A Study on the Reliability of Cable Applying to Front Steering System

Yuji Kimura[1], Kouichi Suyama[2] and Yasuo Shimizu[2]

1. Department of Materials Science and Technology, Kogakuin University, Tokyo, Japan
2. Honda R&D Co.Ltd. Tochigi R&D Center, Tochigi, Japan

ABSTRACT

For realizing better safety performance, driving position flexibility and layout flexibility various demands to improve steering structure of a current automobile have been pointed out in these days. For this purpose, some trials have been conducted to apply cable to a steering system which transmits steering torque to front wheel. After clarifying the tasks generated in the case of applying the cable to front steering, authors have proposed the new cable structure. As a first step, the reliability of cable was evaluated by FTA method. Then, the main factors controlling the reliability of cable system was proved to be wear fatigue behavior of cable which contact with pulley. Therefore in this paper, fatigue behavior of cable used in the abovementioned front steering system was also investigated, especially in relation to the wear characteristics of cable material. Fatigue tests were conducted under the condition of loading torque of 29.4 Nm using cable made of SWRH62A covered with plastic coating filled with oil inside. From these experiments, degradation behavior of cable made of SWRH62A was investigated under repeated bending fatigue condition, and effect of oil supply amount upon wear behavior of a cable material was examined. As a result, acceleration in fatigue damage by wear was recognized in the cable especially under insufficiently oil supplying conditions.

1 INTRODUCTION

Authors have examined reliability in the case of applying cables to a steering system which transmit steering torque to front wheel [1][2]. As a current automobile steering system is constructed by a column shaft, an intermediate shaft and universal joints between a handle and a steering gear box, the shaft's reliability is ensured by ordinal mechanical design method. However, it is difficult to design cables by using the ordinal mechanical design method. After clarifying the tasks in the case of applying the cable to front steering, the new structure of the cables was proposed. And we confirmed a possibility to ensure the reliability by an ordinal mechanical design method by using the S-N diagram which is obtained from fatigue test of the new cables [1]. As a first step, the reliability of cable was evaluated by FMEA and FTA methods. Then, the main factors controlling the reliability of cable system was made clear to be wear fatigue behavior of cable which contact with pulley. Therefore in this paper, fatigue behavior of cable used in the abovementioned front steering system was also investigated, especially in relation to the wear characteristics of cable material. Fatigue tests were conducted under the condition of loading torque of 29.4 Nm using cable made of SWRH62A covered with plastic coating filled oil inside of coating. From these experiments, degradation behavior of cable made of SWRH62A under repeated bending fatigue condition was investigated, and effect of amount of oil supply upon wear behavior of a cable material was examined.

2 FTA OF NEW STEERING SYSTEM

To evaluate the reliability of a new cable structure applying to steering system shown in Figure 1, FMEA and FTA were employed [3]. As a result of FMEA analysis failure modes of new materials system were divided into two categories, i.e., steer free and steer lock. Then, the governing factors for each failure mode were investigated and the results obtained for steer free failure mode were partially indicated in Table 1. As shown in this table, objective parts which cause the steer free failure of new cable system were pointed out as follows, (1) Inner cable, (2) End, (3) Outer cable and so on. Also, expected factors which cause the failure of abovementioned parts were considered as (1) Shortage in strength, (2) Corrosion, (3) Erosion (outside), (4) Erosion between wire strands, (5) Bending fatigue, (6) Tensile fatigue, (7) Degradation of coating and so on depending upon using situation of each part.

