Development of Winches with Wet-type Multi-disk Brakes

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Drum-brakes (dry-type-brakes) have been used for conventional winches on mobile cranes. However, this kind of brake presents problems in terms of performance, size and maintenance under severe operating conditions. KOBELCO CRANES CO., LTD. has developed a new winch with a wet-type multi-disk brake (free-fall brake) to solve these problems. New crawler-cranes, equipped with these new winches, are now being commercially produced. These new winches have achieved a wide-spread favorable reputation in the market.

Introduction

Winches on mobile cranes are used to lift and move loads (crane work) and to excavate earth (bucket work). Winches comprise clutches which, in clutch-on states, transfer rotations of hydraulic motors to winch drums to lift and lower suspended loads. Conversely, in clutch-off states, suspended loads fall free through their own weight. Winches with wet-type brakes (hereinafter denoted as "wet-type brake winches") comprise clutches equipped with wet-type multi-disks which control braking during free fall.

Winches for conventional cranes (**Figure 1**) comprise dry-type expandable inside-drum clutches and band-type drum brakes (hereinafter denoted as "band brakes"). They suffer from the following problems and are not very suitable for free fall operations.

1) Small coefficient of dynamic friction at high speeds
2) Overheating of brakes (Fade phenomena)
3) Wear of brake lining

Although wet-type brake winches had been considered and commercialized overseas, they have problems, associated with wet-type multi-disks, which have not been solved. However, KOBELCO CRANES CO., LTD. has developed an original wet-type brake winch for crawler cranes and successfully solved those problems. This article introduces the development.

1. Comparison between band brakes and wet-type brakes

The brake torque T_{BB} of a band brake is given by the formula (1).

$$T_{BB} \quad F_B \times \quad \exp \mu_B \times \quad 1 \times R_B \text{ N m } \quad \ldots\ldots\ldots(1)$$

where
F_B force exerted on the band, or band force (N)
μ_B coefficient of friction
     brake band lining contact angle (rad)
R_B drum radius (m)

In the case of a band brake, it is difficult of obtain stable brake torques proportional to the band force (F_B), because deformation of the band by the band force changes   and, also, μ_B and   tend to vary due to material variation, aging, surface temperature and friction speed.

The brake torque T_{BD} of a multi-disk type brake is given by the formula (2).

$$T_{BD} \quad F_D \times \mu_D \times Z \times R_D \times \quad \text{N m } \quad \ldots\ldots\ldots\ldots(2)$$

where,
F_D force exerted on the disk, or disk force (N)
μ_D coefficient of friction
Z number of friction surfaces
R_D disk friction radius (m)
     disk efficiency.

As is clear form the formula (2), the multi-disk configuration allows increase of the number of friction surfaces and, therefore, enables decrease of
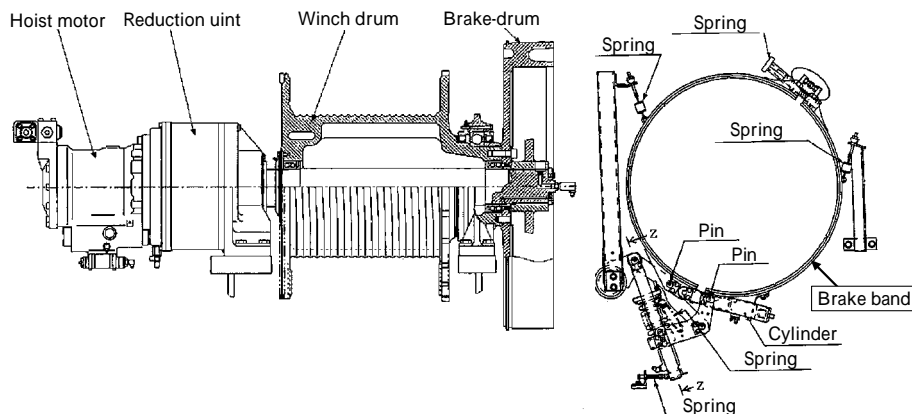

