A flexible retraction cable reel based on planetary gear drive

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ABSTRACT. *This paper designs a flexible retraction cable reel based on planetary gear drive. Taking planetary gear as the actuator, the proposed device can accommodate the cable automatically to the proper retraction force through the auto transmission of actuator, thereby achieving the balance between output torque and friction torque. In addition, the relationship between the torque and the speed of each output shaft was discussed by the physical design of the device, and the working mode of the cable reel was described in details. Through an application test, the proposed device was proved flexible in retraction, allowing the reel to furnish the cable with less tensile during operation. The research findings provide an effective way to prevent the cable damage in existing cable reel units.*

RÉSUMÉ. *Cet article conçoit un enrouleur de câble de rétraction flexible basé sur une transmission par engrenage planétaire. En prenant un engrenage planétaire comme actionneur, le dispositif proposé peut adapter le câble automatiquement à la force de rétraction appropriée grâce à la transmission automatique de l'actionneur, ce qui permet d'équilibrer le couple de sortie et le couple de frottement. De plus, la conception physique du dispositif a été adaptée à la relation entre le couple et la vitesse de chaque arbre de sortie, et le mode de fonctionnement de l'enrouleur de câble a été décrit en détail. Lors d'un test d'application, le dispositif proposé s'est avéré souple en rétraction, ce qui a permis à l'enrouleur de fournir au câble une résistance moindre à la traction pendant le fonctionnement. Les résultats de la recherche offrent un moyen efficace afin de prévenir les dommages aux câbles dans les enrouleurs de câbles existants.*

KEYWORDS: *cable reel, flexible retraction, friction disk, planetary gear, torque.*

MOTS-CLÉS: *enrouleur de câble, rétraction flexible, disque de friction, engrenage planétaire, couple.*

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1. Introduction

A cable reel is a coiler device that supplies power, control source, and sends control signal, to the movable equipment, which is assembled on the movable equipment for simultaneous mobility. Currently, all types of cable reels operate at a roll-cable speed greater than travelling of movable equipment, relying on the slip mechanism set in the reel drive train (Chen and Mei, 2015), such as hydraulic coupling, magnetic coupling, stalling torque and other types, to maintain the cable a reliable retraction (Lee *et al.*, 2016). To make sure the cable is wound stably on the reel, these cable reel devices contributes a large tensile to the cable, which exacerbates the cable wear and reduces the service life of the cable. This paper proposes a kind of cable reel device which enables a flexible retraction based on planetary gear drive, and can accommodate the cable to a certain force as required by cable retraction by auto transmission of actuator. The flexible retraction is realized so that the reel only contributes a least tensile as required to the cable, thus eliminating damage of cable from the existing cable reel devices. The technology has been patented as a national invention.

2. Working principle and structure design

The structure of this reel device is shown in Fig. 1. It includes the box 1, 2K-H (WW) + planetary differential actuator 2, planet carrier gear 3, motor 4, worm gear reducer 5, transition gear 6, reel spool gear 7, collector rotatory blade 8, collector fixture blade 9, power cord, movable equipment 10, reel 11, power cable 12, pivoting friction disk 13, movable friction disk 14 compression spring 15, regulator seat 16, platen 17, drive lever 18, bearing 19, and handle gear 20. Lube added in the box 1 can ensure that the rotatable parts in the box 1 are always in the lubrication state (Tang *et al.*, 2017).