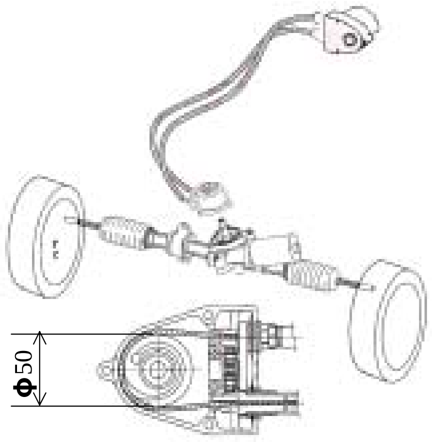


Fig. 1 New steering system employing wire

Then, through evaluating the frequency and the degree of incidence (impact factor) of occurring failure event for each failure mode, the grade of failure (risk priority number) of each part caused by each failure factor was obtained. As the most important factors which cause steer free failure of new cable steering system “Bending fatigue of inner wire together with erosive degradation between each wire” was indicated. Then, based on the FMEA the FTA was also conducted and result of the FTA was obtained as shown in Figure 2. Also in this case, importance of “Bending fatigue of inner wire together with erosive degradation between each wire” was clarified. Therefore in the following chapters, bending fatigue characteristics of wire under erosive condition were investigated.

Table 1 Result of FMEA for steer free failure mode

No.	Objective parts	Functions	Failure mode	Affecting factors	Influence to the systems
1	Inner cable	Steering control	Steer free by the inner cable fracture	1.Shortage of strength 2.Corrosion 3.Erosion(Out side) 4.Erosion between wire strands 5.Bending fatigue 6.Tensile fatigue	Steering : out of control
2	End	Steering control	Steer free by end fracture	1.Shortage of strength 2.Corrosion 3.Tensile fatigue	Steering : out of control
		Steering control	Steer free by end pull out	1.Shotage of strength 2.Corrosion 3.Degradation of coating	Steering : out of control
3	Outer cable	Steering control	Steer free by outer cable fracture	1.Shotage of strength 2.Corrosion 3.Crack 4.Degradation of outer coating 5.Bending fatigue 6.Compressive fatigue	Steering : out of control