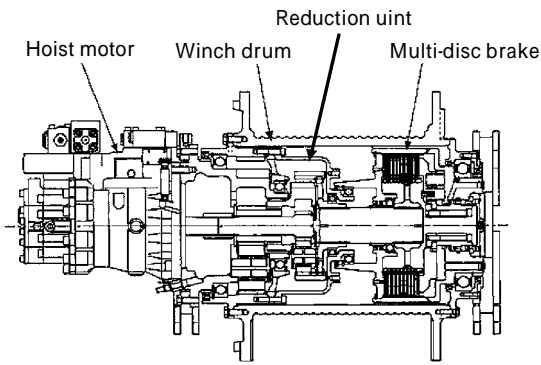Fig. 1   Winch with Band-type drum brake

Fig. 2 Winch with wet-type multi-disk brake

the disk friction radius R_D, or the radius of the disks. Taking this advantage, we developed a winch with a drum having internal wet-type multi-disks, which work as a clutch and also as a free-fall brake (hereinafter denoted as "brake"). **Figure 2** shows the cross sectional structure of a wet-type brake winch, commercialized[1] by KOBELCO CRANES CO., LTD. The winch has the following features.

1) Downsized brake and winch
   The high-speed brake, connected to a reduction unit mechanism, enabled reduction of brake torque and downsizing, allowing both the brake and reduction unit to be built into the winch drum.

2) Improvement of safety and controllability
   Precision machined parts of the brake reduce the probability of brake torque instability. In addition, the wet-type configuration prevents overheating of the brake with large coefficient of dynamic friction at high speeds.

3) Improvement of economic efficiency and environmental friendliness
   An optimized brake disk contact pressure and adequately designed cooling system reduce wear of the wearing parts to minimum, making the apparatus maintenance free. In addition, the brake assembly is enclosed so that no abrasion powder is released externally and thus is friendly to environment.

2. Technical challenges for wet-type winch brakes

Wet-type brakes have already been used as brakes for heavy vehicles and are not new in terms of their mechanism, however, the following technical challenges have to be overcome before they can be applied to winches.

1) Large solid/fluid frictional coefficients slow the free fall speeds of light suspended loads, resulting in inefficient operation.

2) The braking control during free fall is not smooth (on/off control-feeling), making speed control difficult.

3. Reduction in rotation drag resistance of wet-type brakes

3.1 Countermeasures against increase in fluid frictional resistance due to low temperature cooling oil (with high viscosity)

The developed wet brake uses the hydraulic oil of the system which actuates the mobile crane, as cooling oil. As shown in **Figure 3**, brake drag torques, which inhibit free fall characteristics, increase with lower oil temperatures, as a result of increased viscosity. The brake cooling oil is supplied for cooling; however, it does not necessarily have to be at low temperature, but only should have sufficient quantity to extract heat generated by the brake. So, an apparatus was introduced to control the temperature of the brake cooling oil in a suitable manner. When hydraulic oil passes through a pressure control valve set to a differential pressure (between inlet and outlet) of P, a temperature rise, $t[\ ]$ $0.64 \times P$[MPa], occurs as a result of energy converted to heat. (The formula assumes that the density of the oil is 850[kg/m^3] and all the energy is converted into heat and not into other forms, such as sound and vibration.) An oil heat apparatus (**Figure 4**) was developed[2] based on this characteristics. The apparatus controls
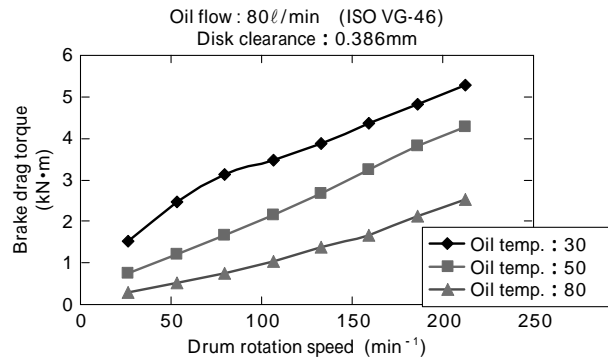

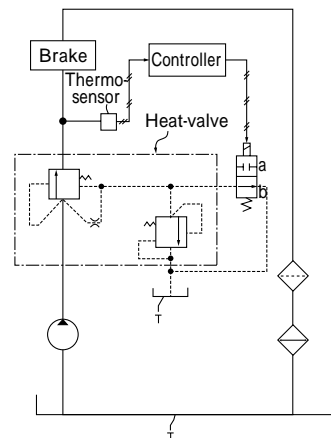Fig. 3 Brake drag-torque at each oil temperature

Fig. 4 Brake cooling oil heat apparatus

the temperature (viscosity) of the cooling oil at a suitable level by heating the supplied cooling oil when its temperature is low.

