TRACTION TECHNOLOGY FOR ELEVATORS

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ABSTRACT

In various industrial fields, energy and resource saving has been promoted, and also in the elevator industry, miniaturization of driving devices, lightness of cars, etc. have been pursued. Since these attempts reduce the traction capacity between the hoisting rope and the driving sheave, improvement in traction capacity by betterment of the friction transmission part is important. This paper describes friction and the wear mechanism between the hoisting rope and the driving sheave of a traction type elevator, further, the results of evaluation test of the new rope that makes substantial improvement in traction capacity possible.

1 CONVENTIONAL METHOD FOR IMPROVEMENT IN TRACTION CAPACITY

From the viewpoint of safety and reliability of an elevator, securement of traction capacity is important. Here, we introduce a calculation method of traction and conventional means for improvement in traction.

1.1 Calculation Method of Traction

A traction type elevator has structure in which the hoisting rope is wrapped on the driving sheave and the car is hung on its one end and the counterweight weighing car deadweight and a half of movable load is hung on the other end. Shown in Figure 1 is a model of the structure. Calculation of traction can be done by the following equations.

$$\Gamma_0 = e^{\mu \cdot K_2 \cdot \theta} \quad \cdots\cdots \quad (1)$$

$$\Gamma = \frac{T_1}{T_2}(T_1 > T_2) \text{ or } \frac{T_2}{T_1}(T_1 < T_2) \quad \cdots\cdots \quad (2)$$

$$\Gamma_0 > \Gamma \quad \cdots\cdots \quad (3)$$

Where, Γ_0 is traction capacity, μ is coefficient of friction between the rope and the sheave, K_2 is shape coefficient of the groove, θ is wrapping angle of the rope to the sheave, T_1 is tension of the rope on the car side and T_2 is that on the counterweight side with acceleration taken into consideration, and Γ is traction ratio. In an actual elevator, traction capacity must be secured so as to satisfy Equation (3).

1.2 Conventional Means for Improvement

As made clear by Equation (1), traction capacity is determined by μ, K_2 and θ, so that improvement in capacity can be made by increasing these values. We would like to introduce some conventional means, which have been adopted in order to heighten traction capacity.
(1) Improvement in friction coefficient
For the purpose of increasing friction coefficient of the driving sheave, there have been some cases where wood, rubber and aluminum alloy were adopted for sheaves for heavy hoists for mines and polyurethane for those for elevators. In general, however, cast iron sheaves are employed, meaning that little improvement in friction coefficient has been made.
(2) Improvement in groove coefficient
Undercut groove, which is most widely used for elevators, is indicated in Figure 2 (a). By increasing the undercut angle α, improvement in groove coefficient can be achieved. From the equation below, groove coefficient of this groove is obtainable.

$$K_2 = \frac{4(\sin\frac{\gamma}{2} - \sin\frac{\alpha}{2})}{\gamma - \alpha + \sin\gamma - \sin\alpha} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (4)$$

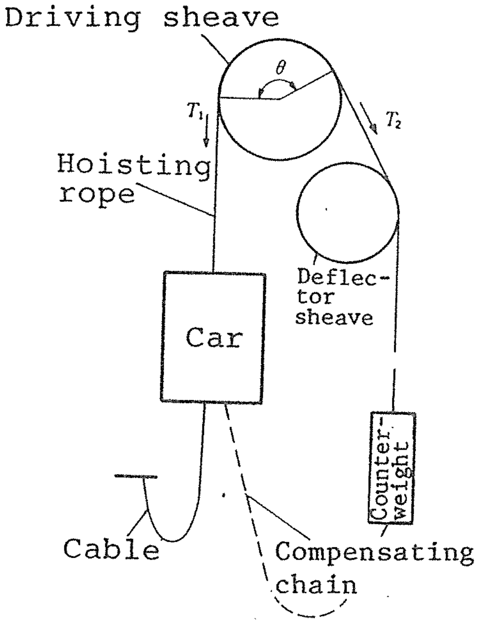
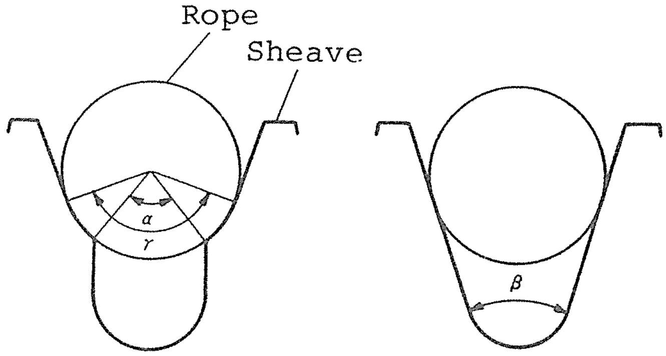


