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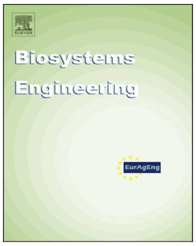

Research Paper

Theoretical analysis of micro-vibration between a high moisture content rape stalk and a non-smooth surface of a reciprocating metal cleaning screen matrix

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Because rape stalk has a high water content, rape materials easily adhere to the cleaning screens of combine harvesters leading to a high screen loss. Inspired by friction-reducing research on bionic non-smooth metal surfaces, a special rape cleaning screen with non-smooth surface was developed and compared with a standard screen in field experiment. It showed good anti-adhesion performance to rape components. To understand the mechanism, a reciprocating friction test between a rape stalk and non-smooth metal surface was carried out. The result was consistent with the findings of a field experiment. In the test, a vertical micro-vibration was discovered between rape stalk and the non-smooth metal surface. This did not exist in the case of a common smooth metal surface and was considered as an important factor in the mechanism. In this paper, a theoretical analysis was proposed to explain how the vertical micro-vibrations occurred during a horizontal reciprocating translation of non-smooth units. Firstly, according to the case of friction test, a geometry contact model and a dynamic equation were established. Then computing methods of vertical impact force and its action time were respectively deduced. Finally, a simulation was produced with a time-scale factor of two. The result from the simulation was consistent with basic trend of test data. Although the theoretical analysis requires improvement for further investigation, it could still provide the basis of a theoretical model and the foundation for further friction-reducing research for non-smooth surfaces.

1. Introduction

Rape is an important oil crop in China and throughout the world. In recent years, the annual mean producing area of rape in China is about 7 million ha with annual output of about 12 million tonnes, which accounts for about 35% of whole world production (Zhan, Yaoming, Jin, & Lizhang, 2010). However, compared with the other main producing countries, the mechanisation of rape combine harvesting in China is still

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Nomenclature

y	displacement of mass, μm
x	displacement of convex unit, μm
b	spacing between adjacent convex units, mm
N	number of convex units in a half cycle
l_2	length of $\overline{OB}$, mm
l_1	length of $\overline{OA}$, mm
θ	dip angle of $\overline{OB}$, °
A	amplitude of reciprocating motion, mm
ω	angular velocity of $\overline{OB}$, rad/s
ω_0	circular frequency, rad s^{-1}
m	mass,g
k	stiffness coefficient, N m^{-1}
c	damping coefficient, Ns m^{-1}
R_1	radius of convex unit, mm
p	$p = \sqrt{k/m}$
F_{cq}	equivalent compact force, N
P	momentum of mass, kg m s^{-1}
I	impulse, N s^{-1}
Δt	impact time, s
v	velocity of convex unit, mm s^{-1}
v_A	velocity of point A, mm s^{-1}
$v_{A\tau}$	tangential velocity of point A, mm s^{-1}
v_{An}	normal velocity of point A, mm s^{-1}
v_B	velocity of point B, mm s^{-1}
$v_{B\tau}$	tangential velocity of point B, mm s^{-1}
v_{Bn}	normal velocity of point B, mm s^{-1}
ζ	ratio of damping
η	scaling factor
n	$n = c/2m$
p_d	$p_d = \sqrt{p^2 - n^2}$

very low (<17%), which indicates that the rape harvesting in China is mainly depend on manual power leading to high producing costs (Ma, Li, & Xu, 2011). The main reason of the low mechanisation of rape is the high loss that occurs in the combine harvesting process, where cleaning losses account for more than 50%. Although there are more than 10 kinds of rape combine harvesters used in China, they are all simply adapted from wheat and rice combine harvesters. Furthermore, in the Yangtze River area where is the main rapeseed production area of China occurs, the water content of rape stalks during the harvesting period is 70%–80% leading to a damp and sticky rape materials in the mechanical harvest process. During harvesting, damp rape materials are easily retained and they can adhere on cleaning screens (Fig. 1) even blocking the holes resulting in a high cleaning loss (Li, Ma, & Xu, 2010; Ma et al., 2011). This problem is not reported in other areas of China or in other countries. In other words, it is a particular problem associated with the mechanical harvesting of rapeseed in China. The problem is so severe that the driver of a combine harvesting rape in China often has to stop the machine and clean the screen when only <2 ha has been harvested. This is very troublesome, and moreover the cleaning losses cannot be controlled. This is why the combine harvester is not used widely to harvest rape in China even though manual harvesting is very hard and time-consuming.

To try and solve the problem, research works has been carried out based on bionic technology. Bionic studies have shown that some soil animals with non-smooth body surfaces can move easily through damp sticky soils with less adhesion (Ren et al.,2007; Zhang et al. 2007). Tong et al. (2007) studied effect of the fold body form of pangolin in a free friction and abrasion, which could provide a reference for friction-reducing research between soil and the soil-contacted parts of agriculture machinery. Luquan, Qian, Liankui, and Ying (1997) and Hong, Cui, and Ren (2006) made ploughs and mouldboards, respectively, with bionic non-smooth surfaces and carried out experiments, the results of which showed anti-adhesion and anti-wear properties. The research was carried out to solve the problem of contact between soil and moving metal soil-touched parts with non-smooth surfaces of millimetre and centimetre magnitude. Inspired by these studies, a special rape cleaning screen with non-smooth surface with millimetre scale was manufactured by a stamping process. It is shown in Fig. 2 compared with common smooth screen when used in a field experiment (Ma et al., 2011). The result of field experiment was encouraging and surprising. It is showed that about 70% area of the common smooth screen was adhered to by rape material when ~2 ha of rape had been harvested (as shown in Fig. 1), but the non-smooth screen could still work normally when about 6 ha of rape had been harvested (as shown in Fig. 2). However, we don't know why the nonsmooth screen could have a good performance; it is just a simple simulation from other bionic nonsmooth research.

In order to provide a quantitative explanation for this phenomenon, a reciprocating friction test between rape stalks and the non-smooth metal surface was carried out (Ma, Z. 2011; Zheng, Yaoming, & Lizhang, 2011), as shown in Fig. 3. The result shows that the non-smooth metal surface could reduce friction by 50%–60% compared to a common smooth metal surface. This contributed to the result of the field experiment, but it cannot provide a theoretical analysis of the phenomenon. However, micro-vibration of rape stalks (upper specimen) in a vertical direction in the friction test was found when the non-smooth metal surface (lower specimen) moved back and forth in horizontal direction, but it was not found in the case of the standard smooth metal surface. Naturally, the vertical micro-vibrations generated by the non-smooth metal surface were considered as an important factor leading to reduced friction. Hence in this paper, in order to more deeply understand and explain the phenomenon of vertical micro-vibrations, the aim was to establish a physical model and carry out theoretical analysis. This will put forward a basis for the next research between vertical micro-vibration and horizontal friction in the future.

2. Physical model

Building a proper contact model is the first step in the process. Later the contact relationship between the interfaces in reciprocating friction test will be introduced (Section 2.1). Then the process of simplification from actual contact relationship to physical geometry model will be provided (Section 2.2) before the building of physical contact model (Section 2.3)