used as part of a congestion-responsive adaptive cruise control system to keep the vehicle stopped in line with a vehicle in front, it can prevent drivers from forgetting to release the parking brake, and it saves space around the driver's seat by replacing the handbrake lever with an operating button.

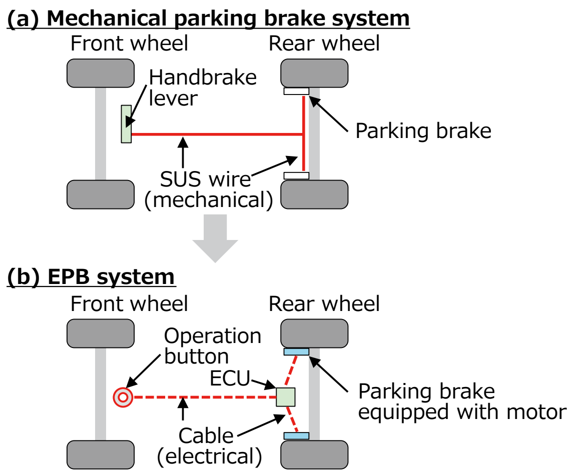


Fig. 2. Differences between mechanical and EPB systems

Since the multi-core composite cable connects the body-side ECU to the EPB unit installed inside the wheel, this cable receives repeated bending due to the vertical movement of the wheel (Fig. 3). Therefore, the appealing point of the multi-core composite cable is high bending resistance, and the conductor must not break even after it received repeated bending. The greater the number of bending cycles that lead to conductor breaking (bending life), the higher the bending resistance.

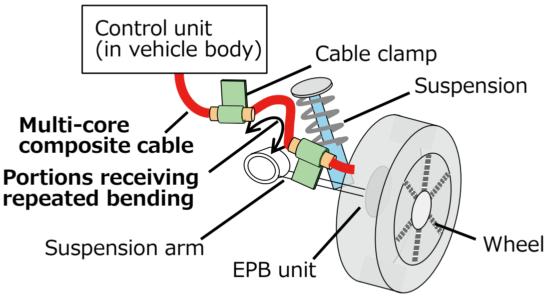
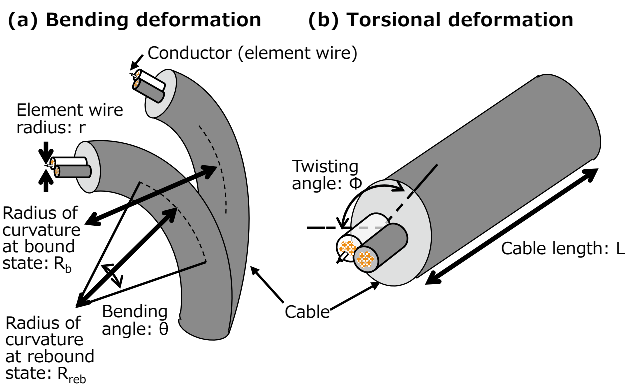


Fig. 3. EPB cable routing method

Even with the same cables, if the actual vehicle layout shape (cable length between fixing points, fixing angle, etc.) is different, the magnitude of the bending load will change and the bending life will also change. The bending load is expressed as the amount of change in strain of the conductor (amount of conductor strain) during the vertical movement of the wheel (from full extension (= full bound) to full retraction (= full rebound) of the suspension) (Fig. 4).



Amount of conductor strain due to bending

$$= r \times \left(\frac{\theta_b}{R_b} - \frac{\theta_{reb}}{R_{reb}} \right) \quad \cdots (1)$$

Amount of conductor strain due to twisting

$$= r \times \left(\frac{\Phi_b}{L} - \frac{\Phi_{reb}}{L} \right) \quad \cdots (2)$$

Fig. 4. Bending load calculation method(1)

The amount of conductor strain consists of two components: one derived from the bending deformation of the cable and the other derived from the torsional deformation. Using the radius of curvature (R_b, R_{reb}), bending angle (θ_b, θ_{reb}), and twisting angle (Φ_b, Φ_{reb}) of the cable in its full-bound and full-rebound states, respectively, the cable strain can be calculated using Eqs. (1) and (2) shown in Fig. 4.

