A New Model to Predict the Slippage Coefficient of Tracked Vehicles During Steering

ZHAO DING\textsuperscript{1,2}, ZHIMING WANG\textsuperscript{1,2}, ZHAN SU\textsuperscript{1,2}, LIQUAN TIAN\textsuperscript{1,2}, YONGSEN XIONG\textsuperscript{1,2}, XIAOLIAN WU\textsuperscript{1} and ZHONG TANG\textsuperscript{3}

\textsuperscript{1}College of Mechanical and Electrical Engineering, Jinhua Polytechnic, 321017, Jinhua, China
\textsuperscript{2}Key Laboratory of Crop Harvesting Equipment and Technology of Zhejiang Province, 321017, Jinhua, China
\textsuperscript{3}Key Laboratory of Modern Agricultural Equipment and Technology, Ministry of Education and Jiangsu Province, Jiangsu University, 212013, Zhenjiang, China

Corresponding author: Zhan Su (e-mail: sz_627@126.com) and LiQuan Tian (e-mail: tlqbuct@sohu.com)

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ABSTRACT Tracked vehicles during steering are always subjected to track slippage relative to the ground. Studies show that an excessive slippage coefficient reduces the steering ability of tracked vehicles and increases the risk of soil shear failure. Accordingly, fast and accurate tests of the slippage coefficient of tracked vehicles under different ground conditions can be effectively referenced to select track parameters and reach optimal operation. Aiming to resolve shortcomings of the conventional testing method in determining the slippage coefficient of tracked vehicles, a novel method is proposed in the present study. Then the trajectory of an arbitrary point on the tracked vehicle during steering was analyzed. Moreover, the time of vehicles steering around and the speed of track sprocket were measured, and the slippage coefficient of tracked vehicles steering on the specific ground condition was determined. Meanwhile, the slippage coefficient of the tracked combined harvester steering under different ground conditions was explored using the conventional method. The obtained results were compared quantitatively, and the accuracy of the established model was verified. The performed analyses demonstrate that the proposed method has a simple structure and can be effectively applied to various complicated working conditions. This method is expected to lay a theoretical basis to establish an online testing system for the slippage coefficient of tracked vehicles during steering.

INDEX TERMS Model, Steering speed, Steering trajectory, Track slip and skid.

I. INTRODUCTION

In the steering process of tracked vehicles, the vehicle track is constantly accompanied by slippage relative to the ground. This phenomenon, which reduces the maneuverability of tracked vehicles compared to the theoretical maneuverability, can be classified by different degrees of slip and track skids on both sides under different ground conditions [1]–[5]. Studies show that excessive slippage coefficient directly affects the safety, steering stability, and operating efficiency of tracked vehicles [6]–[9]. Accordingly, the operation of vehicle tracks is limited to the optimal range of slippage coefficient to reach reasonable drive efficiency and steering stability. Furthermore, slippage of tracked vehicles in field operations may cause the compaction and shear of the tracked soil [10], destroy the original structure of the soil, and increase the risk of soil erosion [11], [12]. Accordingly, performing rapid and accurate tests on the slippage coefficient of tracked vehicles during steering is of significant importance for selecting the track parameters and optimal operating conditions under different working conditions.

The conventional methods to test the slippage coefficient of tracked vehicles are complicated [13]. Currently, the theoretical and actual moving speeds of tracked vehicles are tested respectively, and then the slippage coefficient is calculated. In this regard, the theoretical movement speed of tracks can be determined by measuring the sprocket rotation speed. The sprocket rotation speed is generally tested using a Hall sensor and photoelectric encoder. Moreover, the actual moving speed of a tracked vehicle can be calculated using GPS, radar, and other positioning devices. Zhong et al. [14]
tested the slippage coefficient of a tractor. In this regard, the speed of the driver wheel of the tractor was measured using an encoder, while the actual speed of the vehicle was measured using GPS, radar method, and minimum wheel speed method. The obtained results revealed that the GPS method is highly affected by the weather condition, the radar method is applicable for good road conditions, and the minimum wheel speed method is applied to high-speed speeds. Lu et al. [15] designed a slippage coefficient prediction system of tractors based on simulations in the LabVIEW environment. To this end, a coded speed sensor, a low-speed radar velocimeter, and a signal acquisition and processing system were used, and the system accuracy was then verified through numerous field tests.

