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Design of A Cable-locking Device for Cable-driven Manipulators

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Abstract: *In this paper, a kind of cable-locking device is proposed, which replaces the motor driving device of the former cable-driving manipulator, and makes the cable-driving manipulator become a passive manipulator which can be applied in limited space, has larger workspace and has larger load-carrying capacity. The device has the characteristics of compact structure, good adaptability and strong versatility. The Integral structure and each part of this device are introduced. As the key part of this device, the detail structure and working principle of the cable-locking unit are proposed in this paper. Mechanical calculation of the force amplificatory structure is proposed in this paper to ensure that sufficient locking force can be provided..*
Keyword- *cable-driven manipulator; cable-locking device; force Amplificatory structure; mechanical design*

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I. Introduction

Traditional manipulator usually uses the motor at the joint to make the manipulator move. Such manipulators are usually large. While used in a narrow working environment and without the need for motor control, a passive manipulator with multi-link is often used. The position and posture of the manipulator are adjusted artificially through spherical joints or common rotating joints with joint locking devices, such as minimally invasive surgery robot[1]. However, the current passive manipulator often has many problems, such as low degree of freedom, which usually makes the operator unable to adjust the manipulator to a satisfactory posture; the locking devices of joints are mostly electromagnetic brakes, which make the weight of the manipulator larger and more laborious to operate.

Cable-driven manipulators will be a good solution[2]. Compared with the traditional rigid link manipulator, the main characteristics of the manipulator include: reducing the weight and inertia of the end effector[3] and greatly increasing the reachable workspace of the manipulator[4]. But at present, cable-driven manipulators are mostly driven by motor[5]. Since each cable needs a motor to drive, the driving device of this kind of manipulator has such problems as huge volume, high cost and difficult to control.

In order to make the cable-driven manipulator be used as a passive manipulator in limited space, a cable-locking device for the cable-driven manipulator is proposed in this paper. The device has the characteristics of relatively small volume, simple operation and large locking force of cable.

II. Integral structural design of cable-locking device

The overall structure of the cable-locking device is shown in **Figure 1**, which contains cable-guiding mechanism, cable-locking mechanism and cable-loosening mechanism. 15 locking units arearranged inside thedevice, and each five of them are circumferentially distributed, making the overall device cylindrical. The cables are extended from the locking unit, transferred into the cable-guiding mechanismand continue to transmit into the cable-driven manipulator.

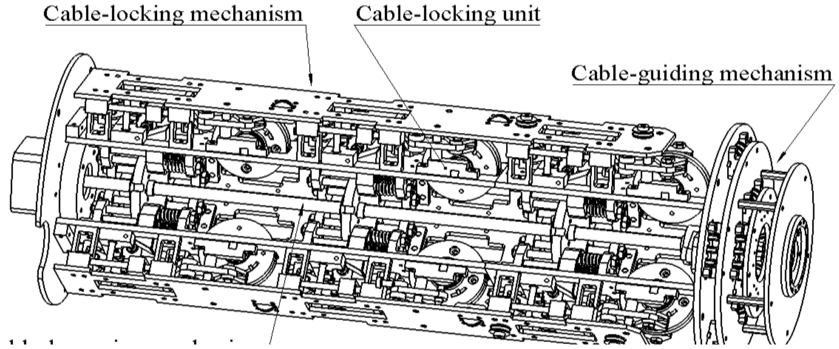

Figure 1. Integral structure of cable-locking device

Figure 2 shows the frame of the cable-locking device, which consists of one motor bracket plate, five baseplates and one calbe-guiding plate 1, and they are tightly connected by bolts.

