Device for Determining the Adhesion Coefficient at the Slippage Point

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Abstract. For the building of the new structures, as well as for the repairs or the reconstruction works on existing buildings, the building industry uses a wide variety of handling equipment. Industrial high-rise construction, but also low-rise family homes uses a broad range of standardized lifting means that enable handling of the construction elements. Of these, tower cranes and mast cranes, both stationary and mobile, are among the most widely used types of handling equipment. A change in the position of the crane jib is made by either raising or lowering the crane boom meaning an angular motion of the jib in a vertical plane, or by a central motion of the traveling trolley, to pick up the load, along with the boom or crane bracket. Mobile tower, or potentially mast cranes, move these using crane wheels moving along the crane track. Travelling crane trolleys move along the crane boom using traction cables or motor units that apply the necessary traction force to the perimeter of the given number of the crane wheels.

1. Introduction
Single-girder crane trolleys are classified as lifting equipment that usually moves along the lower flange of a rolled profile, which represents the crane track. To change position along the length of the travel track, crane trolleys use rolling trolley units controlled by electrical or manual force. Manual and electric trolleys are primarily designed for overhead electric cable or chain pulley cranes. These machine trolleys allow easier handling of construction loads in the space of the crane track.

The relocation of loads using crane trolleys is cyclical. Cyclical transport allows moving only a limited number of loads in a given time interval, the number of which is proportional to the so-called “cycle time” [1]. The number of loads moved is mainly a function of time, which increases with the increase of travel distance and decreasing travel speed of the crane trolleys. If moving a higher number of loads per time unit over a certain travel distance is required, it is necessary to either increase the number of transported loads during one working cycle of the mobile crane trolley or increase its transport speed. As a rule, increasing the number of loads to be carried during one cycle is not possible in practice, as the capacity of the crane trolley itself is often exceeded as well as the load capacity and rigidity of the boom (or crane track) or the stability of the tower crane. The only way to increase the number of loads to be carried per unit of time is to reduce the travel time of a crane trolley.
The total travel time of the crane trolley can be determined as the sum of the work travel (i.e., from the point of gripping the load to the place of unloading) and the time of the return trip (usually without a construction load) of the crane trolley. The travel and return times of the crane comprise three stages: start time, drive time at a constant design speed and braking time. The limiting parameter of both the start period and the braking time of the crane trolley is the adhesion, that is, the ability to transfer the traction between the drive wheels and the travel track without slippage. For more details see [2].

2. Aspects of Transfer of Traction Force by Adhesion
The mobile crane trolleys consist of a drive unit and driving and driven wheels. To prevent jamming, (that is, the contact of the wheel flanges with the sides of the rail heads), at least the opposite wheels must always be driven. If the drive mechanism is configured as a so-called "central drive" then it can be assumed that the speed of both drive wheels is the same, as the torque on the drive wheels is supplied by the torsion bars from the transmission output shafts. However, if the travel mechanism is designed as an "individual drive", i.e. each drive wheel is driven by its own drive unit, it is necessary to achieve the same speed of both drive wheels by controlling the speed of the electric motor with a frequency converter [3].

![Figure 1. Suspended crane trolley a) pulled, b) fitted with a trolley unit](image)

The travelling mechanism of hand-operated crane trolleys consists of four beveled wheels, mounted on an axle with rolling or sliding bearings. For light-weight loads and for occasional relocation of loads, crane trolleys are not equipped with a motor drive, see Figure 1,a. The movement of the trolley is achieved either by application of tensile force to the trolley mechanism frame or using a toothed gear that transfers the torque applied to the drive pinion to the drive wheels, see Figure 1,b.

As a rule, manual crane trolleys only have driven wheels on one side of the frame. The trolley drive wheels are subject to so-called adhesion weight, i.e. only a part of the total weight of the crane and the weight of the load.

In this paper, the following chapter describes in detail the design of the device, used to determine the coefficient of adhesion between the conical drive wheel, which is in contact with the upper surface of the lower flange of the rolled profile. At the same time, the paper describes the procedure for the experimental determination of the coefficient of adhesion at the drive wheel slippage point.

3. Device for Determining the Adhesion Coefficient at the Slippage Point
A device for determining the coefficient of adhesion at the wheel slippage point of a manually operated crane trolley, see Figure 2, it consists of two basic parts. The first is an overhead crane trolley \( T \), the second is a rigid crane track (rolled profile I 140) \( L \), over which the crane trolley (by forward or reverse movement exerted by the operator's manual force) travels.

Suspended overhead crane trolley \( T \) is fitted with four beveled wheels \( 3 \), of which three are driven and one is the drive wheel [4].

