ANALYSIS FOR SOIL-LUG INTERFACE FORCES OF A LUGGED WHEEL

Tadashi Kishimoto, Tetsuji Taniguchi, Koh-ichi Ohtomo, Makoto Yoshida

Department of Agro-environmental Science
Obihiro University of Agriculture and Veterinary Medicine
Inada-cho, Obihiro 080, Japan

ABSTRACT

A lugged steel wheel was operated with two kinds of travel reductions on a sandy clay. "Small-sized transducers of the three-surfaced lug type" were installed to the wheel for the measurement of normal and tangential forces acting on a trailing lug side, a lug face and a leading lug side separately. The external forces acting on each surface were calculated from those measured forces. This result proved qualitatively that the relationships between external forces and lug surfaces obtained from mathematical analyses were correct. The traction, the motion resistance and the dynamic load were changing at the three lug surfaces under various operating conditions. Therefore, total analyses of three surfaces were indispensable to discuss the performance of the wheel lug.

Key Word : lug, agricultural wheel, travel reduction, traction, motion resistance dynamic load, lift resistance

INTRODUCTION

Lugged wheels have been widely used in field operation for the increase of traction of self-propelled machine. A leading lug side of the lug, CD surface in Fig. 1, has been mainly studied for improving the tractive performance by many researchers such as Gee-Clough et al.(1976)[1] and Tanaka et al.(1986)[2]. The characteristics of the interactions between soil and lug surfaces such as a trailing lug side, a lug face and a leading lug side were analyzed through the wheel motion by Kishimoto et al.(1990, 1991)[3][4]. The analyses of the horizontal and vertical directions of resultant force acting on the surfaces indicated the relationships between the lug surfaces and the external forces such as net traction, motion resistance and so on qualitatively;(1)the trailing lug side(AB surface in Fig. 1) produces the motion resistance and the reaction of dynamic load(flotation), (2)the lug face(BC surface in Fig. 1) produces the motion resistance, the traction and the reaction of the dynamic load and (3)the leading lug side produces the traction and the reaction of the dynamic load.

In order to prove the above relationships from the results of the mathematical analyses, experiments were conducted on indoor soil bin which contains sandy clay. A steel wheel was used for the experiments to eliminate the effect of lug deformation. "Small-sized transducers of the three-surfaced lug type" developed by Kishimoto et al.(1991)[5] were installed to the steel wheel for the measurement of normal and tangential forces acting on a trailing lug side, a lug face and a leading lug side separately. Horizontal and vertical components of the resultant force acting on three lug surfaces were calculated from measured normal and tangential forces with the inclined angle of a lug surface and lug design factors.

CALCULATION OF HORIZONTAL AND VERTICAL COMPONENTS OF RESULTANT FORCE ACTING ON LUG SURFACES

Fig. 2 shows a schematic diagram of external forces acting on a trailing lug side. The horizontal component of a resultant force, *ABFH*, and the vertical component, *ABFV* can be calculated with the normal force, *ABFn*, the tangential force, *ABFt*, the wheel rotational angle, ϕ, and lug design angles $\delta, \gamma, \lambda, \xi$ as shown in Fig. 1. The horizontal component is considered as the motion resistance when it shows the negative. The component is considered as the net traction when it shows the positive. The vertical component is considered as the reaction of dynamic load when it shows positive. The component is considered as the lift resistance[6)7)] when it shows negative.

The horizontal and the vertical components of the lug face and the trailing lug side can be also calculated with the same method. The components of the resultant forces acting on three surfaces are expressed as following equations.