FIGURE 1 Structure model of traction type elevator



(a) Undercut groove (b) V groove

FIGURE 2 Groove configuration of driving sheave

In case a greater groove coefficient than undercut groove is required, the V groove shown in Figure 2 (b) is adopted, and the groove coefficient is calculated by the following equation.

$$K_2 = \operatorname{cosec}\frac{\beta}{2} \quad \cdots\cdots\cdots\cdots \quad (5)$$

The groove coefficient of the V groove declines due to wear in the groove. As contact condition between the rope and the sheave becomes similar to that obtained in an undercut groove if the V groove has got worn, the groove coefficient of the V groove after wear can be calculated from Equation (4). Indicated in Figure 3 are groove coefficients of worn V and undercut grooves. Owing to wear in the groove, the groove coefficient of the undercut groove increases, however, that of the V groove drastically decreases. European Committee for Standardization (CEN) stipulates that traction should be calculated with groove coefficient evaluated about 80% of that of the new one. Thus, allowable wear depth of the 30° V groove shown in Figure 3 is approximately 0.7mm, and the use of a material superior in wear resistance is essential when adopting a V groove.

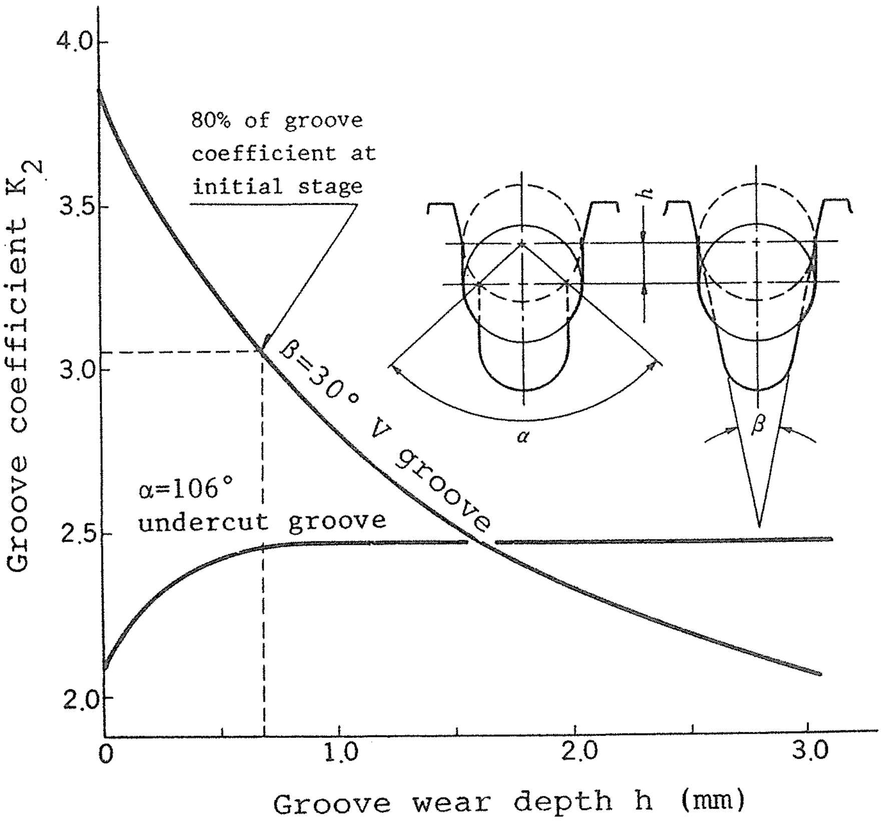


FIGURE 3 Variation characteristics of groove coefficient due to wear (in case of rope with dia. of ϕ12)

(3) Increase of wrapping angle

Single or double wrap is usually introduced as a wrapping way of the rope. Cross connection has been adopted, or, three-time wrapping has been suggested to increase wrapping angles. For these ways, new ideas have been incorporated in configurations of grooves and materials as well as the increase of wrapping angles.