A series of methods have been proposed by some researchers to predict the track slippage coefficient using models. Song et al. [16] built a model relating to the theoretical moving speed, actual steering radius, steering angular speed of tracked vehicles, as well as the slippage coefficient of tracks. As indicated by their study, the slippage coefficient of both sides of tracks could be obtained by measuring the parameters of the moving track. Lu et al. [17] developed a soft-switching slippage mode observer to measure the track slip parameters of the tracked robot, and the observations were compensated into the adaptive backstepping controller to reduce the effects arising from track slippage. Song et al. [18] developed a slippage mode observer to estimate track slippage using the kinematic model of a skid-steering tracked vehicle and the measurement results achieved by on-board sensors. The accuracy of the slippage mode observer was verified in accordance with both simulation and experimental results. Yamauchi et al. [19] built a slip estimation method using a slippage model for tracked vehicles and applied it to slip-compensated odometry on Loose Slope. Their method was validated through experiments using small-scale robotic tracked vehicles.

As indicated by the review of the relevant literature, the actual moving speed of vehicles is generally required for the calculation of track slippage coefficient. However, the actual moving speed of tracked vehicles is difficult to measure directly, the test methods are complicated, and rigorous operating environment requirements should be satisfied. Thus far, existing methods have been not sufficiently fast and accurate to calculate the slippage coefficient of tracked vehicles during steering.

In this paper, to build an accurate and simple method of calculating the slippage coefficient of tracked vehicles during steering, a model of predicting the track slippage coefficient without detecting the actual moving speed of vehicles was built. A hypothesis that proposed method could effectively reduce the measuring errors as compared with the conventional method was put forward. After the steering trajectory of tracked vehicles at different track slippage coefficients was theoretically analyzed, the correlation between the vehicle steering time and slippage coefficient of tracked vehicles was investigated. Subsequently, the track slippage coefficient was obtained by examining the steering around time of vehicles under the given ground conditions. Afterward, a tracked combined harvester was adopted to calculate the track slippage coefficient under different ground conditions, so as to verify the accuracy of the model.

II. MATERIALS AND METHODS

A. THEORETICAL ANALYSIS

1) SLIP AND SKID OF TRACKED VEHICLES DURING STEERING

To simplify the model, the following assumptions were made.

(1) The tracked vehicle is operating in a horizontal plane and has a steady-state steer.

(2) The longitudinal and lateral load transfers caused by the centrifugal force during the vehicle’s steer are absent.

(3) The steering speed of tracked vehicle is constant.

(4) The friction forces between the moving parts of the track are absent.

When the tracked vehicle steers, the actual steering center of the low-speed and the high-speed side tracks shifts by \( Y_1 \) and \( Y_2 \), respectively. Fig. 1 shows that this phenomenon mainly originates from the braking of the low-speed side track and the driving action of the high-speed side track. Accordingly, the theoretical speed \( U \) (the winding speed of the track relative to the vehicle body) of both sides differs from the actual speed \( V \) (the rotation speed of the tracked vehicle around the steering center).