3.2 Reduction of solid friction resistance

After a transition from a braked state, in which multi disks contact each other by pressure, to a free fall state, in which the brake pressure is released, the contacts among disks are released to separate the steel plates from the friction plates, however, the brake cooling oil, passing through both the plates, tends to force them to contact each other by adsorption. As a result, the solid frictional resistance increases to resist and inhibit the free fall performance. In addition, there has been a potential problem that the free fall performance is inhibited drastically, as a result of all the multi-disks contacting each other, which causes force, along with the absorption by fluid, exerted toward the disk contact direction[note] maximizing the internal resistance against the free fall.

As a countermeasure, ring shaped compression springs (wave springs) were disposed[3] between the steel plates outside the outer periphery of the friction plates (see **Figure 5**). This creates a space at least on

Fig. 6 Result of reducing brake friction

one side of the friction surfaces, reduces the resistance associated with the pressure component ($P \times A_B$), in the disk compression direction, proportional to the brake internal pressure P, halves the number of friction contact surface, along with the absorption component ($P_B \times A_B \times Z$) and reduces the overall friction resistance significantly. **Figure 6** shows the effect (demonstration result) of the countermeasure.

3.3 Reduction in fluid friction resistance (viscosity resistance) by clearance adjustment

In general, the fluid friction resistance of wet-type multi-disk brakes decreases with increasing clearances between the steel plates and friction plates. However, when disk clearances are increased, the strokes of brake cylinders increase, along with the stroke volumes. This leads to degradation of brake operational responses and, therefore, the brake clearances cannot be increased indefinitely. The developed winch has an optimized clearance, which is determined experimentally from the balance of reduced viscosity resistance and operation responses. **Figure 7** is an experimental result showing the relation between the multi-disk clearance and brake drag
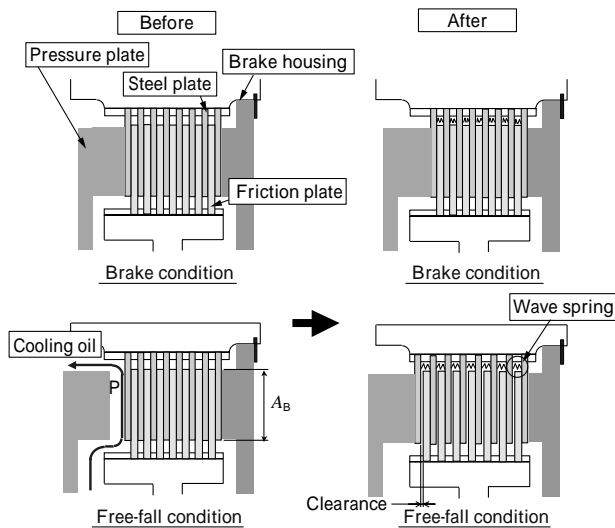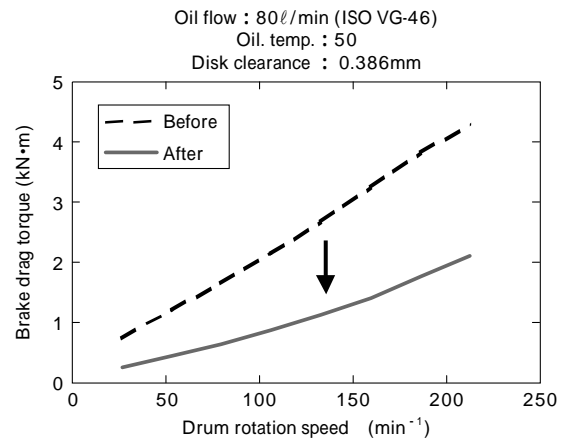
Fig. 5 Countermeasures for flow-force between multi-disk plates

Note) Disregarding the groove for oil passage on the friction plate, the maximum force F exerted toward the disk contact direction is given by the formula (3).

$$F = P_B \times A_B \times Z + P \times A_B \text{ (N)} \dots\dots\dots\dots(3)$$