Trailing Lug Side

$$ABFH = ABFtH - ABFnH = -ABFt\sin(\phi + \beta - \frac{\gamma}{2}) + ABFn\cos(\phi + \beta - \frac{\gamma}{2}) \quad (1)$$

$$ABFV = ABFtV + ABFnV = -ABFt\cos(\phi + \beta - \frac{\gamma}{2}) + ABFn\sin(\phi + \beta - \frac{\gamma}{2}) \quad (2)$$

Lug Face

$$BCFH = BCFtH - BCFnH = -BCFt\cos\phi - BCFn\sin\phi \quad (3)$$

$$BCFV = BCFtV + BCFnV = BCFt\sin\phi - BCFn\cos\phi \quad (4)$$

Lug Leading Side

$$CDFH = CDFnH - CDFtH = -CDFn\cos(\phi - \alpha + \frac{\gamma}{2}) - CDFt\sin(\phi - \alpha + \frac{\gamma}{2}) \quad (5)$$

$$CDFV = CDFnV + CDFtV = CDFn\sin(\phi - \alpha + \frac{\gamma}{2}) - CDFt\cos(\phi - \alpha + \frac{\gamma}{2}) \quad (6)$$

APPARATUS AND PROCEDURE

Transducers

Fig. 3 shows the schematic view of a small-sized transducers installed to a tested wheel. Normal and tangential forces acting on the three surfaces of the lug were measured independently by these transducers with strain gauges. Horizontal and vertical components can be calculated from Eq.(1) through Eq.(6).

The transducers have the same installing angles of the trailing and the leading lug side as the conventional lug shape. The transducers are installed to a tested wheel with a special spoke. The tested wheel was assembled and connected to the frame by an axis transducer(orthogonally holed cantilever type) for measuring the net traction and the reaction of the dynamic load acting on the whole wheel.

Apparatus

Fig. 4 shows the schematic view of a experimental apparatus. The apparatus consists of a carriage, trailing arms, a wheel mounting frame, a pulling wire, a tested wheel and a soil bin (length 1100 cm, width 85 cm, depth 45 cm). The tested wheel is driven by a variable speed motor when it is operated as a positive travel reduction of the wheel, so called a traction wheel. The desired slip of the wheel can be obtained by the motor and a wire-pulling system by a motor-driven winch. Experiments were conducted as the traction wheel. The outside diameter of the tested wheel was 600 mm in this study. Eight steel lugs were installed to the tested wheel. A wheel rotational angle is detected by a photo-interrupter.

Procedure

Experiments were conducted on a indoor soil bin which contains sandy clay. The composition of the sandy clay was 57.0% sand, 12.0% silt and 31.0% clay. Preparation of the soil for experiments was done by rotary tilling, compacting and leveling after adding adequate water for desired moisture content. Moisture content of the soil was about 26 % in wet base. Average cone index of the soil in 20 cm depth were 450KPa. The forward velocity of the tested wheel was adjusted to the 0.3m/s at zero slip. The wheel was operated under the conditions of 11.5%

and 31.2% travel reduction by selecting the adequate position of the winch transmission. Sinkage and wheel distance per revolution were measured after each experiment. Data from the rotational angle detector, the rim sectional transducers and the axis-transducer were recorded to a data-recorder. All recorded data were converted to digital signals by an A/D converter and processed by a micro-computer.

RESULTS AND DISCUSSION

The results of the experiments at 11.5% and 31.2% travel reduction are shown in Figs. 5 through 11. The x-axis of coordinates shows the wheel rotational angle. Zero point of the rotational angle is defined at the point right above the wheel axle.

Trailing Lug Side

Examples of the horizontal and the vertical components of the resultant force acting on the trailing lug side are shown in Figs. 5 and 6 at 11.5% travel reduction. Fig 5 shows the magnitude of each term in Eqs.(1) and (2). Fig. 6 shows the horizontal and the vertical components of resultant force obtained from Eqs(1) and (2). The horizontal component, *ABFH*, is obtained as the negative quantity through the trailing side acts to the soil. This shows that the trailing side produces the motion resistance. The vertical component, *ABFV*, is obtained as the positive quantity through the trailing side acts to the soil. This shows that the trailing side produces the reaction of the dynamic load. These results qualitatively corresponded with the wheel motion analyses.