The theoretical velocity of the high-speed side track \( U_2 \) is greater than the actual velocity \( V_2 \), resulting in the track slip. Moreover, the theoretical velocity of the low-speed side track \( U_1 \) is less than the actual velocity \( V_1 \), resulting in the track skid. Considering the slip and skid of the track, the actual steering radius \( R_S \) of the vehicle is always greater than its theoretical steering radius \( R_L \). Similarly, the actual steering angular velocity \( \omega_S \) is always less than the theoretical steering angular velocity \( \omega_L \). The skid coefficient \( \sigma_1 \) of the low-speed side track and the slip coefficient \( \sigma_2 \) of the high-speed side track can be expressed in the form below:

\[
\sigma_1 = \frac{V_1 - U_1}{U_1} = \frac{S_{S1} - S_{L1}}{S_{S1}} \tag{1}
\]

\[
\sigma_2 = \frac{U_2 - V_2}{U_2} = \frac{S_{L2} - S_{S2}}{S_{L2}} \tag{2}
\]

where \( S_{L1} \) and \( S_{L2} \) are the theoretical driving distances of the low-speed and high-speed tracks, respectively. Furthermore, \( S_{S1} \) and \( S_{S2} \) denote the actual running distance of the low-
speed and high-speed tracks, respectively. These parameters can be calculated using the following expressions:

\[
\begin{align*}
S_{t1} &= 2\pi n_1 t \\
S_{t2} &= 2\pi n_2 t \\
S_{s1} &= (R_s - 1/2) \alpha B \\
S_{s2} &= (R_s + 1/2) \alpha B
\end{align*}
\]

where \(n_1\) and \(n_2\) are the sprocket rotation speeds of the low-speed and high-speed tracks, respectively. Moreover, \(\alpha\), \(r\) and \(B\) denote the vehicle steering angle, radius of the track sprocket, and the track gauge of the tracked vehicle, respectively. \(t\) is the running time of tracked vehicle under the vehicle steering angle \(\alpha\). Under the slip and skid conditions of tracks, the actual steering radius \(R_s\) and the actual steering angular velocity \(\omega_s\) of the vehicle can be expressed in the form below:

\[
R_s = \frac{B}{2} \left[ U_2 (1 - \sigma_1) + U_1 (1 - \sigma_2) \right] \\
\omega_s = \frac{U_2 (1 - \sigma_1) - U_1 (1 - \sigma_2)}{B}
\]

where \(\sigma_1\) and \(\sigma_2\) are the sprocket slips of the low-speed and high-speed tracks, respectively.

![FIGURE 1. Slip and skid of the tracked vehicle during steering.](image1)

2) TRAJECTORY OF THE TRACKED VEHICLE DURING STEERING

Given the slippage factor of tracked vehicles during steering, the trajectory of an arbitrary point on the track during steering can be analyzed. Fig. 2 shows a ground-based static coordinate system XOY and a dynamic coordinate system \(x_1o_1y_1\) rotating with the track chassis. The subscript \(P=1\) and \(P=2\) represent the low-speed and high-speed side track, respectively. Considering the correlation between the unit vector in the moving coordinate system and the unit vector in the static coordinate system, the velocity at an arbitrary point on the track in the static coordinate system can be obtained indirectly. Subsequently, integrating the velocity with respect to time \(t\) results in the trajectory equation on the track.

![FIGURE 2. Velocity diagram of an arbitrary point on the track.](image2)

Fig. 2(a) shows that at the initial state \(t=0\), the static coordinate system XOY overlaps with the dynamic coordinate system \(x_1o_1y_1\). In this case, the coordinate of a point \(M\) on the track of the \(P\) side in the moving coordinate system \(x_1o_1y_1\) can be expressed as \((x_{p0}, y_{p0})\). As the test progresses, point \(M\) constantly moves relative to the ground. When the test time reaches \(0<t\), the steering angle of the tracked vehicle reaches \(\phi\), and the coordinate of the point \(M\) in the coordinate system \(x_1o_1y_1\) can be expressed as \((x_p, y_p)\), where components are as follows:

\[
\begin{align*}
x_p &= x_{p0} \\
y_p &= y_{p0} - v_p t \\
\phi &= \omega_s t
\end{align*}
\]