Mentioned above are the general means for improvement in traction capacity. Because of problems related to life of the rope and the sheave, space of the machine room, load born by the driving device, etc., which must be cleared up for putting these means into practice, left unsolved, the means have been uncommon. For this reason, it is necessary to develop technique which can achieve improvement in traction capacity unaccompanied with the problems mentioned above.

2 FRICTION AND WEAR MECHANISM BETWEEN ROPE AND SHEAVE

Wear mechanism between the rope and the sheave must be given consideration together with that brought about on the friction surface. In this chapter, we show friction and a wear phenomenon between the rope and the sheave and explain improvement in traction capacity using sheave materials of various kinds.

2.1 Friction and Wear Mechanism

In most cases, elevators are operated under the condition that weight of the car side and that of the counterweight side are different. Figure 4 shows the distribution of contact pressures on the rope and the sheave when the relation between rope tension on the car side and on the counterweight side is $T_1 > T_2$.

P_1 and P_2 indicate contact pressures produced by T_1 and T_2 respectively. Since tension of the rope varies from T_2 to T_1 on the sheave, creep is produced on account of difference in dilation of the rope. Within the range of the angle θ_1 required for retaining difference in tension of the rope, creep is brought about. Speed of creep is amazing 0.25mm/s when speed of the elevator is 300m/min.

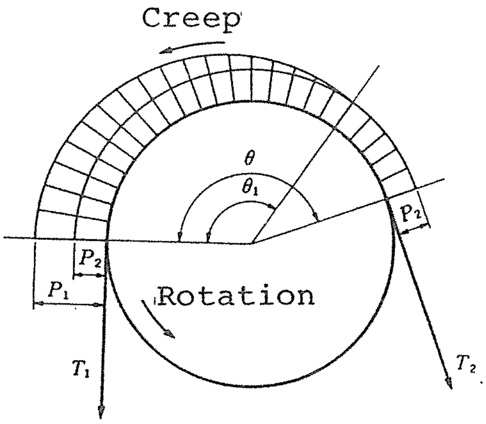


FIGURE 4 Distribution of contact pressure between rope and sheave ($T_1 > T_2$)

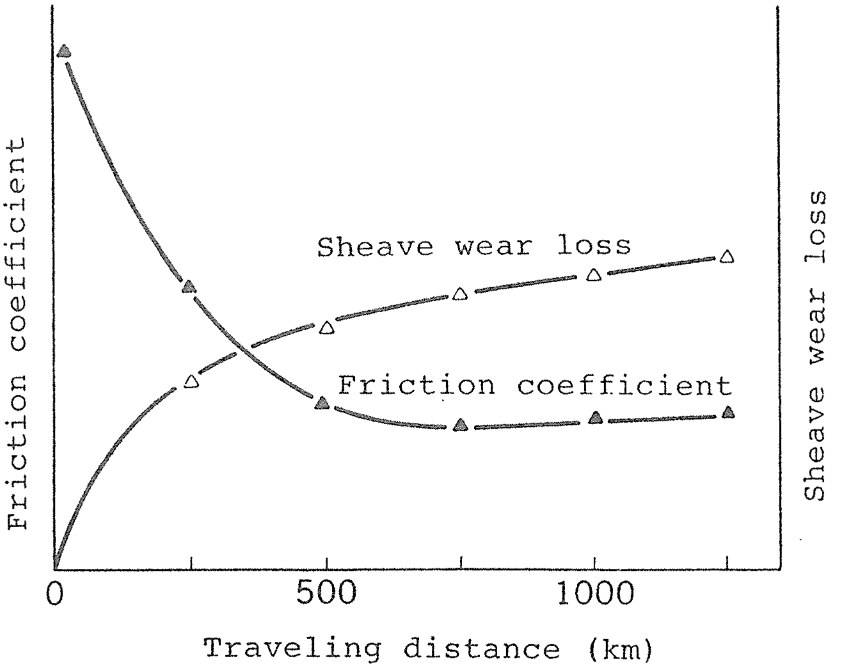


FIGURE 5 Transient variation characteristics of friction coefficient and sheave wear