Both the motion resistance and the reaction of the dynamic load were not detected at 31.2% travel reduction. The trailing side passed in the space where the lug face passed and disturbed the soil when the travel reduction increases. Therefore, the trailing side came in less contact with the soil in front as travel reduction increased. This phenomenon suggests that the motion resistance can be reduced by designing the side not to compress the soil in front[8)].

Lug Face

Examples of the horizontal and the vertical components of the resultant force acting on the trailing lug side are shown in Figs. 7 and 8. Fig 7 shows the magnitude of each term in Eqs.(3) and (4). Fig. 8 shows the horizontal and the vertical components of resultant force obtained from Eqs(3) and (4). The horizontal component, *BCFH*, is obtained as the negative quantity at the beginning of lug penetration into soil. The negative force changes into positive quantity as the wheel rotates. This shows that the lug face produces the motion resistance and the traction. The vertical component, *BCFV*, is obtained as the positive quantity through the trailing side acts to the soil. This shows that the lug face produces the reaction of the dynamic load. These results qualitatively corresponded with the wheel motion analyses.

The transition point from the negative to the positive is thought to vary with operating condition. Further research should be needed to clarify this point.

Leading Lug Side

Examples of the horizontal and the vertical components of the resultant force acting on the leading lug side are shown in Figs. 9 and 10. Fig 9 shows the magnitude of each term in Eqs.(5) and (6). Fig. 10 shows the horizontal and the vertical components of resultant force obtained from Eqs(5) and (6). The horizontal component, *CDFH*, is obtained as the positive quantity through the side acts to the soil. This shows that the side produces the traction. The vertical component, *CDFV*, is obtained as the positive quantity through the side acts to the soil. This shows that the side produces the reaction of the dynamic load. These results qualitatively corresponded with the wheel motion analyses.

The vertical component shows the negative when the side removes from the soil. This phenomenon occurs when the leading side scrapes soil in the rear. This negative force is considered as the lift resistance[6)7)].

External forces such as traction or motion resistance change their magnitude at each lug surface on different travel reduction. Dynamic load is supported by three surfaces, but the magnitude of the reaction of the dynamic load is different at each surface. The magnitude of the reaction force at each surface changes as the wheel rotates. These show that the simultaneous analyses of the three lug surfaces are important for the better understanding of lug performance.

CONCLUSIONS

Experiments were conducted on sandy clay in order to analyze the forces acting on the rigid lug surfaces of a traction wheel. The following conclusions were drawn from the experiments.

1. The trailing lug side produced dynamic load as the vertical positive component and motion resistance as the horizontal negative component of the resultant force acting on the side. The motion resistance and the dynamic load produced by the side became smaller when the travel reduction increased.
2. The lug face produced dynamic load as the vertical positive component and not only the motion resistance but also the net traction as the horizontal component changing form negative to positive with wheel rotation.

3. The leading lug side produced the dynamic load as the vertical positive component and the net traction as the horizontal positive component of the resultant force on the side. At the end of the interaction between the side and soil, the lift resistance was also produced by the side.
4. Above results from 1 to 3 proved qualitatively that the relationships between external forces and lug surfaces obtained from mathematical analyses were correct.
5. Motion resistance was mainly produced by the trailing lug side. It is thought that reducing the motion resistance produced by the side improves the wheel performance through the optimum designing of the installing angle of the side.
6. External forces such as the net traction, the motion resistance and the dynamic load were changing at three surfaces under various operating conditions. Therefore, total analyses of the three lug surfaces were indispensable to discuss the performance of the lug.

ACKNOWLEDGMENT

A part of this study was conducted with the Grant-in-Aid for Scientific Research funded by the Ministry of Education, Science and Culture, Japan. The authors wish to express their appreciation to Mr. Akira Kanda, Technical Officer, Obihiro University, for the assistance to developing the transducers and to the experiments.