Where,
P_B Absorption force per unit area (N/mm²)
A_B Friction surface area (mm²),
Z Number of friction surfaces,
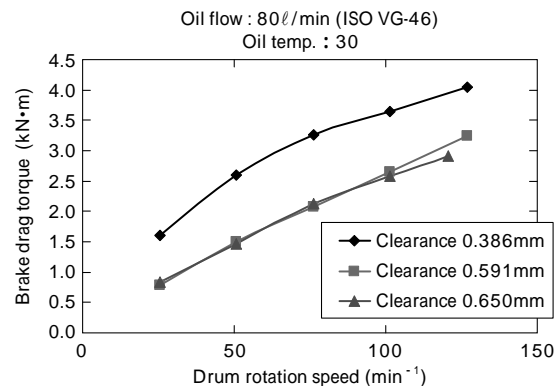P Internal pressure (MPa)
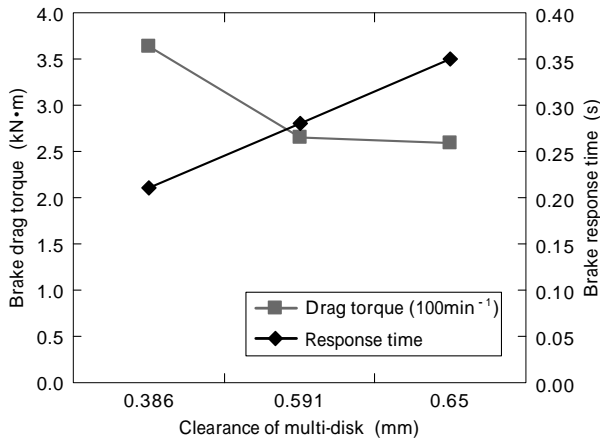
Fig. 7 Brake drag-torque for each clearance

Fig.8 Brake drag-torque & response for each clearance

torque and **Figure 8** is an experimental result showing the multi-disk clearance and the brake response time.

3.4 Free-fall accelerator

Even with the measures described from 3.1 to 3.3, the wet-type brake cannot exhibit high free-fall speeds as exhibited by conventional band brakes when suspended loads are very light (e.g., free fall of hooks alone without a suspended load.) We developed an apparatus (free fall accelerator)[4),5)] which exhibits a free fall at a high speed even for light suspended loads, by making effective use of resistance, which may be reduced, but never be eliminated fundamentally. The apparatus enables a fall at the speed of "free fall speed" + "power lowering speed" by transmitting the rotation of the hydraulic motor for lowering to the
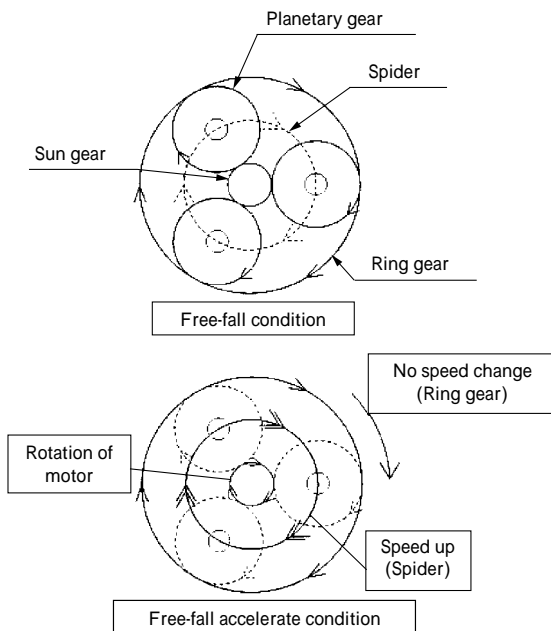
drum, during free falls with clutch off.

The following explains the action of power transmission. **Figure 9** schematically shows a cross sectional view of a first stage planetary gear mechanism of the present winch reduction unit, in which the upper figure shows the state during a normal free fall and the lower shows the state during an accelerated free fall. A sun gear is connected to a motor axis which is stopped during a "free fall" and rotates during an "accelerated free fall". On the other hand, the spider (carrier) of the planetary gears is engaged with a second stage planetary gear mechanism, which is connected to the winch drum. A ring gear, connected to the friction plates of the brake, is released during a free fall, in which the clutch is off, making the planetary gears rotate and revolve around a circle. In an accelerated state, when the motor is driven to the "lowering" direction to rotate the sun gear, almost all the driving power of the motor is transmitted to the rotation of the drum through the spider, instead of being lost in the idling of the brake portion (instead of acceleration of the ring gear connected to the friction plates of the brake), because the reduction unit drag torque is considerably smaller than the brake drag torque, as shown in **Figure 10**. As a result, the falling speed of the winch drum is increased by the increase of the rotation of the spider connected thereto, of which rotation is increased by the rotations (revolutions) of the planetary gears and the sun gear.