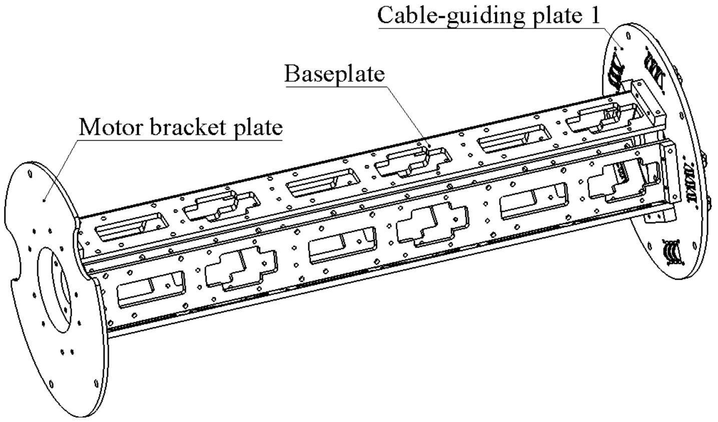

Figure 2. Frame of the cable-locking device

III. Concrete structural design of the wire-locking device

3.1 Design of wire-guiding mechanism

The diameter of the cable-locking device is larger than that of the manipulator. To make cables penetrate into the manipulator without interference, a cable-guide mechanism (see **Figure 3**) between the cable-locking device and the manipulator is required. To avoid the permanent deformation of the cable in the transmission due to the excessive bending angle[6], there are 5 pully groups which contains three pullies, one shaft and two shaft fixators distributed round the cable-guiding plate 1and 2. Also, there are 15 cable-guide holes on the guide plate 3 and 4. A cable is led out from the cable-locking unit, penetrated into the manipulator through two pullies and two cable-guiding holes.

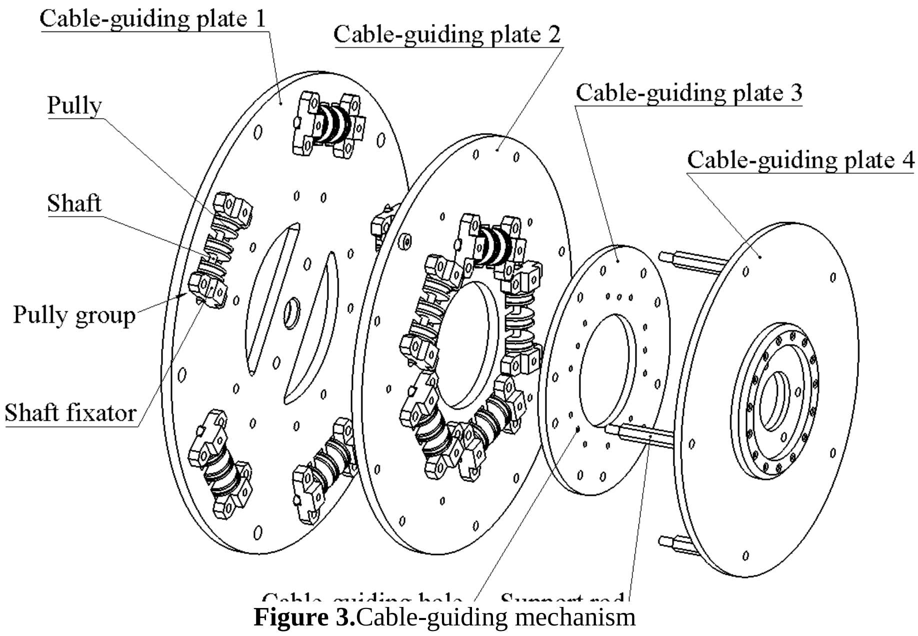

Figure 3. Cable-guiding mechanism

3.2 Design of cable-locking mechanism

The structure of the cable-locking unit is shown in **Figure 4**(a), mainly including a spring which is the force input device, a fourclasses force amplificatory structure and a cable wheel. The spring provides the force of locking cables. The force amplificatory structure[7] amplifies the force four times to ensure that there is enough pressure to lock the cable wheel. Using springs instead of motor to provide input force is to maintain clamping force at all times without using force sensors, thus saving the manufacturing cost.

It is necessary to tighten the wire when using cable transmission. The locking unit implement the tension of the cable at the cable wheel.As shown in **Figure4**(b), the wheel shaft is fixed and will not rotate,the front and rear half of the cable wheel are bolted to form a whole wire wheel rotating around the shaft. In the inner of the wheel, there is a power spring. The cable is fixed to the front half of the wheel through a cable fixing hole and wound counterclockwise around the wheel in the cable slot. When the cable is pulled, the power spring is compressed, and then the cable is given a force opposite to the pulling direction. Thus, the steel wire was tensioned.