REFERENCES

1. Gee-Clough, D., Chancellor, W. J. : Pull and Lift Characteristics of Single Lugs on Rigid Wheels in Rice Soils, TRANS. of the ASAE, 19(3), 433-441, 1976
2. Tanaka, T., Nakashima, H. : Interactions in Soil-lug Systems(Part1), J. JSAM, 48(2), 225-232, 1986
3. Kishimoto, T., Inoue, E., Sakai, J., Matsuo, T. : Basic Studies on Design Theories of Agricultural Wheels (Part 2), J. JSAM, 52(4), 11-19, 1990
4. Kishimoto, T., Sakai, J., Inoue, E., Matsuo, T. : Basic Studies on Design Theories of Agricultural Wheels (Part 4), J. JSAM, 53(3), 25-34, 1991
5. Kishimoto, T. et al. : Development of Devices for Measuring External Forces acting on Agricultural Lugged Wheels (Part 2), Res. Bull. Obihiro Univ., 17(3), 279-287, 1991
6. Sakai, J., Kishimoto, T., Taniguchi, T., Zhou, E., Inoue, E. : A Proposal of Lift Resistance on Wheel Dynamics, Proceedings of the International Agricultural Mechanization Conference, Beijing, Part 2 116-133, 1991

7. Kishimoto, T. et al. : Effects of Lift Resistance on Dynamic Load acting on a Circular Wheel, Proceedings of the International Conference for Agricultural Machinery and Process Engineering, Seoul, 1166-1175, 1993
8. Kishimoto, T., Sakai, J., Inoue, E. : Basic Studies on Design Theories of Agricultural Wheels (Part 3), J. JSAM, 53(2), 3-, 1991