2. Development Challenges

In the past, cable routes in the actual vehicle layout shape were drawn with CAD (Computer Aided Design). However, since CAD cannot take into account the physical properties of the cable, the bending of the cable differs from reality, and the bending load cannot be accurately calculated. For that reason, cable designs and cable routes in the actual vehicle layout shape were determined whether good or bad by time-consuming bending tests reproducing the cable routes in the actual vehicle layout shape. However, there were many cases in which the cable design or cable routes in the actual vehicle layout shape had to be reviewed because the cable failed the bending test, causing the development period to be prolonged.

In this study, we worked on the development of a technology to accurately calculate the bending load by using CAE (Computer Aided Engineering) analysis based on CAD design data. The aim was to reduce the number of adjusting operations in cable design and prototyping /evaluation of cable routes in the actual vehicle layout shape, and to efficiently develop EPB cables with guaranteed bending reliability.

First, we will explain the differences between CAD and CAE and the advantages of CAE.

CAD is a tool for computer-aided design (Fig. 5 (a)). The purpose of CAD is to draw cables and peripheral parts, including fixing parts (often made of rubber material), in a virtual space to check interference and routing between parts. The bending of the cable is determined by the cable length between the fixing points, the fixing angle, the mechanical properties of the constituent materials of the cable and fixing member, and the stress and strain working inside the cable due to the frictional force between the cable and the fixing member. In CAD, the bending of the cable is drawn by the spline curve interpolation*1 between the center points of the fixing members. Since the bending load is determined by the bending of the cable, the accuracy of the bending load calculated with CAD was low. Some commercially available CAD software offers options

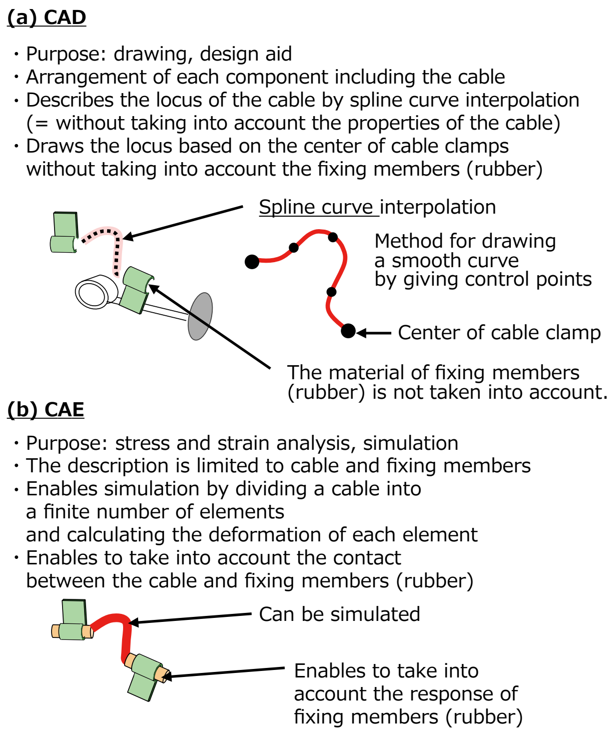


Fig. 5. Differences between CAD and CAE

for stress and strain analysis, but it is still difficult to analyze large deformations of flexible objects such as cables, and the accuracy of bending load calculation is low.

CAE, on the other hand, is a tool for stress and strain analysis of design data (Fig. 5 (b)). The description is limited to cables and fixing members, which are divided into a finite number of elements, and the equations of motion for each element are calculated. Bending and torsional deformations of the cable and the frictional force between the cable and fixing members are also taken into account, allowing for a realistic cable bending behavior and accurate calculation of bending load.