Calculated on creep speed and various conditions, thickness of oil film formed on the contact portion between the rope and the sheave is $10^{-3}\sim10^{-2}\mu m$. Since surface roughness of the sheave is around 25μm, lubricated area on the contact surface is assumed to be a mix-lubricated area in which contact of the surface projection and partial oil film are found. In this lubricated area, a relatively large coefficient of friction and wear are caused. Figure 5 indicates transient variation characteristics of friction coefficient and wear loss of the sheave.

Figure 5 shows that a large friction coefficient and rapid wear occur at an early stage, however, the friction coefficient and wear speed decrease with the increase of traveling distance. This is because that the expansion of the area, on which oil film is formed, is caused by such factors as wear in projection on the surface and plastic deformation of the sheave solid surface. And, it is regarded as the cause of the decrease of the friction coefficient and wear speed. The friction coefficient shows the characteristic as indicated in Figure 5 irrespective of the speed and the capacity of the elevator. Accordingly, the minimum friction coefficient after transient variation must be adopted in design of traction.

The above results make clear that the friction coefficient varies with wear in the contact surface, and it is required to investigate the factors that pertain to wear.

2.2 Examination of High-Friction Materials

Among the factors to determine traction capacity, amelioration of only groove coefficient and wrapping angle is not expected to bring a remarkable improvement. For this reason, a special lubricant and coefficients of materials of several kinds for sheaves were evaluated to obtain high friction. For sheave materials, high-elasticity polyurethane, soft aluminum alloy of which melting point is low, copper alloy and carbon steel having the same constituent as the rope were used, and a synthetic lubricant utilized for roller speed changers was selected as the lubricant. In the test, transient variation of friction coefficients of test sheave materials combined with the standard rope was measured. The friction coefficient of the test synthetic lubricant was gauged by applying to both the present standard rope and the sheaves when the friction coefficient between the rope and the sheave was the minimum during transient variation. Measuring results are indicated in Figure 6.

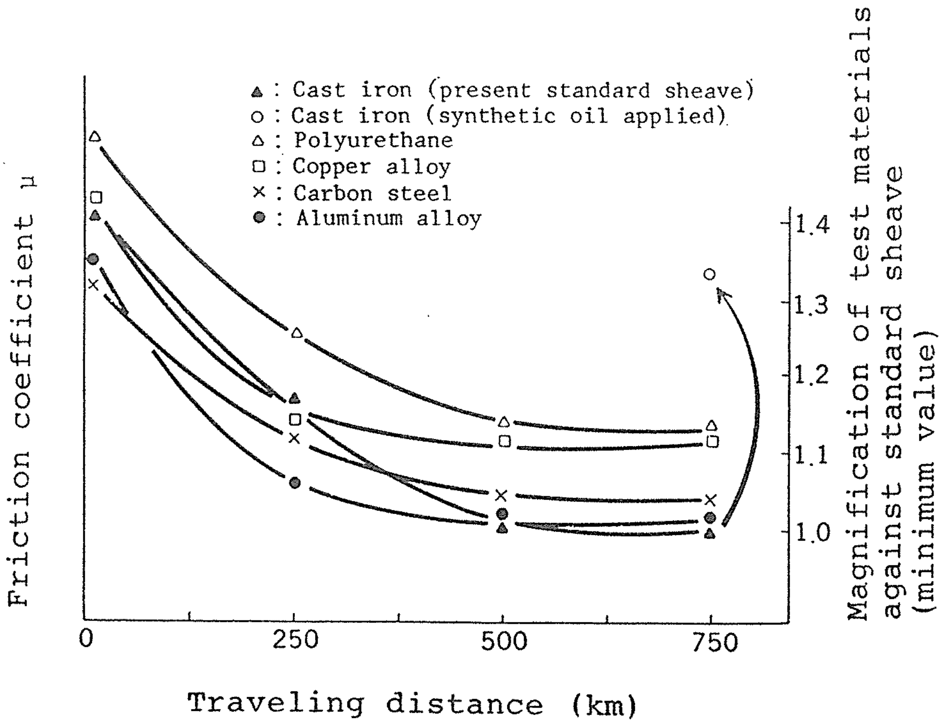


FIGURE 6 Transient variation characteristics of friction coefficient of prospective materials