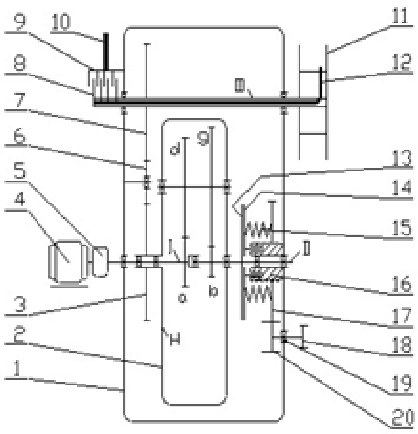

Figure 1. Structure principle of cable reel with flexible retraction

2K-H (WW) + 0planetary differential actuator 2 consists of input shaft I, sun gears a and b, planetary gears d and g, planet carrier H, output shaft II (adjusting shaft). The speed and torque generated by the motor 4 are transmitted to the input shaft I via the worm gear reducer 5. The speed and torque of the input shaft I are distributed to the output shaft II and the planet carrier H by the planetary differential actuator 2. The speed and torque of the planet carrier H are in turn transmitted to the output shaft III (reel shaft) via the planet carrier gear 3, the transition gear 6, the reel spool gear 7. The output shaft III drives the reel 11 and the collector rotary blade 8 to rotate together. The reel 11 is coiler and storage device for the power cable 12. Power cable 12, after passing through the reel 11, penetrates through-hole in the center of the output shaft III and is connected to the collector rotary blade 8. Power cord 10 for the movable equipment itself is connected to the collector fixture blade 9, which, as a fixed power source, supplies power to the movable equipment. Pivoting friction disk 13 is rotated together with the output shaft II; the end face pin of the movable friction disk 14 is inserted into the end face hole of the adjuster seat 16, but not rotatable. The cylindrical surface of the adjuster seat 16 is machined with threads. A lead screw nut mechanism is made up by inner bore thread of platen 17 and regulator seat 16. There is a compression spring 15 mounted between movable friction disk 14 and platen 17. The drive lever 18 drives handle gear 20 to rotate toget000her, thus platen 17 rotates with them. The horizontal displacement produced when platen 17 rotates will compact and release the compression spring 15, altering the friction force between pivoting friction disk 13 and movable friction disk 14, so that the resistance torque of output shaft II is subjected to change (Zhang *et al.*, 2017).

3. Dynamic analysis (Rao, 2014)

When the torque of the planet carrier H is transmitted to the output shaft III, the friction loss and torsion loss of stirring lube occur. The sum of the various torsion losses is expressed by M_f. then:

$$\mathrm{M_H} = \mathrm{M}_{III} + \mathrm{M_f} \tag{1}$$

The number of teeth is defined as $\mathrm{Z_a}$, $\mathrm{Z_b}$, $\mathrm{Z_d}$, $\mathrm{Z_g}$in the 2K-H(WW)+ planetary differential actuator 2, then latent parameters $\alpha = \mathrm{Z_d Z_b / Z_a Z_g}$ =0.5. The speeds, torques of input shaft I, output shaft II and planetary carrier H satisfy the following formulas (Wu, 2013):

$$\mathrm{n_{\,I}} - 0.5\mathrm{n_{\,II}} - 0.5\mathrm{n_H} = 0 \tag{2}$$

$$\mathrm{M_{\,I}} = -2\mathrm{M_{\,II}} = -2\mathrm{M_H} \tag{3}$$

Substitute formula (1) into formula (3), we can obtain:

$$\mathrm{n_{\,I}} - 0.5\mathrm{n_{\,II}} - 0.5\mathrm{n_{III}} = 0 \tag{4}$$

We can see from formula (4), when the motor 4 rotates and the torque is applied to the input shaft I, the input shaft I distributes the torque evenly to the output shaft II and the planet carrier H, so that the active torques of output shaft II and the planet carrier shaft H are always equal. The friction force between the pivoting friction disk 13 and movable friction disk 14 is adjusted to make $\mathrm{M}'_{\mathrm{II}} = \mathrm{M}_{\mathrm{IIImax}} + \mathrm{M}_{\mathrm{f}}$, the resistance torque of the output shaft II. When the reel 11 is full of cable (as shown in Fig. 2), the resistance torques of the output shaft II and planetary carrier H are also equal. When the movable equipment starts to move forward at the speed V from the starting point, the motor 4 rotates. When the reel 11 retracts the cable, the reel also stays in the initial state. As shown in Fig. 3, the torque that the cable applies to the output shaft III is less than $\mathrm{M}_{\mathrm{IIImax}}$. it can be seen from formula (2) that the resistance torque of the planetary carrier H is also less than $M_{II}^{'}$, then the output shaft II does not rotate under the braking action of the resistance torque M_{II}, $\mathrm{n}_{\mathrm{II}} = 0$. Only the planetary carrier H drives the output shaft III to rotate together, according to formula (5), $\mathrm{n}_{\mathrm{III}} = 2\mathrm{n}_{\mathrm{I}}$, the reel 11 retracts the cable at a higher speed. The motor 4, worm gear reducer 5 are used as specified. The output shaft III is set to a speed slightly higher than that of the cable retraction as required. The cable retraction speed is slightly higher than the running speed V of movable equipment, then you can achieve cable reel retraction (Zhong, 2013).

When the cable is just tightened, as shown in Fig 4, the torque that the cable applies to the output shaft III is equal to $\mathrm{M}_{\mathrm{IIImax}}$. The output shaft II and planetary carrier H of the planetary differential actuator 2 are subjected to equal resistance torque. The output shaft II will start to rotate. The formula (5) shows that the output shaft III speed will decline, and the reel retraction speed slows down. The cable slackens. As the reel 11 and the pivoting friction disk 13 all have rotation inertia, when the cable retraction speed drops to a certain value, the cable slackens to a certain extent (Zhong, 2013, Sui, 2017; Esmail, 2017; Chen *et al.*, 2017). As shown in Fig. 5, the pivoting friction disk 13 gradually stops under the action of the braking torque, whereas the reel speed increases slowly to $2\mathrm{n}_{\mathrm{I}}$ .Then the reel 11 retracts the cable at a higher speed. This is the process of flexible retraction of the said cable reel device.