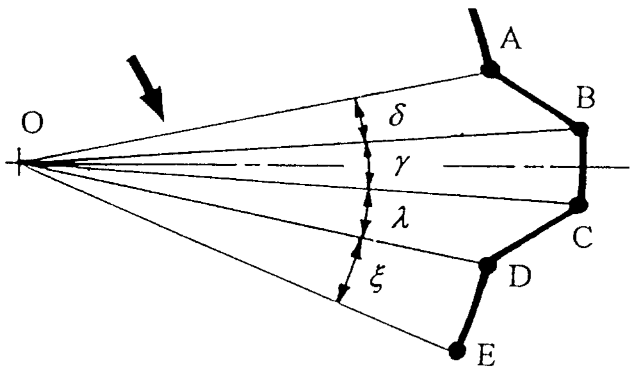

Fig. 1 Angle factors of agricultural wheel lug

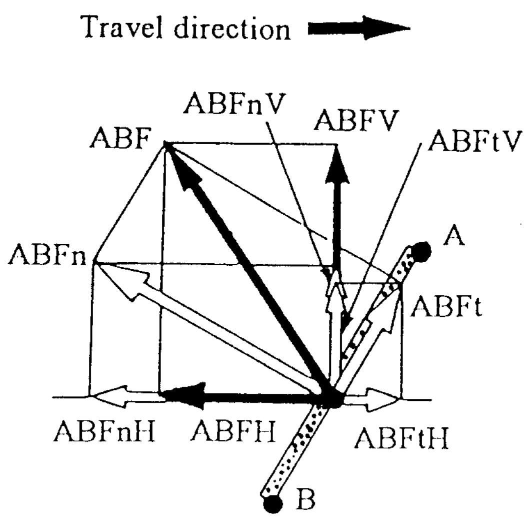

Fig. 2 Schematic diagram of external forces acting on a trailing lug side

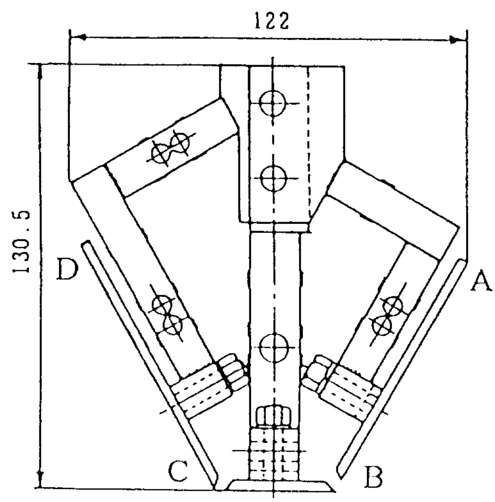

Fig. 3 Schematic view of small sized transducers

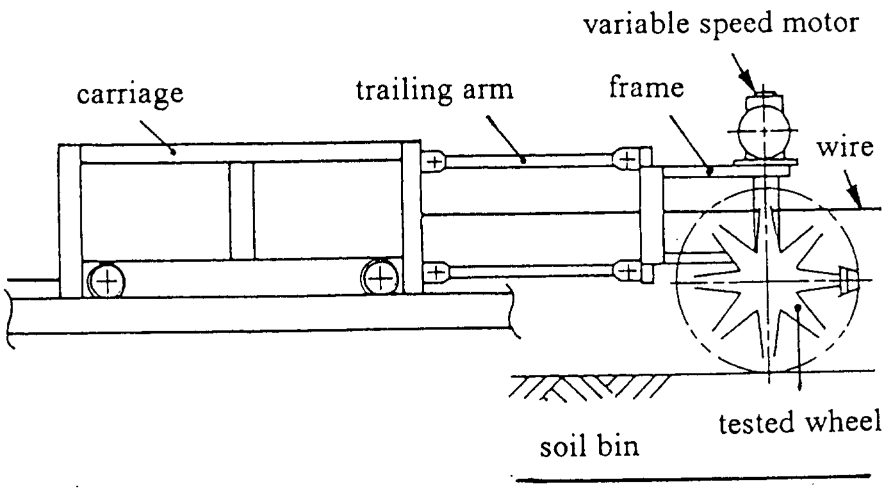