Judged from the results above, all the test sheaves had greater friction coefficients than conventional sheaves, among which the one combined with the rope applied with the synthetic lubricant marked the highest coefficient. It is also generally known that friction coefficients between materials, which have low melting points and tend to burn, and between materials of similar kinds, in which intermolecular attraction easily works, reach considerably high. These actions, however, have not been expected in such a mix-lubricated area as the friction mechanism between the rope and the sheave. Polyurethane shows a relatively high coefficient, but, the amount of slip was 10 times those of the other materials. Ununiform tension among plural ropes and elastic deformation due to load are considered as the cause of this phenomenon. Higher hardness or thinner wall thickness of polyurethane is necessary for its practical use.

The above results disclosed that a remarkable increase of friction coefficient could be achieved by improving lubricant to be soaked with the rope. And, we have developed a rope soaked with this type of oil (high-traction rope).

3 DEVELOPMENT OF HIGH-TRACTION ROPE

Specifications of ropes for elevators are stipulated more strictly than those for general industrial use. In terms of prevention of scatter and protection capability, oil content is especially prescribed in a low and restricted range. Lubricant bears local load, so that the lubricant must maintain lubrication and protection capabilities for a long term without deterioration.

Next, we are going to give the results of evaluation test to the high-traction rope developed by Mitsubishi Electric Corporation, Tokyo Rope Manufacturing Co., Ltd. and Hakko Kouyu Co., Ltd.

3.1 Selection of High-Friction Lubricant

In a local area of the contact surface between the rope and the sheave, markedly high pressure is produced by contact of the projection on the surface. It is broadly understood that viscosity of oil exponentially increases with the increase of pressure born by the contact surface, and oil solidifies in glass state at the specified or higher pressure. Therefore, high-friction lubricant is required to have such characteristics as remarkably high viscosity under high pressures and being hard to shear when it solidified. It is a general thought that this characteristic largely differs depending on base oil composition and chemical construction and is affected by ramification of molecular chain structure and the number of cyclohexyl rings but barely influenced by atmospheric viscosity. Twenty odd kinds of oils were selected as prospective oils to examine friction coefficients and evaporation. In Figure 9, the test results are given.

Test oils were of polyolefin system used for base material for grease, etc. and synthetic naphthene system applied to speed changers, and naphthene mineral oil utilized for refrigerators. Since a lubricant for ropes is used in an open environment for a long time, it is also needed to possess a characteristic of being hard to evaporate, so that oils of different viscosity were adopted. Friction coefficients were measured by applying test oils to ropes. As for evaporation, variation in weight of test oils was gauged after a certain period by putting in a container and heating. Each test oil showed a higher friction coefficient than the oil in current use. On the other hand, evaporation of oils of polyolefin system was extremely low while evaporation of oils of synthetic naphthene system and naphthene mineral oils was very high. Judged from the results stated above, an oil of polyolefin system (Figure 7.A), of which friction coefficient is slightly lower than synthetic naphthene oils but evaporation is infinitely low, was selected.