3. Study of CAE Analysis Technology

Next, we will explain the way of thinking the CAE analysis model and how to proceed with CAE analysis.

As shown in Fig. 1, a real cable has a structure in which multiple core wires are twisted together and covered with a jacket that provides mechanical protection. Meanwhile, we treated the cable as a one-dimensional uniform string (a beam element in CAE analysis) without considering its detailed structure and adjusted its parameters to the real values using the actually measured properties. Accordingly, we thought we could calculate the bending and torsional deformations and estimate the bending load with sufficiently high accuracy.

We treated the fixing members as solid elements in the CAE analysis, because it is necessary to analyze three-dimensional deformation.

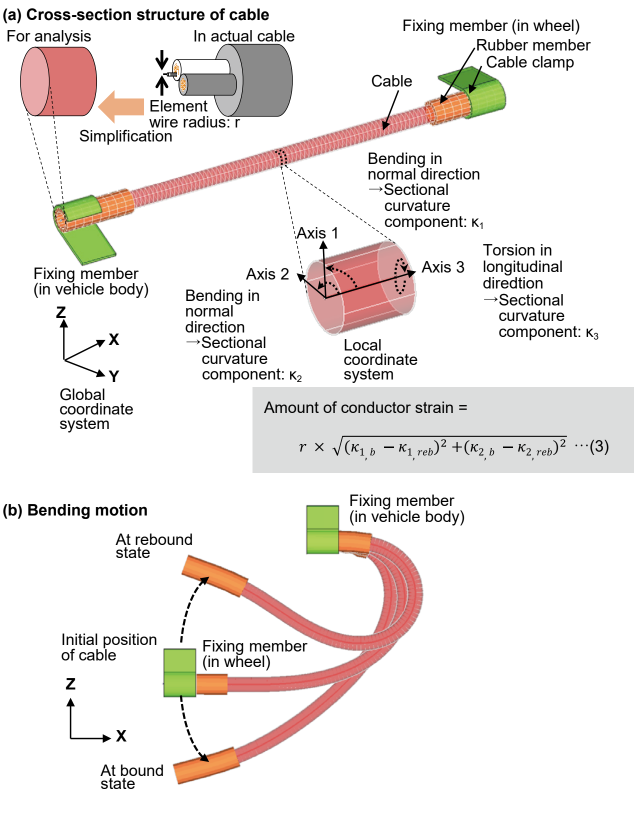


Fig. 6. Modeling of analysis object and behavior

For this analysis, we defined a local coordinate system for the cable as a beam element by specifying the longitudinal direction (local coordinate system, axis 3) and its normal directions (axes 1 and 2) of the cable.

We can calculate the amounts of the bending deformations in the directions of axes 1 and 2 and the torsional deformation in the direction of axis 3, and calculate the amount of conductor strain of the cable using Eqs. (1) and (3) given in Figs. 4 and 6.

We need the actually measured properties of the cable and fixing members such as their bending modulus of elasticity, Poisson's ratio, and specific gravity. In particular, the bending modulus of elasticity has a significant influence.

In this way, we built a CAE analysis model to proceed the CAE analysis. The following is a description of the bending motion analysis and validation of the model case.

As mentioned above, the full-bound/full-rebound fixing member positions of the suspension were drawn in CAD, the cable (beam element) and fixing member (solid element) were modeled, and the amount of conductor strain caused by the bending motion of the cable due to suspension motion was calculated by CAE analysis.

4. Verification of Analysis Accuracy

The validity of the analysis was verified in two ways as described below.

The first verification method is to measure the shape between the two ends of a model cable using a 3D scanner when the cable is bent with both ends fixed, and to check the agreement with the bending shape calculated by CAE. As a result, CAE can faithfully reproduce the actual bending shape of the cable (Fig. 7).