Fig. 2(b) indicates that the implicated motion velocity of the point, which overlaps with the point \(M\) on the body can be calculated from the following expression:

\[
\vec{V}_{ep} = -y_p \omega_s \vec{l}_1 + x_p \omega_s \vec{j}_1
\]

The relative movement speed of the track relative to the vehicle is:

\[
\vec{V}_{rp} = -V_p \vec{j}_1
\]
where \( i \) and \( j \) are two unit vectors in the moving coordinate system \( x_i y y_1 \). Velocity of the point \( M \) relative to the ground is:

\[
\vec{V}_{ap} = \vec{V}_{ep} + \vec{V}_{rp}
\]

(9)

Substituting Eqs. (6), (7), and (8) into Eq. (9) yields:

\[
\vec{V}_{ap} = \left(V_p t - y_{\rho b} \right) \vec{i}_1 + \left( x_{\rho b} \alpha - V_p \right) \vec{j}_1
\]

(10)

On the other hand, the unit vectors \( \vec{i} \) and \( \vec{j} \) in the static coordinate system \( XOY \) can be expressed as:

\[
\vec{i}_1 = \cos \phi \vec{i} + \sin \phi \vec{j} \\
\vec{j}_1 = \cos \phi \vec{j} - \sin \phi \vec{i}
\]

(11)

Substituting Eqs. (1), (2), and (11) into Eq. (10) yields:

\[
\vec{V}_{ap} = \left[ \left( U_p t f \left( 1 - \sigma_p \right) - y_{\rho b} \right) \cos \alpha t - \left( x_{\rho b} \alpha - U_p f / \left( 1 - \sigma_p \right) \right) \sin \alpha t \right] \vec{i} + \left[ \left( U_p t f \left( 1 - \sigma_p \right) - y_{\rho b} \right) \sin \alpha t + \left( x_{\rho b} \alpha - U_p f / \left( 1 - \sigma_p \right) \right) \cos \alpha t \right] \vec{j}
\]

(12)

In the static coordinate system \( XOY \), the velocity \( V_{ap} \) can be expressed in the form below:

\[
\vec{V}_{ap} = \frac{dX_p(t)}{dt} \vec{i} + \frac{dY_p(t)}{dt} \vec{j}
\]

(13)

Comparing Eqs. (12) and (13) yields the following system of equations:

\[
\begin{align*}
\frac{dX_p(t)}{dt} &= \left( U_p t f \left( 1 - \sigma_p \right) - y_{\rho b} \right) \cos \alpha t - \left( x_{\rho b} \alpha - U_p f / \left( 1 - \sigma_p \right) \right) \sin \alpha t \\
\frac{dY_p(t)}{dt} &= \left( U_p t f \left( 1 - \sigma_p \right) - y_{\rho b} \right) \sin \alpha t + \left( x_{\rho b} \alpha - U_p f / \left( 1 - \sigma_p \right) \right) \cos \alpha t
\end{align*}
\]

(14)

Eq. (14) is the trajectory equation of an arbitrary point \( M \) on the track plate with slippage.

3) CALCULATING THE SLIPAGE COEFFICIENT OF TRACKED VEHICLES DURING STEERING.

In this section, it is intended to establish a mathematical model of the relationship between vehicle steering time \( t \) and slippage coefficient \( \sigma_p \) based on the steering trajectory equation of tracked vehicle during slippage. Fig. 3 shows the displacement of an arbitrary track grouser on the P-side track that contacts the ground with a slippage coefficient \( \sigma_p \).