Fig. 4 Schematic view of a experimental device

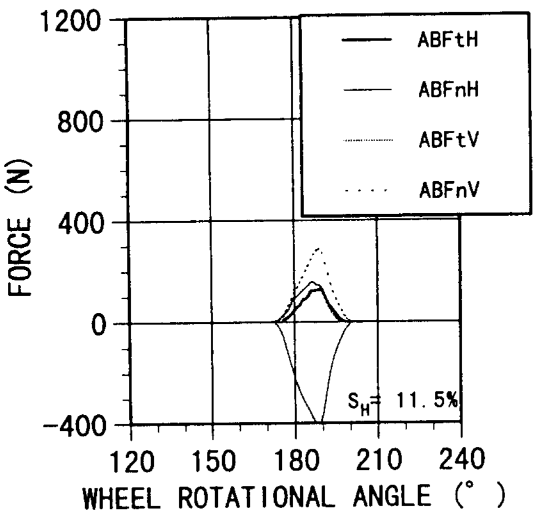

Fig. 5 External forces acting on AB surface

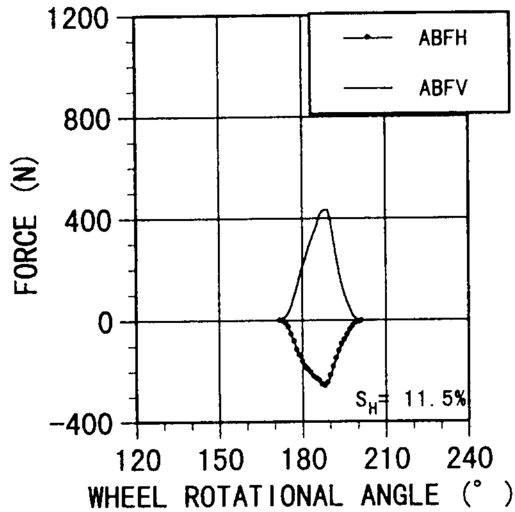

Fig. 6 Horizontal and vertical compornents of the resultant force on AB surface

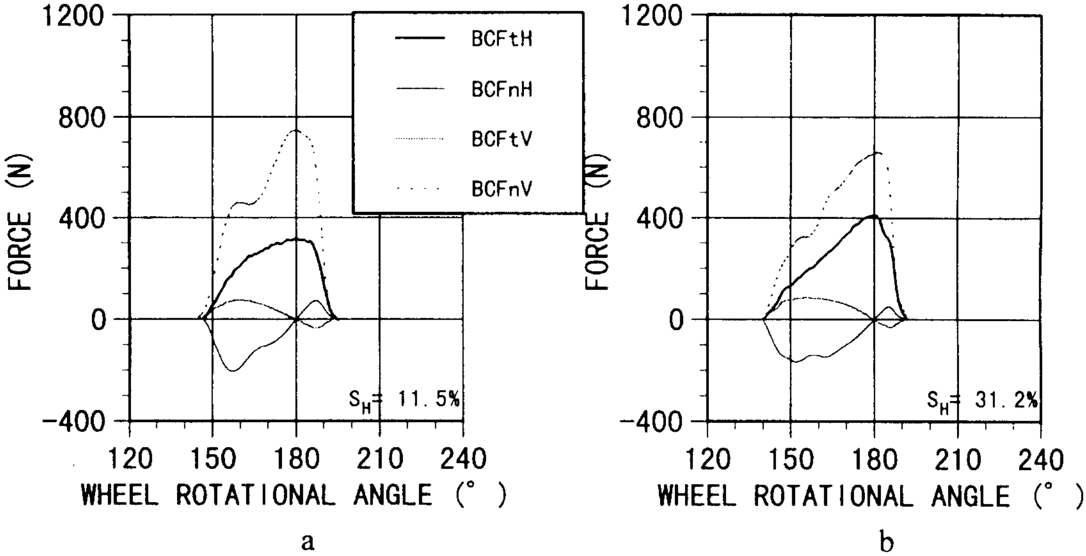

Fig. 7 External forces acting on BC surface