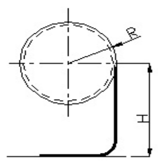

Figure 2. Schematic diagram of reel full cable

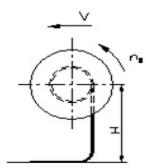

Figure 3. Initiate status of cable reel at retraction

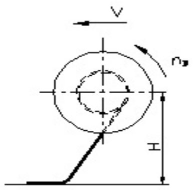

Figure 4. Schematic diagram of cable tensile status

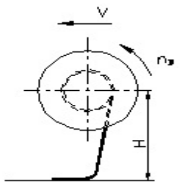

Figure 5. Schematic diagram of cable position when reel stops

It can be seen from the above operating process that the friction disk pair is although similar to that of friction clutch slip cable reel, its function differs from it significantly: when the friction disk pair designed in this paper slips, the cable is relaxed (D'Elia *et al.*, 2017; Zhang *et al.*, 2017; Hammami *et al.*, 2016). However, the friction disk of friction clutch cable reel slip, a high tensile is always applied to the cable.

When the movable walking equipment needs to stop during operation, the motor 4 stops supplying power. The input shaft I stops rotating under the self-locking action of the worm gear reducer 5. The output shaft II also stops under the braking action of the resistance torque M'_{II}. Neither is the planet carrier H or the output shaft III. In this case, the output shaft II prevents the output shaft III rom reversing and does not release the cable that has been wound well. During cable retraction, when the cable is subjected to an external force and the torque that the cable applies to the output shaft III is greater than $\mathrm{M}_{\mathrm{IIImax}}$, the resistance torque of the planet carrier H will be greater than that of the output shaft II. The planet carrier H will stop turning, so does the input shaft III. It is known from formula (5) that $\mathrm{n}_{\mathrm{III.}} = 0$, $\mathrm{n}_{\mathrm{II}} = 2\mathrm{n}_{\mathrm{I}}$, i.e., the faster relative rotation between the friction disk pairs is produced to have a protective effect on the cable, preventing it being pulled off (Zhou *et al.*, 2016; Wei *et al.*, 2017; Du *et al.*, 2014).

In conclusion, the cable reel described in the paper retracts the cable at a slightly higher speed than the traveling speed of movable device; when the cable tensions to a certain value, the cable speed automatically declines and the cable tensile diminishes; when the cable retraction speed and cable tensile are reduced to a certain extent, the reel draws in the cable at a faster speed. This achieves a flexible retraction for the cable reel.

4. Working mode

When working, this cable reel works in two modes. The first mode is that the access terminal of power cable 12 is in the center of traveling distance of movable equipment. In this case, only the device stops traveling can the motor 4 fail to be energized, and the reel stop working. When the device moves and the reel draws in, as described above, the cable is drawn in normally; when the reel releases the cable, the torque that the cable applies to the output shaft III is $M_{III\max}$, but remains in the original direction. However, the cable tensile makes the reel rotate reversely at a maximum speed 2nI. According to the formula (5), the maximum speed of output shaft II reaches $n_{II} = 4n_{I}$. At this time, the torque of input shaft I remains M_{I}, active torque applied to the output shaft II is still $M_{III\max}$. In this case, it is flexible when retracting cable; the output shaft II expedites to rotate when releasing the cable, so that the reel achieves cable drawing-out.

The second mode is that the access terminal of power cable 12 is at the end of traveling distance of movable equipment. In this case, when the movable device moves backward, namely the reel lets the cable out, the motor 4 does not need to supply the power and stops operating. The input shaft I also stops under the self-locking action of worm gear reducer 5, $n_{I} = 0$; the torque applied by cable to output shaft III is $M_{III\max}$, and n_{III} reverses at a maximum speed of $2n_{I}$.According to the formula (5), the maximum speed of output shaft II hits $n_{II} = 2n_{I}$. In this case, it is in a flexible way when retracting cable; the output shaft III expedites output II to rotate when releasing the cable, so that the reel achieves cable drawing-out.

5. Conclusion

A cable reel device with flexible retraction is designed hereby. Since the roller drive of the device is connected to a governor, there is no planetary differential actuator installed in the box of the governor; the rotation axes of input shaft, the governor shaft and the planet carrier are collinear; no brake mechanism is arranged between the governor shaft and the box. The planetary differential actuator is connected to the roller drive via its planet carrier. Therefore, when using it, the driving force that the reel is subjected to may be distributed by planetary differential actuator, so that the reel only contributes the least tensile as required for the cable, relying on the automatic transmission of the actuator to auto adjust the retraction force as required, thus to achieve a flexible retraction mode. This device has effectively addressed the problem caused by the fact that the existing reel unit may damage the cable.

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