When the track is at the initial position \( t=0 \), the track grouser \( A_0 C_0 \) at the front end of the track is in contact with the ground, and the track grouser \( A_2 C_2 \) at the last end of the track. When the vehicle steering time reaches \( t=t_1 \), the corresponding track steering angle reaches \( \alpha \). Meanwhile, track grouser \( A_0 C_0 \) leaves the ground, while track grouser \( A_2 C_2 \) touches the ground. Under this circumstance, the angle \( \alpha \) of track steering in the period from \( t=0 \) to \( t=t_1 \) can be expressed as follows:

\[
\alpha = \omega_s \left( Y_p(t) \right) / X_p(t)
\]

(15)

The required time \( T \) for steering around the tracked vehicle is:

\[
T = \frac{2\pi \alpha}{a(R_s + B/2)}
\]

(16)

Substituting Eqs. (4), (5), (14) and (15) into Eq. (16) yields the functional relation between slippage coefficient \( \sigma_p \) and the time \( T \) for steering around the tracked vehicle. Then the slippage coefficient of the track \( \sigma_p \) can be calculated by measuring the time \( T \) for steering around and the sprocket rotation speed of the track \( n_p \).

As revealed by the preceding analysis, the track slippage coefficients refer to a function of the vehicle motion parameters and the structure parameters. The input of the proposed model consists of track width \( B \), sprocket radius \( r \), vehicle steering around time \( T \), and track sprocket rotation speed \( n_p \); the output of the model refers to track slippage coefficient \( \sigma_p \). The track slippage coefficient can be calculated by measuring the input parameters under the given soil conditions.

B. EXPERIMENTAL TEST

1) TEST VEHICLE AND LOCATION

In the present study, a tracked vehicle (Ruilong 4LZ-5.0E, China) combined with a harvester (Jiangsu Word Agricultural Machinery Co., Model, China) was used in the experiments, as shown in Fig. 4. The vehicle was unloaded during the test. The main parameters of the vehicle are presented in Table 1. It is worth noting that steering tests were performed on three different surfaces, including cement ground, sand ground, and soft ground. The steering test on soft ground was carried out in paddy soil, and the soil parameters are listed in Table 2.

To evaluate the influence of the soil water content on the slippage coefficient of tracks, experiments were performed in...
the paddy soil with different water contents. To this end, tests were performed before and after rainfall. To facilitate the test, the combined harvester adopted the steering mode of unilateral braking, low-speed track braking, and high-speed track driving to complete the steering. During steering, the moving velocity was kept constant, and high-, medium- and low-speed gears were selected, respectively. Moreover, three groups of repeated tests were performed under each condition. Before the test, the surface soil was sampled to determine the soil moisture content.

2) TESTING PROCESS

The slippage coefficient of the combined harvester under different ground conditions was calculated using the conventional [21] and the proposed test method. In the conventional method, the sprocket rotation speed \( n_p \) and the actual steering radius \( R_S \) are initially measured, and the track slippage coefficient can be calculated through Eqs. (1), (2), and (3). In the proposed method, the sprocket rotation speed \( n_p \) and the time \( T \) of the steering around were measured, then the slippage coefficient of the track was calculated by the proposed model in the MATLAB environment.

The actual steering radius \( R_S \) of the combined harvester was calculated by measuring the real trajectory of a certain point when the tracked vehicle was being steered. Fig. 5 shows the hourglass device installed at point B at the rear of the vehicle. Transverse and longitudinal distances of the hourglass device relative to the geometric center \( O_v \) of the vehicle were measured. Then the coordinate value \( (x_v, y_v) \) of point B relative to the geometric center \( O_v \) of the vehicle was determined [22].

When the vehicle entered the stable steering state, the hourglass device was used to record the steering trajectory of the vehicle. Then the starting point A and the ending point B were determined using the path remaining on the sand, and the midpoint C was marked. The steering trajectory was reduced to a certain proportion and was plotted on the graph. The center \( O_s \) of the arc AB was determined by the vertical bisector of chord length AC and BC. The radius \( R_d \) of the arc AB can be determined by connecting \( AO_s \) or \( BO_s \), and the actual steering radius \( R_S \) of tracked vehicles can be calculated from the following expression:

\[
R_s = \sqrt{R_d^2 - x_v^2 \pm y_v^2} \tag{17}
\]