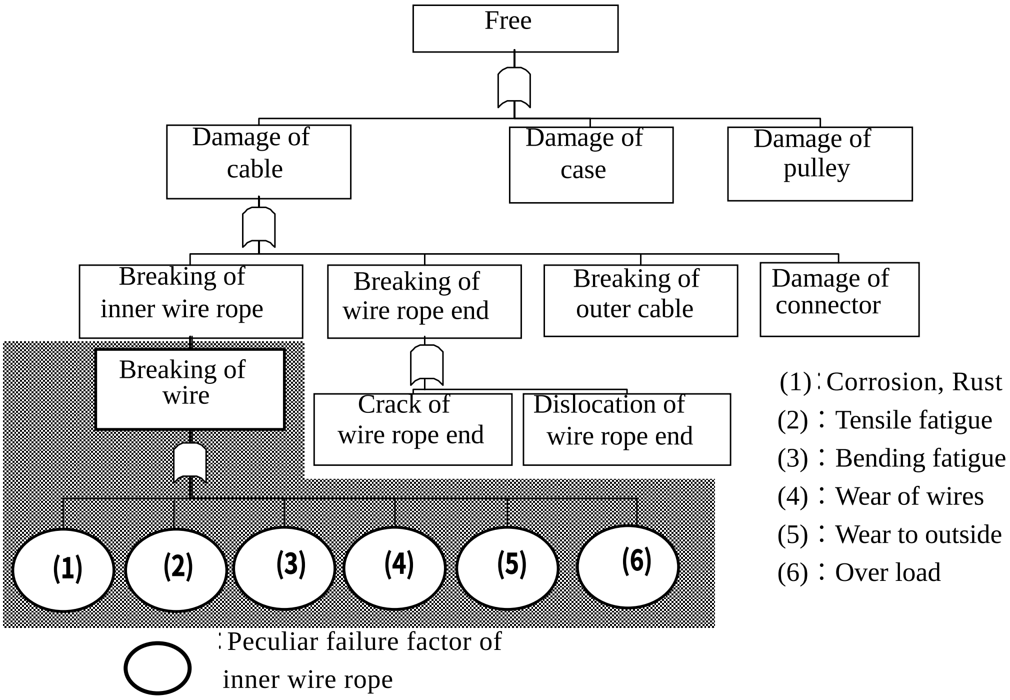


Fig. 2 Result of FTA

3 BENDING FATIGUE OF WIRE UNDER EROSIVE CONDITION

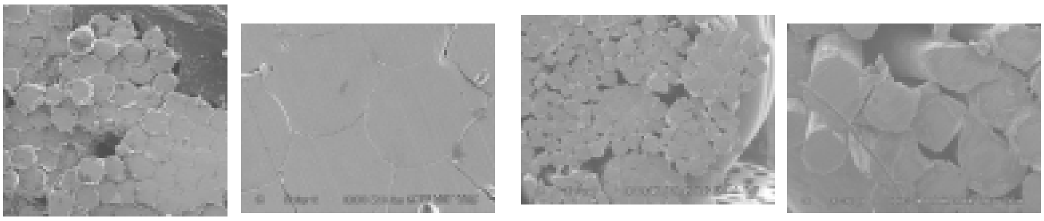
3.1 Specimen and Experimental Procedures

The test piece used in this study is the wire whose outer diameter is 3.0 mm with a 0.25 mm thick plastic coating. Total outer diameter of this wire rope is 3.5 mm. This test piece of wire made of hard drawn steel material SWRH62A has the composition of 19×19 , i.e., which has 19 strands and each strand has 19 thin element lines [4]. A fatigue test was carried out under the frequency condition of 0.3 Hz using the pulley with a diameter of 50 mm made of plastics. In order to grasp a fatigue behavior of wire, fatigue test was carried out up to the number of cycles of 5×10^5. To suppress the generation of wear between strands of wire under fatigue loading, some amount of lubricating oil was filled inside the plastic coating covered outside the wire strands. In this study, the amount of lubricating oil is ranged from 0.1 cc/m to 1 cc/m. Therefore in this study, the influence of lubricating oil amount upon the wear characteristics of wire strands was investigated. Also, the effect of ambient temperature upon the wear behavior of wire was investigated through conducting abovementioned fatigue tests in room temperature and in 100 ℃.

3.2 Influence of the wear phenomenon upon fatigue life of wire

Fatigue fracture generated after stress cycles of $N_f=4.8\text{x}10^5$ under the oil supply condition of 0.1 cc/m may be caused only under co-operating state with other degrading factors for wire materials. For this degrading factor wear effects may play the dominant role for progressing bending fatigue process of wire [5]. Therefore in this section, detailed examinations to the fracture morphologies of wire materials for fatigue fractured wire specimen and to the degraded morphologies of severely bended parts of non-fractured wire wound around plastic pulley were conducted using SEM after bending fatigue tests. Results obtained from the detailed observation of wire with rubricating oil less than 0.1 cc/m inside of plastic coating were shown in Figure 3.

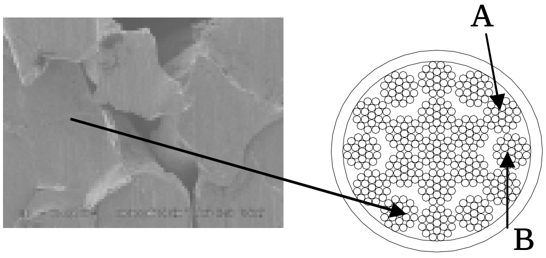
Judging from the photographs shown in Figure 5(a), no clear gaps between 19 wire elements in each of 19 wire strands were observed before fatigue testing. Also, each strand was located each other under relatively closed packed state in this case. On the contrary, in the case of wire specimen with rubricating oil less than 0.1 cc/m inside plastic coating, some gaps were generated between each wire element and packed density of wire element was considerably decreased after bending fatigue test conducted until its fatigue life of $N_f=4.8\text{x}10^5$ cycles as shown in Figure 3(b).