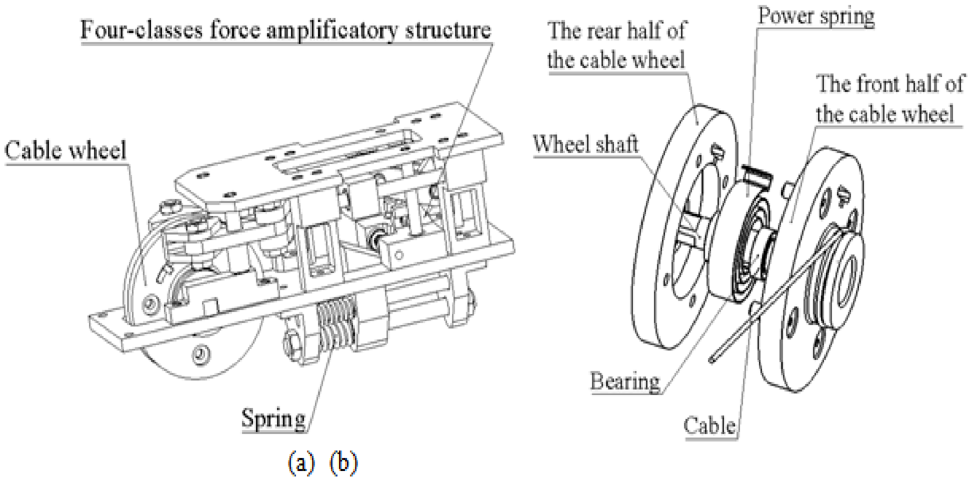

Figure 4. Cable-locking unit

The working principle of the locking unit is shown in **Figure 5**. In the cable-locking stage, the spring pushes the wedge slider and provides a pressure F_1, and F_1 is amplified to F_3 by a wedge-lever-toggle-toggle-lever four classes force amplificatory structure. The wedge slider pushes the slider 1 upward to achieve the first amplification of the force; the slider 1 transfers the thrust to the toggle 1 through the permanent force increasing lever 1 to achieve the second amplification; the toggle 1 push the slider 2, making the pressure angle β reduce, and the third amplification of the force is achieved by the principle of angle amplification; the slider 2 drives the toggle 2 to reduce the pressure angle θ, achieving the fourth amplificationagain by the principle of angle magnification; lever 2 is an equal arm lever, which only changes the direction of the force. Finally, the pressing block is forced to tighten the cable wheel, making it impossible to rotate. Thus, all cables are locked, making the cable manipulator a rigid body.

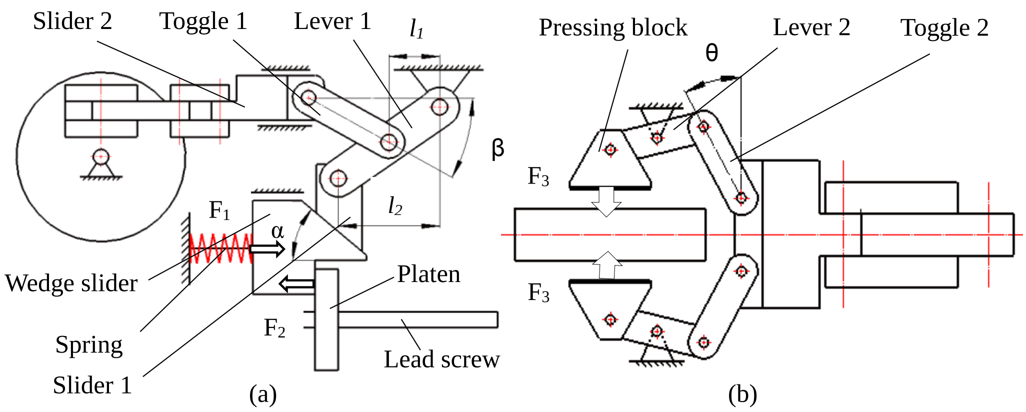

Figure 5. Working principle of the cable-locking unit

3.3 Design of cable-loosening mechanism

When we need to adjust the pose of the manipulator, the cable-loosening mechanism(see **Figure 6**) will be activated so that all cables can move freely and all the joints of the cable-driven manipulator will become flexible joints. The stepper motor drives the lead screw to make the platen connected with the screw nut move to the left, generating the thrust F_2. Then platen pushes the wedge slider and recompress the spring, so that the motion of the force amplificatory structure is opposite to that of the locking stage. The force on the cable wheel is removed, and the cable wheel can rotate freely, thereby enabling the cable fixed on it to move freely.