Track sprocket rotation speed \( n_p \) was tested using a wireless telemetry analysis system (Jiangsu Donghua Testing Co. DH5905, China), and the test system were illustrated in Fig. 6, a Hall sensor (Company name CHE18-15N11-HZF710, China) was used to measure the sprocket rotation speed. The main parameters of Hall sensor are listed in Table 3. Subsequently, the acquired data was transmitted to the computer acquisition system through a wireless router to realize real-time monitoring of track sprocket rotation speed \( n_p \). The time \( T \) for steering around was measured using the manual timing method [21], [23].
soft ground
sand ground

1. D-Link 2. Hall sensor bracket 3. Hall sensor 4. Power module 5. Power module bracket 6. Power module lead

FIGURE 6. Track sprocket rotation speed test system

3) STATISTICAL ANALYSIS
In the previous sections, the effects of the sprocket rotation speed and soil water content on the measured track slippage coefficient were explored. It is found that none of the studied variables follow a normal distribution. Accordingly, a one-way analysis of variance on ranks (Kruskal–Wallis test) with Post Hoc analysis (Dunn test) was applied. To this end, Origin 8.0 data analysis software was used to perform the calculations.

III. RESULTS AND DISCUSSION
A. COMPARISON OF SLIPPAGE COEFFICIENT BETWEEN TWO TEST METHODS
Since the combined harvester adopts the steering mode of unilateral braking, the low-speed track is completely braked during steering. Accordingly, the skid coefficient remains almost constant [24], [25]. The high-speed track’s slip coefficient of the combined harvester under different ground conditions at specified sprocket rotation speed is shown in Table 4. It is observed that the relative error between the average slip coefficient of the track calculated by the proposed model and the average measured using the conventional method is 5.7%-11.9%, which is within a reasonable range. Accordingly, it is inferred that the proposed model for the slip coefficient of tracked vehicles during steering is accurate and reliable.

The deviation between the results of the two methods can be explained as follows: First, the measurement of the time T for steering around is not accurate enough. Moreover, since the steering time is measured manually, human errors are unavoidable. Second, the measurement of the actual steering radius R_s is not accurate enough. Considering large vibrations during the test, deviations may occur when using the hourglass method to record the trajectory of the vehicle steering. Moreover, the centrifugal force of vehicle steering increases the actual steering radius [26], [27].

Compared with the conventional testing method, the proposed new method is simpler and easier to operate so that it can be used in complicated ground conditions. When the conventional testing method is applied to test the actual moving speed V of the track, vehicle vibration originating from uneven ground and the sensitivity of the measuring tool decreases. On the other hand, bad weather conditions which occasionally occur, adversely affect the testing accuracy [28].

However, the proposed testing method can predict track slip coefficient without detecting vehicle actual moving speed. The time T for steering around was used to replace the actual track speed V, thereby simplifying the testing process regardless of ground conditions and environmental factors.

B. INFLUENCE OF DIFFERENT GROUND CONDITIONS ON THE SLIP COEFFICIENT.
Table 4 reveals that the largest slip coefficient can be achieved from the tracked vehicles being steered on soft ground, followed by the coefficient on the sand and cement ground. Analyzing the obtained results demonstrate that the slip coefficient of tracked vehicles varies from 0.18-0.32 on hard ground (i.e. cement ground and sand ground) and 0.3-0.6 on soft ground. This may be interpreted as follows: (1) the friction coefficient between tracked vehicles and soft ground is smaller than that on hard ground; (2) Relative movement occurs among particles in the soil.

