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Advanced power supply of construction hoists for supertall buildings

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ABSTRACT

The operational efficiency of construction hoists is increasingly important for successful project completion of supertall buildings. In supertall building construction, the traditional power supply using cable systems for construction hoists not only breaks down frequently from its own weight and wind load, but also reduces the maximum payload capacity of the hoist. This study proposes an advanced power supply system of the contact type to enhance operational efficiency and reduce the operation costs of construction hoists. In a field test, the proposed system required only one repair taking 4 h, whereas the cable systems required 21–41 repairs that caused 20–30 days of construction delay. The proposed system also reduced the total operation cost of power supply by up to 22% over the cable systems. Moreover, it could maximize the payload capacity of the hoists. It is expected that the proposed system can reduce the overall construction period with stable operation of the hoists.

1. Introduction

The operational efficiency of construction hoists is increasingly important for successful project completion, as the heights of tall buildings have continued to increase [1]. The average height of the 10 tallest buildings completed each year in the world has increased from about 150 m in 1960 to about 420 m in 2009 [2]. More specifically, 36 supertall buildings over 300 m were built during the four years 2010–2013, which comprise nearly half the total number of existing supertall buildings [3]. Although they are essential for the vertical transportation of resources, the operational efficiency of a construction hoist decreases as the load and vertical travel distance increase with the building height, which can significantly affect the overall project duration [4]. In response to this emerging need to improve the efficiency of construction hoists for supertall buildings, various studies have focused on hoist operation management methods based on information technology and ubiquitous sensor networks (USNs) [4–6], and simulation-based operation planning techniques [7–9]. However, there has been little research into improving the actual hardware to increase hoist efficiencies.

Conventional construction hoists show height-dependent constraints on hardware performance. In particular, constraints associated with power supply equipment severely affect the operational efficiency of construction hoists. Currently, power cables are commonly used to supply power to construction hoists. While sliding up with the cage of the hoist, the power cable is exposed to both a height-dependent tensile force induced by its own weight and wind load. Hoisting operations are therefore highly likely to be interrupted by such problems as disconnection and twisting of power cables, especially in supertall buildings. These failures of power cable systems greatly increase not only the downtime of construction hoists, but also the operation costs, because the entire power cable must be replaced. To reduce these problems, hoists used on supertall buildings are usually installed in several sections. However, such intervals require transfers, which incur delays in material and manpower transport and decrease the hoist efficiency.

Against this background, the aim of this study was to develop an advanced power supply system of construction hoists (APS) for supertall buildings to improve their operational efficiency. The existing power supply for construction hoists is first reviewed to analyze the problems of power cable systems. Then, alternative systems of power supply are proposed to resolve these problems and a new system is selected and designed to meet the requirements for practical use on construction sites. Next, the feasibility of the proposed system is verified by conducting a field test on a tall building. The advanced power supply developed in this study not only overcomes the height-dependent limitations of construction hoists, but also enables a stable power supply for hoists for supertall buildings.

2. Power supplies for construction hoists

2.1. Power cable systems for construction hoists

Power cable systems have conventionally been used to transmit electrical power to construction hoists. Power cables cannot be fixed on masts because they are connected to a hoist that moves up and

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down continuously. However, as the lengths of the unfixed power cables increase, higher loads from wind and mass affect the cables. For this reason, the cable is fixed only up to half of the installation height and moves upwards. A cable trolley is used for the movement of the cable for the other half of the height (Fig. 1). The cable trolley is attached to the mast and prevents the unfixed cable from becoming loose. It limits the travel path in the vertical direction while moving up and down with the movement of the lift car. In this manner, the cable trolley prevents the power cable from disconnecting by becoming entangled in the mast or hoist because of wind and vibrations.

2.2. Problems with power cable systems

2.2.1. Cable disconnection

As construction heights increase, hoist power cables are more likely to be disconnected because of the proportional increase in tensile stress. The conductor in the power cable is likely to malfunction when the tensile force, which results from the self-weight of the cable and the wind load, exceeds the permissible tensile force of the cable. The tensile force reaches its maximum value when the unfixed cable is at the maximum length because the top end point (point A in Fig. 1) receives half of its own weight and the wind load of the cable as tensile force. The tensile force exerted at point A can be expressed by Eq. (1), and the wind load can be calculated by using Eq. (2) (from the "Safety certificate criteria for dangerous machinery and equipment") [10]:

$$T_{max} = \sqrt{(L_{weight})^2 + (L_{wind})^2}, \tag{1}$$

$$L_{wind} = \frac{V^2}{30} \times \sqrt[4]{H} \times C \times A, \tag{2}$$

$$L_{weight} = 2.2kg/m \times l_{cable}, \tag{3}$$

where V is wind velocity; H is the height from ground level; C is the wind force coefficient; A is the area resisting wind force; and l is the cable length from cable trolley to hoist.