The drive wheel \( 3 \) is housed in the left crane crossmember \( 4 \) of the crane trolley \( T \). The drive wheel \( 3 \) is pressed onto the drive shaft \( 5 \) and secured against rotation by means of a tight spring \( 6 \). The drive
shaft 5 is provided on its one end with an outer metric thread onto which a low hexagonal nut 7 is screwed. A washer 10 is inserted between the nut 7 and the front face of the drive wheel 3. A shaft locking ring 8 prevents the drive shaft 5 from sliding out of the opening in the crossmember 4.

The drive shaft 5 is fitted with a square on its other end part, which is inserted into a four-sided opening on the torque sensor 9.

Two continuous holes with an internal M6 thread have been made in the outer face of the left crossmember 4 of the trolley 1, through which the torque sensor 9 holder 13 is attached by means of two screws 12 and flexible washers 11.

Figure 2. 2D Construction design for a device determining the adhesion coefficient at the slippage point of a crane trolley

The torque sensor 9 has an internally threaded bore in its housing, at its end section. The shank of the screw 15, on which a spring washer 14 is mounted, is threaded through the opening in the holder 13. The threaded section of the screw 15 is threaded into the female threaded hole in the torque sensor 9, thereby preventing movement of the torque sensor 9 around the axle.

The driven travel wheels 3 are mounted in the crossmembers 4 and 16 of the trolley 1. The driven travel wheels 3 are mounted onto the shafts of the driven wheels 17. The shafts of the driven wheels 17 are provided with an outer metric thread on their one end, to which a hexagonal nut 18 is screwed. Elastic washers 19 are inserted between the nuts 18 and the outer face of the crossbar 16 and the outer face of the crossmember 4 on the threaded portion of the shafts of the driven wheels 17. The locking rings for the shafts 20 are provided to prevent the drive wheels 17 from being extended from the openings in the crossmembers 4 and 16.

The required distance between the two crossmembers 4 and 16 (in the front view of the overhead crane trolley 1) is defined by a threaded rod 21. There are two continuous holes bored in the crossbars 4 and 16, through which a threaded rod 21 is placed. From the outside of both surfaces of the crossmembers 4 and 16, a washer 23, a spring washer 24, and a hexagonal nut 22 are fitted on the threaded portion of the threaded rod 21. From the inside of both surfaces of the crossmembers 4 and 16, a washer 23, and a hexagonal nut 22 are fitted on the threaded portion of the threaded rod 21.

The overhead crane truck 1 is mechanically coupled to the crane track 2. A sensor holder 36 is attached to the two crossbeams 4 and 16 by four screws 31. The screws 31 are threaded through the two openings in the longer sensor holder portion 36 (the shafts 32 and the spring washers 11). After the screws, 31 have been passed through the longer part of the strain gauge load cell holder 36, the washers 32 are pushed back onto the two shafts of the bolts 31 and the threaded parts of the bolts 31 are then screwed into the internally threaded holes of the strain gauge load sensor 35.
Two holes are drilled on the bottom flange of the I profile of the crane track 2. Two holes are drilled identically in the rolled profile L 29. Spring washers 27 and washers 30 are pushed onto the shafts of both bolts 25, then the bolt shafts 25 are threaded through the holes in the L profile 29 and the holes in the profile of the crane track 2. The bolt shafts 25 protruding from the openings of the upper surface of the flange are fitted with washers for rods 28, spring washers 27 and, finally, nuts 26 are screwed on. This way the profile of the crane track 2 is connected by screw connections with the L-profile 29.

Two holes are drilled in the vertical flange of the L profile 29. Spring washers 11 and washers 32 are pushed onto the shafts of both bolts 31, then the bolt shafts 31 are threaded through the holes in the L-profile 29 and the holes in the sensor holder 34. The washers 32 are mounted on the bolt shafts 31 extending from the openings of the sensor holder 34 and finally, the nuts are screwed in 26. The L-shaped profile 29 is thereby connected to the sensor holder 34 by means of screw connections. The sensor holder 34 is connected to the L profile 29 by means of screw connections.

Figure 3. Apparatus for determining the adhesion coefficient at the slippage point of the overhead crane trolley - 3D design created in the SolidWorks 2012 SP.5.0 environment

Screw shafts 31 lead from the outer surface of the sensor holder 34 by two holes at a given distance from the lower edge of the sensor holder 34. Before inserting the screws 31 into the holes in the sensor holder 34, spring washers 11 and washers 32 are threaded onto the screw shafts 31. Washers 32 are mounted on the screw shafts 31 protruding from the openings of the sensor holder 34, and the threaded parts of the screws 31 are then screwed into the holes with internal threads in the strain gauge load transducer 35. This connects the sensor holder 34 to the strain gauge load sensor 35 by screw connections.