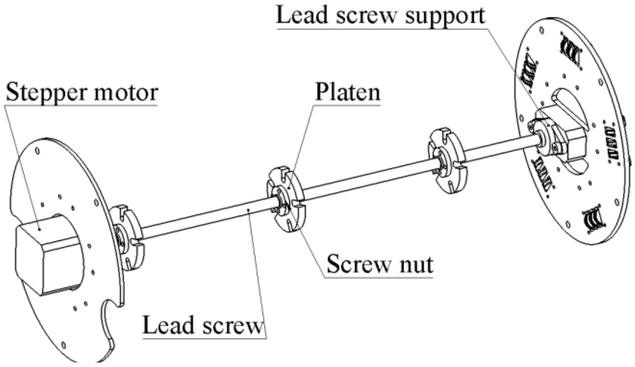

Figure 6. Cable-loosening mechanism

IV. Mechanical calculation of the force Amplificatory structure

Amplificatory coefficient represents the ratio of the output force to the input force. It is expressed with symbol*i*. While in practical use, the actual amplificatory coefficient and the output force will be slightly different due to the existence of mechanical transfer efficiency and friction.It is expressed in symboli_p. Through the mechanical analysis of the force amplificatorystructure[8] by Figure 5, easily obtain the result as follow:

Actual force increasing coefficient: $i_p = \frac{l_2}{l_1 \tan(\alpha+\phi_1)\tan(\beta+\phi_2)\tan(\theta+\phi_3)}\eta$ (1)

Actual output force: $F_3 = F_1 \frac{l_2}{n l_1 \tan(\alpha+\phi_1)\tan(\beta+\phi_2)\tan(\theta+\phi_3)}\eta$ (2)

Here α— dip angle of wedge slide
β, θ— theory of pressure angle of toggle mechanism
F_1 — the pressure of compression spring
l_1—active arm length of permanent force increasing lever
l_2—passive arm length of permanent force increasing lever
φ_1—friction angle between oblique planes on wedge slider
φ_2,φ_3 —equivalent friction angle of the toggle, $\phi = arcsin\frac{2rf}{l}$[9]

Where *r*—the radius of the hinge axis
l—the center distance of two hinge
f—friction factor of hinge, usually, $f = 0.1 \sim 0.15$
η—mechanical efficiency of a lever, usually, $\eta = 0.97$
n— number of pairs of terminal hinge pairs, $n = 2$

For this force amplificatory structure, after the wheel is pressed by the compression block, α=25°,β=15°, θ= 15°, l_1/l_2=2, *f*=0.1, r_1=r_2=2.5mm, φ_1=5°, φ_2=1.1°, φ_3=2.3°, η=0.97. The actual force amplificatory coefficient i_p can be obtained from the formula (1) and it is about 37. It can be seen that the force increasing effect of the force amplificatory structure is very obvious. This enables the block to be pressed more tightly on the cable wheel, which is beneficial to the fixing of the manipulator.

V. Conclusion

The cable-locking device can lock and loosen 15 cables at the same time. The device can control five series cable-driving manipulator units. The device enables the cable-driven manipulator to be used as a passive manipulator in relatively limited workspace, improves the spatial motion of the passive manipulator. It is also well connected with cable-driven manipulator, and the driving cable does not need a lot of bending, which can greatly reduce the resistance and improve the transmission efficiency. The larger cable-locking force makes the manipulator capable of carrying greater load. The inner cavity of the device is almost full of mechanism, compact in structure design and high in space utilization. The cable-driven device has certain universality for cable-driven continuous manipulator.

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