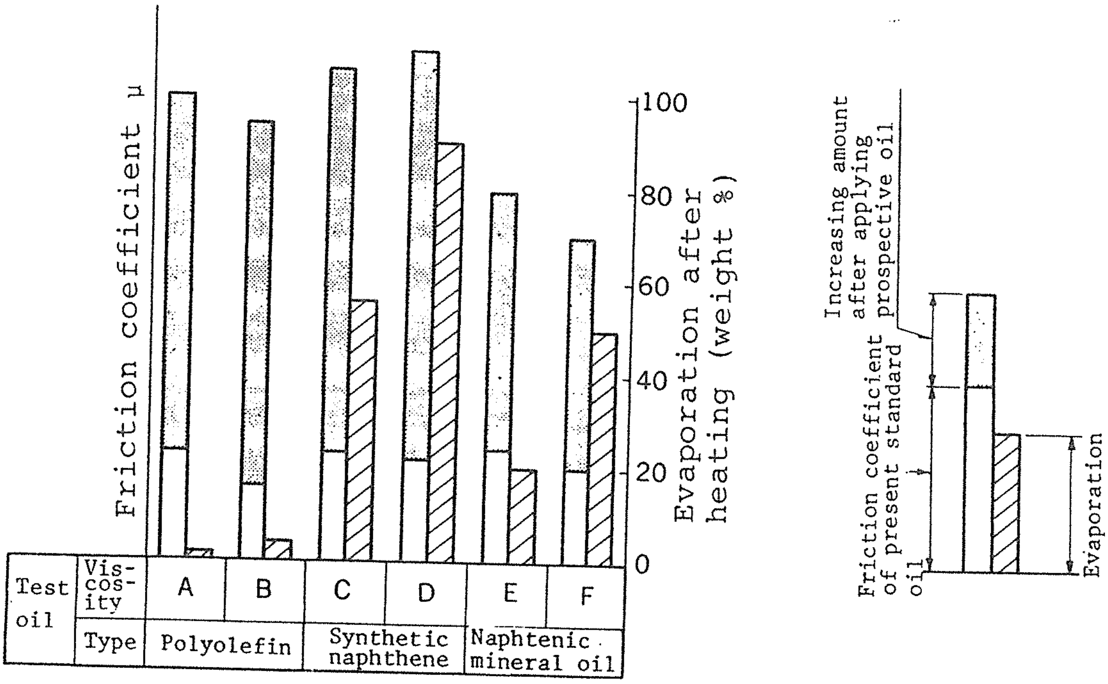


FIGURE 7 Friction coefficient and evaporation of prospective oils

3.2 Soft Solidification of High-Friction Lubricant

Lubricant for ropes for elevators is required to possess and satisfy such characteristics as permeability into the inside of ropes, adhesion strength to surface and fluidity at low and high temperatures. For the reason above, it must be in soft solidified state fulfilling the aforesaid characteristics without a lowering of friction coefficient of base oil. As a thickener, hydrocarbon wax of mineral oil system or synthetic hydrocarbon wax is picked out. Between them, the latter one is suitable for wax of high melting point, and several types of soft solidified lubricants mixed with additives were prepared. A lubricant mixed at the specified thickness showed the most excellent characteristic in the evaluation test of these lubricants. It was also found that consistency has a more prominent effect on rust preventability than the increase of rust preventives.

Furthermore, as for the rope soaked with a lubricant having the most excellent characteristics, mechanical bending fatigue life and friction coefficient were evaluated. Life equivalent to or longer than the rope used at present was confirmed after carrying out 10 million times of bending fatigue tests. Indicated in Figure 8 is the transient variation characteristics of friction coefficient. It was confirmed that the friction coefficient of the rope soaked with the developed lubricant was higher than that of the present standard rope by 30% and the characteristic of making its period to the minimum value shorter during transient variation. This improvement rate is equal to the performance of simple base oil, and we have established technique of soft solidification of base oil without a lowering of friction coefficient. (Patent pending)