The height and wind load were varied to determine the changes in tensile force applied to the cable depending on these parameters. For the analysis target, a high-tensile-strength four-core cable with a total surface area of 25 mm^2 for the conductors was selected [11]. The selected cable of 2.2 kg/m with a permissible tensile force of 350 kgf is commonly used for construction hoists of tall buildings. The height-dependent change in tensile force with the wind velocity was analyzed. The construction hoist equipment could be operated with applied wind loads between 1 and 20 m/s, and the range of wind loads for the analysis was selected accordingly (Fig. 2).

The results showed that the maximum installation heights at wind velocities of 1 and 20 m/s were about 320 and 260 m, respectively, when the permissible tensile force was set to 350 kgf. For supertall buildings exceeding 260 m with working conditions of wind velocities below 20 m/s, hoisting operations were likely to be interrupted by cable disconnections.

2.2.2. Cable twisting

Cable twisting is mainly caused by changes in external temperature and the resulting changes in the elasticity of the cable. The inner structure of a cable consists of four cores twisted to minimize the power loss caused by the magnetic field. The rubber sheath over this inner structure prevents release of the twisting and protects the inner structure. The outer rubber responds to changes in temperature, and its elasticity decreases as the temperature increases. With reduced elasticity, the rubber sheath tends to twist in the opposite direction to the twisting of the four cores (Fig. 3). Once twisted, the cable does not recover to the original status, and the twisting exacerbates through operation.

Cable twisting can easily cause the cable to derail from the trolley, and the twisted cable can squeeze other structures. A longer cable increases the probability of cable twisting, which causes the cable to derail from the trolley and be squeezed between other structures. The derailing of the cable would ultimately result in power failure, interrupting the entire hoisting work.

2.2.3. Cable trolley damage

The cable trolley guides the movement of the cable based on the principle of the moving pulley. As the trolley does not have a cover for

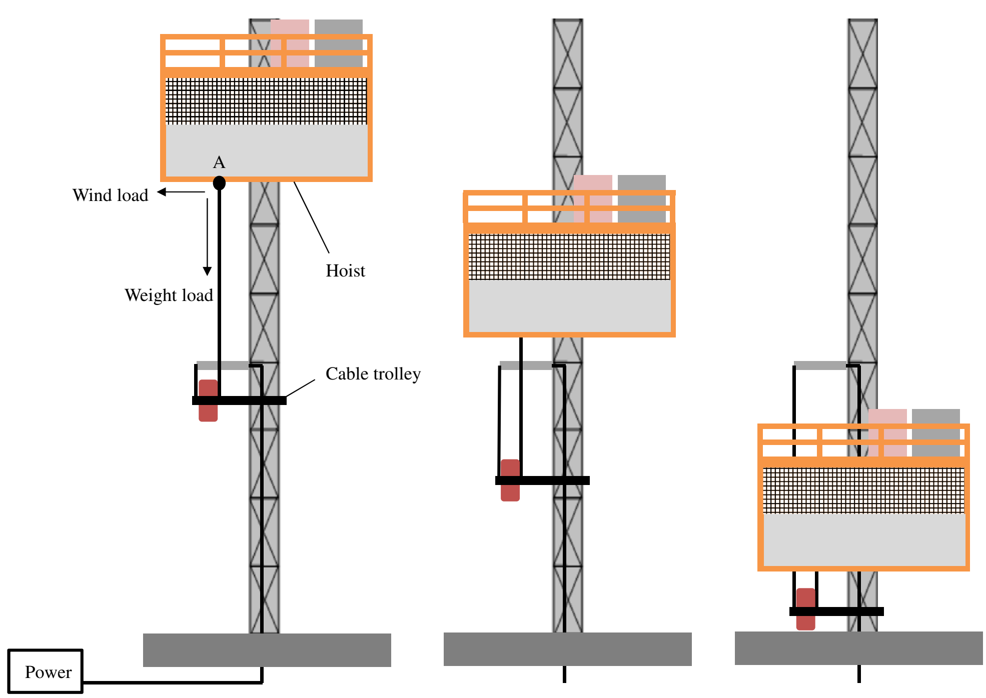

Fig. 1. Cable movement during hoisting operations.