4. Improvement of braking control during free fall

4.1 Optimization of the disk contact pressure

The friction material, selected by KOBELCO CRANES CO., LTD. was proved, by an experiment, to have characteristics in which the difference between the coefficients of static and dynamic friction becomes larger as the disk contact pressure,
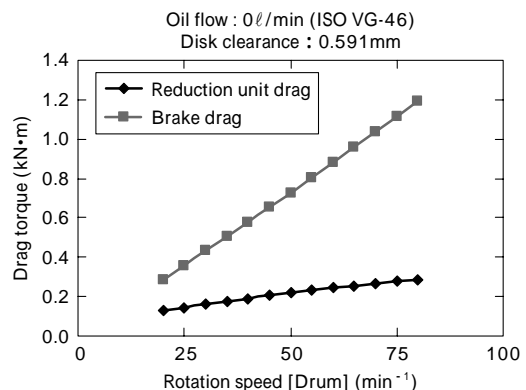

Fig. 9 Sectional view of reduction uint (1-st stage)

Fig.10 Difference of drag torque between brake and reduction unit

Fig.11 Hysteresis characteristic of friction plate

Fig.12 Disk μ -V characteristic for each oil

Fig.13 Winch rope slip speed for each oil

applied prior to a free fall, becomes larger, as shown in **Figure 11**. A large difference in operating position of the brake, between start-up and stopping, is not desirable from the aspect of free fall speed controls, and it reduces braking force drastically as soon as a free fall starts, accelerating the fall and making the fall speed almost uncontrollable. A low disk contact pressure is desired from the above consideration, however, in order to downsize the brake, higher disk contact pressures are more effective. Because of this, the disk contact pressure is reduced as low as possible, within the limitation of the size of the brake, to realize a preferable free fall braking characteristics.

4.2 Optimization of the μ -V characteristics of wet friction materials

In general, positive gradients in the μ -V characteristics of wet friction materials with cooling oil are known to provide better prevention against hunching and better variable controllability of braking forces. Because of this, a large amount of friction modifier is added to cooling oils, as in the case of oil B in **Figure 12**, to obtain μ -V characteristics with positive gradients, however, excessive amount of the additive results in extreme reduction in the friction coefficient at 0 rpm, and, in some cases, complete micro-scale stoppage becomes inpossible (**Figure 13**). Because of this, μ -V characteristics with positive gradient are not always preferable for winch brakes and clutches, which require perfect stoppage.

On the other hand, although it is economical to use the hydraulic oil for the hydraulic system to actuate the mobile crane as brake cooling oil, commercially available general hydraulic oils tend to have μ -V characteristics with extremely negative gradients, as exemplified by oil A in Figure 12, and if used as is, they leads to reduction of μ and large acceleration immediately after the start of falling, making it
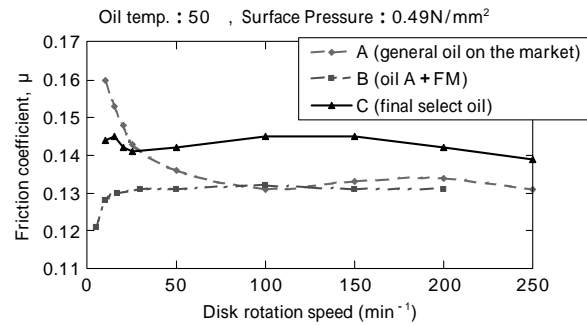
difficult to control the speed. (on/off control-feeling)

Consequently, an almost flat μ -V characteristic, without positive or negative gradient, is desirable for winch brakes, requiring both perfect stoppage and good brake control-feeling. We developed a hydraulic oil, containing adequate amount of friction modifier, having a flat μ -V characteristic as shown in Figure 12 (oil C). The developed winch has an excellent free fall braking characteristics by using the hydraulic oil having adequate amount of friction modifier.

Conclusions

We developed and commercialized our original winches with wet brakes, comprising wet type multi-disk, for the first time domestically and have gained good reputation from users. A full lineup of winches with wet brakes is now available for various capacities.

Referances

1) K. Yamagata, *R&D Kobe Steel Engineering Reports*, Vol.49, No.2, p.87 (1999).
2) *Japanese Patent* No.3644372.
3) *US Patent* No.6, 179,271
4) *Japanese Patent* No.3589051.
5) *Japanese Patent* No.3945505.