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Research paper

Design and working parameter optimization of cleaning device for greenhouse film roofs

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ABSTRACT

The most important factor affecting plant growth is solar radiation. One primary source of loss of solar radiation transmission of greenhouses is accumulation of dust and dirt on the exterior surface of cladding materials. In order to clean greenhouse film roofs, a fly-over disc brush cleaning device which mainly consists of driving mechanism, cambered support mechanism and cleaning mechanism is designed in this paper, and the structure parameters of the cleaning device were optimized. In order to explore the optimum working parameter, the effects of water flow rate, device cleaning speed and disc brush rotation speed were tested and analyzed by orthogonal test and variance analysis. The results show all the 3 aforementioned factors have particularly significant impacts on cleaning effectiveness (CE), and the interaction term of device cleaning speed and disc brush rotation speed are significant. With 360 mL/s water flow rate, cleaning speed of 35 mm/s and disc brush rotation speed of 100 r/min, the value of light transmittance of testing greenhouse films increases from 45% to 84.37%. The results prove that the cleaning device, which has the advantages of good CE, high efficiency, prominent water-saving, high safety and light in weight, is practicable to clean greenhouse film roofs. This research can provide reference for the design and development of cleaning device for greenhouse soft roofs.

1. Introduction

It is well accepted that light is a dominant factor in the greenhouse environment; it directly affects plant physiological processes (Hemming, 2011). One primary source of loss of solar radiation transmission of greenhouses are accumulation of dust and dirt on the exterior surface of the cladding materials (Teitel et al., 2012). This can reduce the solar radiation transmissivity of films by up to 40% (Jaffrin and Morisot, 1994). A study indicated average losses in transmission, for a period of 18 months, were 12.8% before cleaning the films and 6.7% after cleaning the films (Geoola et al., 1998). However, the manual periodic cleaning of the greenhouse roofs need much hand labor, thus requiring many employees. The work is difficult, wastes a lot of time, and can also damage greenhouse cover films. The detergents used in the water for cleaning the roofs are polluting the soil near the greenhouse and around, and in many semi-arid lands water is scarce (Manor et al., 2004). Meanwhile, plastic Greenhouses are now widely used as its very easy to build and cost much less than a large glass frame (Sangpradit, 2014). Therefore, it is imperative to study and design a cleaning device for greenhouse film roofs.

In 1998, Amir developed a wet-cleaning machine for greenhouse glass roofs to test for two year on a soft sheet covered greenhouse (Amir, 1998), but these tests have not yielded satisfactory results. In 2002, Yablonca designed a dust cleaning machine for glass covered greenhouses in the Nederland (Yablonca, 2002), but it can not adjust itself to the curved surfaces of soft sheets. In 2003, Guangxi University designed a kind of greenhouse cleaning machine whose blade of water wheel can be driven by the high pressure water flow produced by high pressure pump to scour the greenhouse film (Qing, 2003) and opted the parameters of the turbine blade and the nozzle by using orthogonal test method in 2006 (Zhong and Qing, 2006). In 2004, Gedalyahu Manor designed a machine for one type of greenhouse roofs, including a bridge, brush component and dust collecting. Rotating speed of 50 r/min

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and pressure force of 30 N/m were found to be the best working parameters for the chosen rotating brush (Manor et al., 2004). In 2007, Agricultural University of Hebei Province designed a kind of cleaning machine, whose fan was driven by a high-speed motor to create internal airflow and remove dust cleaned by a rotating brush (Juan et al., 2009). In 2010, through measuring the water wheel speed, the torque, the nozzle pressure and the spray volume of cleaning equipment, Yangtze University drawn the corresponding characteristic curve and identified some technical parameters of the cleaning equipment (Sanhe, 2010). The preceding studies present some cleaning devices and provide the reference of the best working parameters in some degree. But their results would be more reasonable if they had taken the water flow rate, the cleaning efficiency and effectiveness and practicability into account.

The goal of the present study was to design a cleaning device for greenhouse film roofs, which had the advantages of high cleaning effectiveness and efficiency, prominent water-saving, high safety and lightweight. The particular aim of the experiments reported here was to optimize the working parameters of the cleaning device. This research can provide reference for the design and development of cleaning machine for greenhouse soft roofs.