(a)Before fatigue testing

(b) After fatigue test : N_f=4.8x10^5 ,
cross-section near fractured section

Fig. 3 Cross-sectional morphologies of wire before and after fatigue test: Oil less than 0.1cc/m



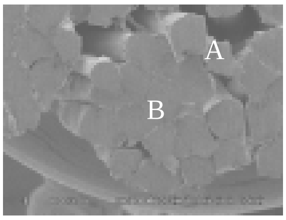
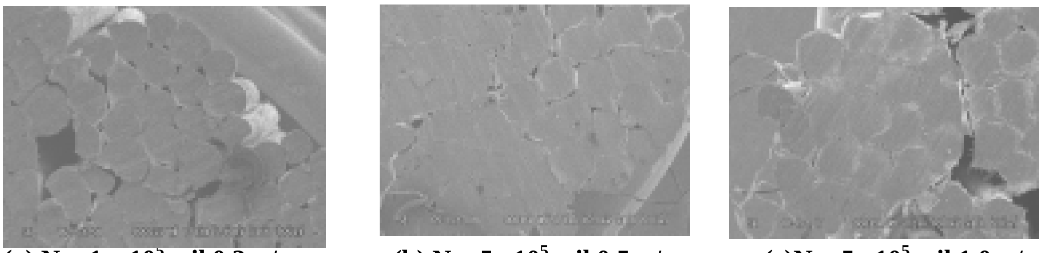


Fig. 4 Morphology of wear observed on wire

Fig. 5 Wear morphology of outer strand of wire :N_f=4.8x10^5, oil less than 0.1cc/m

Also, relatively rounded regions bending loaded by plastic pulley may be remarkably accelerated by the superposed wear effect especially in case of small rubricating oil amount less than 0.1 cc/m. Also, to prepare the specimen for SEM observation, ultrasonic washing in a solvent was conducted for removing the oil that remains between each thin wire element. After the ultrasonic washing, some strands shown in Figure 4 as A and B have revealed to fall off. Then only other strands except A and B can be seen in the cross-section of abovementioned specimen. Therefore, some other break-down of strands may be generated at other section near finally fractured cross-section. As a result, fall off of some strands were brought about by ultrasonic washing. A thin wire element which was remarkably worn off and whose cross-sectional area was clearly decreased was an outside element (A) neighboring inner strand as shown in Figure 5. On the contrary, no wear damages were recognized on a central element (B) of the same strand.



(a) N = 1 x 10^5, oil 0.3cc/m **(b) N = 5x 10^5, oil 0.5cc/m** **(c)N = 5x 10^5, oil 1.0cc/m**

Fig. 6 Wear morphology of outer strand of wire:

In addition, we studied the dependence of progress of the degrading phenomenon which were caused from wear and fatigue upon the supply oil amount. In Figure 6 cross sectional morphologies of outer layer strands of wire specimens after fatigue test of 1.0x10^5 cycles with different oil amounts, i.e., 0.3 cc/m, 0.5 cc/m and 1.0 cc/m, were indicated. From these figures, it was made clear that gaps generated between thin wire elements gradually decreased as the oil supply amount was increased. Therefore, for realizing the reliability of wire [6][7], it is necessary to supply more than 0.5 cc/m oil to a wire in case when applying it to front steering system.

4 CONCLUSIONS

Through applying FTA method to the evaluation of the reliability of cable applying to front steering system, wear fatigue behavior of cable was pointed out as the main factors controlling the reliability of cable system. Therefore, fatigue behavior of cable used in the front steering system was also investigated, especially in relation to the wear characteristics of cable material.

Results obtained are summarized as follows,

1. As a result of the FTA, importance of “Bending fatigue of inner wire together with erosive degradation between each wire” was clarified.
2. Fatigue fracture of wire was generated after stress cycles of $N_f=4.8x10^5$ only under the oil supply condition of 0.1 cc/m. It was caused under co-operating state with wear.
3. Extensive wear generation was especially recognized at the contacting regions between outer strands and inner strands.
4. The degrading phenomenon caused from wear and fatigue depends upon the oil supply amount. Observations of the morphologies of wire elements after fatigue test of $1.0x10^5$ cycles made clear that gaps generated between thin wire elements gradually decreased as the oil supply amount was increased. As a result, acceleration of fatigue damage by wear was generated in the cable especially under insufficient oil supply conditions
5. Therefore, for realizing the high reliability of wire applying to front steering system, it is necessary to supply more than 0.5 cc/m oil to a wire system.

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