Figure 4. Implementation of the apparatus for determining the adhesion coefficient at the slippage point of the overhead crane trolley
A 3D model of the apparatus for determining the adhesion coefficient at the slippage point of the overhead crane trolley, created in the SolidWorks 2012 SP.5.0 environment is presented in Figure 3. An implemented functional example of the overhead crane trolley is shown in Figure 4.

4. Procedure for determining and assessing the adhesion coefficient on start up

The effect of the operating torque applied to the torque sensor shaft, which is mechanically coupled to the drive wheel shaft, generates a traction force at the perimeter of the crane wheel. It is assumed that the tractive force is in balance with the adhesion force. At some point, due to the increase in torque, the crane wheel slips over the rail. The moment of slip, as well as the amount of torque, is recorded by a tensometric torque and rotation angle sensor (type designation T4WA-S3). The instantaneous value of the torque and the angle of rotation of the crane wheel is sensed by the measuring apparatus (Dewetron type designation) and the course of both quantities is graphically represented in the DEWESoft X2 SP5 application software (see Figure 5).

Figure 5. Record of the course of the measured torque and the angle of rotation

At the moment of slipping of the crane’s drive wheel on the rail, the angle of rotation of the wheel is changed, which the sensor is able (due to the installed perforated disc, which is rigidly connected to the measuring rotor and two stator-fixed optical sensors) to register, since the perforated spool moving simultaneously with the rotor Interrupts, with its series of holes and bridges, the light of the optical sensors. The light intensity changes arising are converted into voltage pulses by the phototransistors, whose number (90 openings) is a measure of the rotation angle that is recorded in the measurement program graph through the measurement card.

Determination of the adhesion coefficient value at the slippage point of the drive wheel is possible on the described measuring apparatus in two ways.

The first method is based on the torque rate $M_k$ measured (by the T4WA-S3 torque sensor, with a measuring range from 0 to 200 N. m, see position 9 on Figure 2) using the Dewetron measuring apparatus [N. m] applied to the shaft of the drive wheel. At a known value of the diameter of the drive wheel $D_k$ [m] it is possible, using the relationship (1) to calculate (while neglecting the resistance of the pin friction) the amount of pulling force $T$ [N] on the perimeter of the drive wheel [5].
If the adhesion weight \( G_a \) [N] acting on the drive wheel is precisely determined, it is possible to obtain the sought-after value of the adhesion coefficient according to the relationship (2) at the slippage point \( \mu_a [-] \) of the drive wheel.

\[
T = G_a \cdot \mu_a \Rightarrow \mu_a = \frac{T_{\text{max}}}{G_a} \quad (2)
\]

where \( T_{\text{max}} \) [N] is the tractive force at the moment of slippage of the drive wheel.

The second method is based on the measured magnitude of the applied force \( F \) [N] on the crane trolley frame (strain gauge load transducer, type PW2G with a measuring range of 0 to 12 kg, see position 35 in Figure 2) by the Dewetron measuring apparatus [2]. The magnitude of the force \( F \) [N], as shown in Figure 6, is the same as the pulling force \( T \) [N] on the perimeter of the drive wheel. Knowing the adhesion weight \( G_a \) [N] acting on the drive wheel, it is possible to obtain the desired value of the coefficient of adhesion at the slippage point \( \mu_b [-] \) of the drive wheel according to the relationship (3).

\[
F = G_a \cdot \mu_b \Rightarrow \mu_b = \frac{F_{\text{max}}}{G_a} \quad (3)
\]

where \( F_{\text{max}} \) [N] is the force on the frame of the crane trolley (causing the movement of the crane trolley) at the moment of slippage of the drive wheel.

5. Conclusion

The paper deals with the possible method of establishing the adhesion coefficient at the interface slippage of the handling equipment used; specifically, travelling crane trolleys in the building industry.

To define the contact of a rotating drive crane wheel on a steel rail, the adhesion coefficient is used instead of the friction coefficient. The adhesion coefficient expresses the ability to transfer tangential forces of the contact surfaces of two different surface roughness without slipping.

The physical nature of adhesion has not yet been satisfactorily explained. The original idea that the microscopic unevenness of the wheel and rail surfaces acts as gearing has been long since abandoned,
as the precision and finely machined crane wheels have higher adhesion values than the roughly machined wheels.

Travelling cylindrical or conical drive wheels of the crane are made of steel or cast iron. For cranes and crane trolleys, the torque must always be brought to two opposite wheels from the drive. There are two basic ways of arranging the drive of the drive wheels of the cranes - individual and central. The central drive uses one drive unit where the engine torque multiplied by the gear ratio is evenly brought to the drive wheels.

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