2. Cleaning device

2.1. Structure and working principle

The cleaning device which consists of three parts: driving mechanism, cambered support mechanism and cleaning mechanism. It arches across the greenhouse through the cambered support mechanism and is driven by the driving mechanism. The cleaning mechanism is composed of three parts: plastic disc brush, cleaning motor and parallelogram mechanism which consists of a carbon fiber plate and a metal bar. To ensure vertical contact between the plastic disc brush and the film, the parallelogram mechanism is hinged between the support mechanism and the cleaning motor. The diameter of the plastic disc brush is 150 mm. The overall height of the cleaning motor and the plastic disc brush is 130 mm. In order to save the weight of the cleaning device, the mechanical structure is made of carbon fiber, aluminum plastic and other light materials. Fig. 1 is the cross-section diagram of the cleaning device.

The cleaning motor and the driving motor which is installed on the driving mechanism with decelerating mechanism are 12 V DC motors which can be controlled independently. The cleaning device can be driven by the driving motor and adjusted for speed and direction by controlling the left and right driving wheels. When the device is operating, the tap water sprayed by nozzles pre-wet and wash the film, and the disc brush brushes the film under the driving of the motor. Through the water washing, dust, moss and other debris are flushed into the gutter of the greenhouse.

2.2. Optimization of structure parameters

The cleaning mechanism is the core component of the cleaning device. In order to make the cleaning mechanism work smoothly and ensure vertical contact between the plastic disc brush and the film, it is necessary to select the appropriate-sized parameters. As shown in Fig. 2, through the analysis of equilibrium of horizontal forces of the cleaning mechanism, the support reaction force R_y is defined by the following formula:

$$R_y = \frac{G}{1 + f \tan \alpha} \tag{1}$$

Hence, R_y is related to the friction coefficient f, the gravity of the cleaning mechanism G and the traction angle α. When G and f were decided, R_y is decreased with increasing α. When the cleaning machine is in normal work, the CE increase with the increase of R_y, so the value of the traction angle should not be too large.

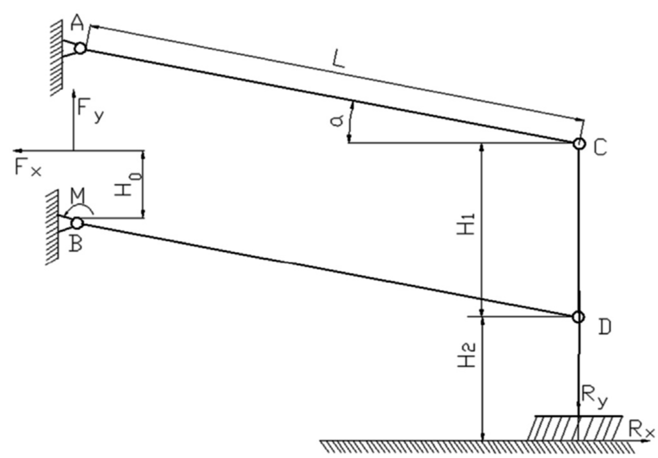

Fig. 2. Force analysis diagram on cleaning structure. Notes: A, B, C and D are four articulated points, A and B are hinged on the support structures, C and D are hinged on the motor; F_x and F_y are tractions; M is traction torque; H_0 is the distance from F_x to the articulated point, mm; L is the length of frame pole, mm; α is the traction angle. H_1 is the height of the motor, mm; H_2 is height from articulated point D to the ground, mm; R_x and R_y are friction resistance and support reaction force on the brush.

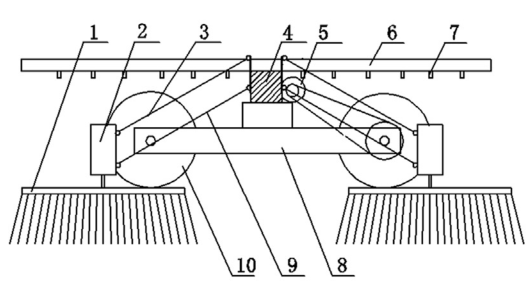

Fig. 1. Cross-section diagram of cleaning device.

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