Fig. 7 illustrates the mean values of the measured track slippage coefficient obtained using the conventional testing method and the proposed method under different soil water contents at a specified sprocket rotation speed. With the increase in the soil water content, the corresponding slippage coefficient of the track tended to increase based on both two methods. There was a significant difference in the track slippage coefficient between soil with relatively low water content (23.8% and 28.2%) and that high water content (38.9%) (P< 0.05). Thus, the track slippage was highly impacted by the soil water content. The reasons for the high slippage coefficient on soil with high water content include: (1) when the moisture content of soil increases, the friction coefficient between the track and soil decreases; (2) As the water content of soil increases, the corresponding soil strength decreases; (3) The increase of the soil moisture content reduces the relative movement resistance between soil particles, making the track more prone to slip.

| TABLE 4. Test values of sprocket rotation speed and track slip coefficient of the combine harvester. |
|---------------------------------------------------------------|
| Sprocket rotation speed m/s | Slip coefficient of high-speed track |
| Cement ground | Sand ground | Soft ground |
| Water content | Water content | Water content |
| 23.8% | 28.2% | 38.9% |

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Previous Studies [29]–[31] show that as the slip coefficient of tracks increases, the tractive force of tracked vehicles and the imbalance of track resistance moment on both sides decreases, thereby decreasing the steering performance of tracked vehicles. Meanwhile, the amount of track subsidence increases, thereby increasing the steering instability of the tracked vehicle [32], [33]. This may be attributed to the slip-sinkage effect of the tracked vehicle. It is inferred that tracked vehicles should not be recommended to be used in the field with high water content during the harvest time (e.g. in or after rainy days) to reduce the risk of reducing the production efficiency and safety accidents caused by unstable steering.

C. INFLUENCE OF THE STEERING SPEED ON THE SLIP COEFFICIENT.

Table 4 lists the mean values of the calculated track slippage coefficient using the conventional and proposed testing methods at a specified sprocket rotation speed. In our field test, three vehicle velocities (0.3, 0.8, and 1.4 m·s⁻¹) were selected. Normally, the harvesting velocity of the combine harvester is between 0.8 m·s⁻¹ and 1.4 m·s⁻¹, which depends on the type of cereals. Meanwhile, the traffic velocity at specific operation conditions (i.e. traffic in the field with high water content) is lower than normal speed. We choose these three traffic velocities because we would like to look at the track slip coefficient at different working conditions of combine harvester. As indicated by this table, the track slippage coefficient obtained using the two test methods did not change significantly with the increase in the track sprocket rotation speed (P > 0.05), indicating that the slip coefficient of tracks is independent of the vehicle steering speed and is mainly affected by the ground conditions (e.g. soil water content). The influence of other properties of the soil, including the soil texture and the soil strength on the slip coefficient of tracks should be further studied.

Fig. 8 presents the change of mean measured track slippage coefficient with sprocket rotation speed obtained using two methods under different ground conditions. According to the figure, with the increase in the sprocket rotation speed of the vehicle, the corresponding slippage coefficient tended to decrease when it was calculated using the conventional method (Fig. 8a), while it remained almost constant when calculated using the proposed method (Fig. 8b). The different results by two methods may due to the increase of steering centrifugal force when increasing the steering speed of the tracked vehicle, which results in the excessive measured value of the actual steering radius Rs of the vehicle. It is concluded that the proposed test method can avoid the calculation error of slip coefficient caused by inaccurate measurement of the actual steering radius Rs.
Moreover, the vehicle steering speed (i.e., sprocket angular velocity) was assumed to be constant in the model. In general, the steering speed of tracked vehicle may not be constant due to different working conditions. Thus, more situations (e.g., vehicle steering at variable speed) should be taken into account to improve the applicability of model in the future studies.

IV. CONCLUSION

1) A novel model to predict the slippage coefficient of tracked vehicles steering under different ground conditions without detecting the actual moving speed of vehicles was built. As demonstrated by the analyses, the proposed model was accurate and could effectively reduce the measuring errors as compared with the conventional testing method.

2) The slippage coefficient of tracked vehicles steering on the soft ground was higher than that on the hard ground (i.e., gravel ground and cement ground). The soil water content had a significant effect on the track slippage coefficient. Vehicles steering on the soil with high water content had larger slippage coefficients than on the soil with low water content.

3) The steering speed of tracked vehicles had an insignificant effect on the track slippage coefficient under different ground conditions.

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