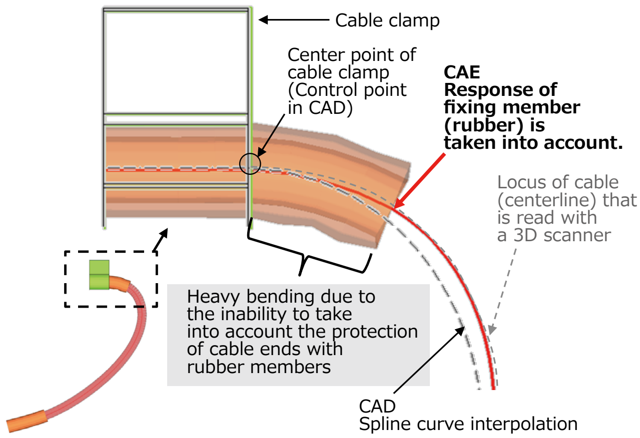


Fig. 7. Comparison with 3D scanner (at bound state)

In the second verification method, first, (i) a cable was subjected to repeated bending tests using a mandrel (a cylindrical jig that provides a certain radius of curvature) with a specified curvature, and actual measured life data (S-N diagram) was obtained. Next, (ii) the bending life of a cable that is fixed only at both ends and free between the two ends was determined, and at the same time, the amount of conductor strain was calculated from a shape simulation using CAE. Plotting (ii) on the same graph as (i), it was found to be on the S-N diagram, and it can be said that the amount of conductor strain was correctly calculated using CAE (Fig. 8, (i) = solid gray line, (ii) = white circle).

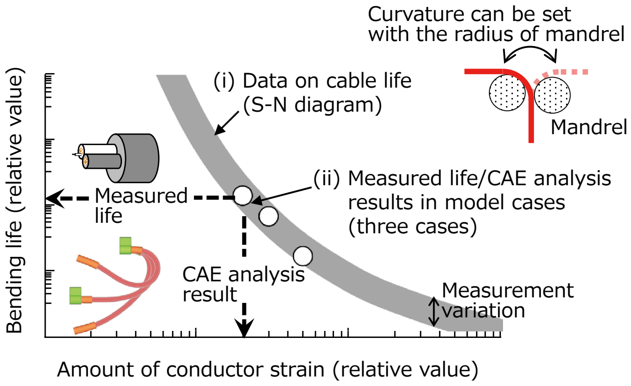


Fig. 8. Life curve and analysis result

5. Practical Use of CAE Analysis Technology

The newly developed analysis technology enables accurate calculation of the bending load of the actual vehicle layout shape, and by optimizing the cable design to match the bending load, the number of prototyping /evaluation adjusting times can be reduced, shortening the development period by 20~30%.

This technology is also used to suggest for customers the optimal shape of the actual vehicle layout. For example, when the bending load is excessively high and it is difficult to develop a cable at a reasonable cost, we suggest improvements to the actual vehicle layout shape to reduce the bending load.

6. Conclusion

As the electrification of automobiles and technical development of ADAS progress, the use of multi-core composite cables installed in the undercarriage is expanding. The appealing point of the cable is their high bending resistance, which prevents conductors from breaking even after it is bent repeatedly. This time, we have established CAE analysis technology that can accurately calculate the bending shape and bending load of a cable when both ends of the cable are fixed at a predetermined position and angle. The accuracy of the calculation was confirmed by the fact that the actual measurement of the cable bending shape using a 3D scanner matched the shape simulation.

This technology enables to suggest cable designs and actual vehicle layout shapes that satisfy bending resistance without repeated adjusting in prototyping/evaluation. We believe that this technology will be utilized in the further electrification of automobiles and, eventually, in the development of self-driving vehicles.

Technical Term

∗1 Spline curve interpolation: In computer graphics, this is a method of expression for drawing curves in a simplified manner. By setting arbitrary control points, a smooth curve can be drawn through all the control points.

Reference

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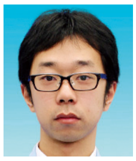

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