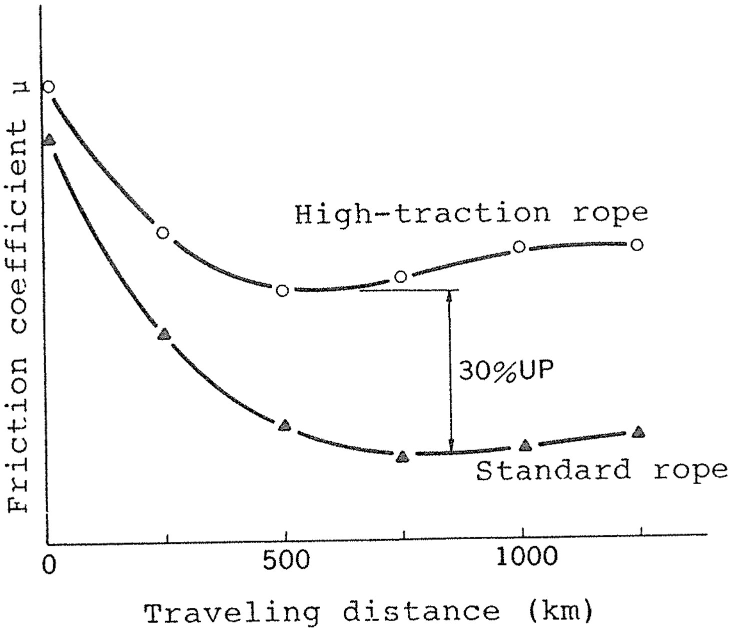


FIGURE 8 Transient variation characteristics of friction coefficient

3.3 Evaluation of Deterioration Performance

Since ropes for elevators repeatedly bear heavy load in an open environment for a long time, performance against oxidation and mechanical deterioration must be analyzed. Comparison of deterioration performance between the developed oil and the present standard oil was made in oxidation stability test after deteriorating the oils by adding oxidation catalyst, heating and applying an excessive load repeatedly. Figure 9 shows deterioration characteristics. Compared with the present standard oils, the developed oils are apt to deteriorate when they are in the state of simple pure base oil, but they attain equivalent or higher stability by giving oxidation preventives even under the condition of adding oxidation catalyst. After the test, it was confirmed that these oils developed scarcely deteriorated in the investigation by infrared spectrochemical analysis. No lowering of friction coefficient was also identified.

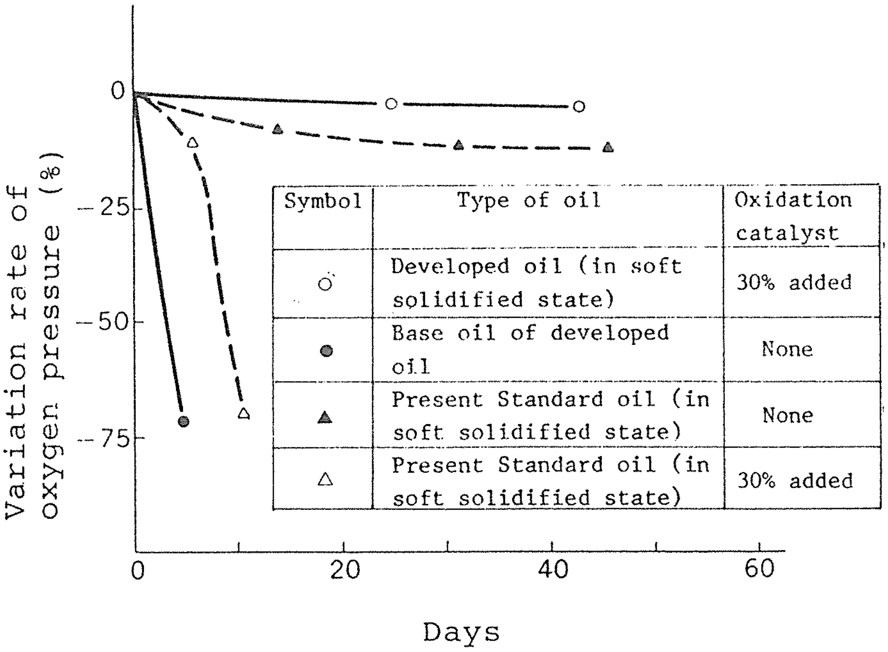


FIGURE 9 Deterioration characteristics of lubricants

4 CONCLUSION

By the steps described above, friction and wear mechanism between the hoisting rope and the driving sheave for a traction type elevator was studied, and a sheave material superior in wear resistance and the high-traction rope soaked with high-friction lubricant have been put to practical use. Thanks to them, a traction system offering longer service life and a high friction coefficient can be attained, and possibility of coping with tremendous reduction in weight of cars and miniaturization of driving devices has now been a bright expectation.
More than 300 elevators utilizing high-traction ropes operate in the field. By reviewing elevator systems with making the best use of the merits of this rope, we intend to pursue space saving and reduction of load on buildings.

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