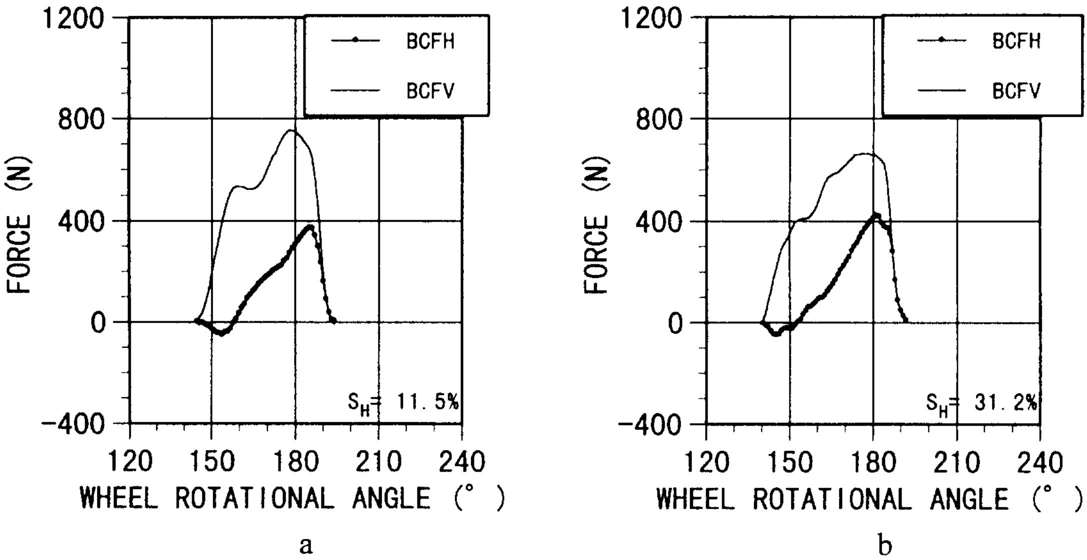

Fig. 8 Horizontal and vertical compornents of the resultant force on BC surface

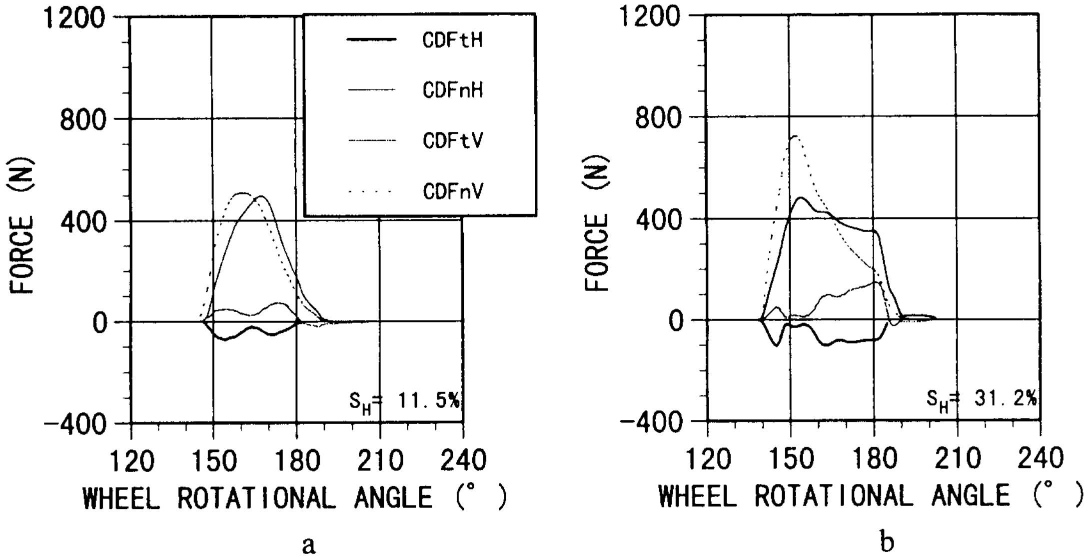

Fig. 9 External forces acting on CD surface

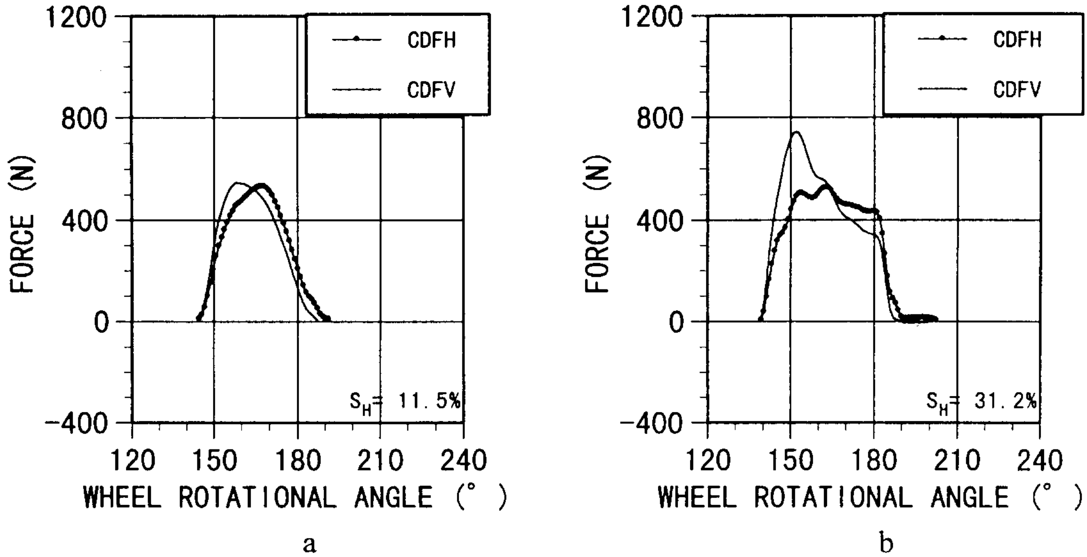

Fig. 10 Horizontal and vertical compornents of the resultant force on CD surface