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# EXPERIMENTAL STUDY FOR RUBBER STICK/SLIP

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## Abstract

Tire noise is one of the environment noise issues. Thus a lot of noise source studies are done to reduce tire noise. One of the tire noise sources is stick/slip noise that is caused by friction between road surface and tire tread. Especially on driving condition external forces such as accelerating, braking force and side force are applied to tire. And these forces induce slip between road surface and tire tread. At that time, this slip ratio is set by the magnitude of external force and general slip ratio is 0 to 1 in normal driving condition. In this slip range stick/slip phenomenon is observed in contact patch and sometimes this stick/slip phenomenon generates noise. The previous study for stick/slip mechanism is reviewed. And we developed test machine to study stick/slip vibration of tread rubber block experimentally. Non contact laser vibro-meter is used to measure the block movement. In this way stick/slip phenomenon is observed experimentally and it is compared with analytical model. From experimental test it is found that sliding speed is one of the major factors to generate stick/slip noise. And stick/slip vibration has the time variant characteristic and occurs about 1.5~1.8Khz.

## INTRODUCTION

In a severe driving conditions like rapid turn at corner side force adds on tire. And tire start to slip when the force exceeds a certain limit which tire could support. At this time stick/slip phenomenon occurs in tread contract area. This is also could be happened in normal driving condition but it is negligible. Roik[1] estimated that 5% of the tire road noise are vibrations induced by friction process. But this stick/slip phenomenon makes some stick/slip noise or squeal noise sometimes. Especially at strong braking condition tire road noise is increased by 20 dB[2]. And this type of noise cause problem in OE approval test or market place. But now there is a little understood about this phenomenon so that it is difficult to improve performance. The problem could be solved sometimes by trail and error methods.
This stick/slip phenomenon or friction induced vibration is studied in many part. For example machine tool[3], turbine blade[4], and brake pad[5] are studied. And in recent

year tire stick/slip is also studied. R.Wozniak[6] studied tire/road noise in longitudinal slip condition. They used special trailer called the "SlipSonic" and measured tire/road noise with respect to longitudinal slip ratio, vehicle speed and different kinds of road surface. They found that for small values of longitudinal slip (from -1.5% to +1.5%) A-weighted SPL increase just a little but it increase rapidly as far as the longitudinal slip achieves values at about 8%. M.Kroger[7] studied physical causes of friction, like adhesion and hysteresis to describe friction induced vibration. Based on analytical and experimental investigations, they describe adhesion and hysteresis friction in contact area.

In this paper, the previous analytical stick/slip model is reviewed. And we developed test machine to study stick/slip vibration of tread rubber block experimentally. Experimental result is discussed and we found the specific condition that stick/slip noise occurs. Also time variant characteristic is observed.

## ANALYTICAL MODELING

Stick/Slip was first rationalized in 1950s [8] by difference between the static and kinetic friction coefficient. This is the simplest argument that can be established as a case of stick/slip behaviour.  It can be explained by 3 steps and stick/slip motion is repeats of step 2 and 3.

- Step 1(Stick period): Rubber block initially stick together with road surface and moves with no relative velocity. Restoring force is increase due to the bending of rubber block, and it lasts until the restoring force is equal to static frictional force.
- Step 2(Slip period): After the restoring force has reached the static friction value, the slip begins. At this time the friction coefficient is changed from static to kinetic. Thus due to force difference between kinetic and static the block move back until the restoring force is equal to kinetic friction force.
- Step 3(Stick period): The stick phenomenon occurs again, and the block stick to road surface until the restoring force is equal to static frictional force.

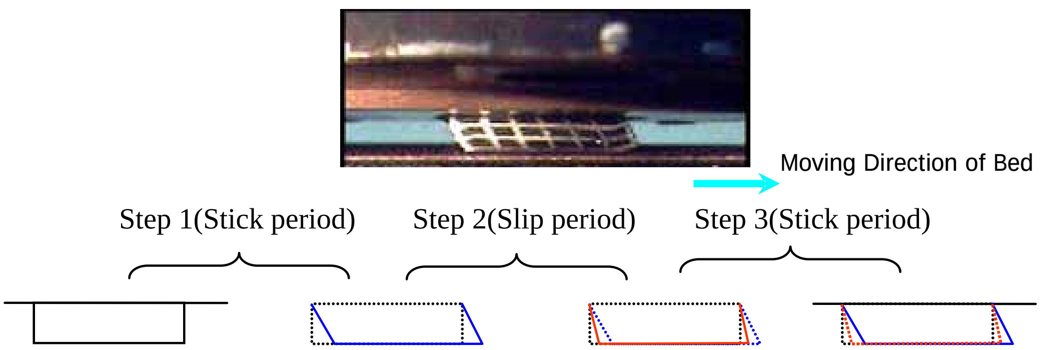


*Figure 1 – Schematics of Tread Block Stick/Slip Phenomenon*

To understand the slip phase, Stick/Slip phenomenon can be modelled with one dimensional single degree of freedom model. K is the mechanical bending stiffness of rubber block and the governing differential equation in the slip phase is (1).

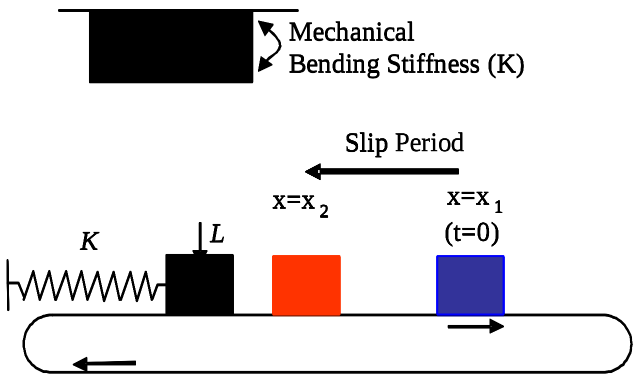


*Figure 2 – Equivalent Mechanical Circuit*

$$\sum F_x = m\ddot{x} = -Kx + sign(\dot{x})\mu_k L$$

$$I.C)\ x(0) = \frac{\mu_s L}{K}$$

$$\dot{x}(0) = 0 \qquad (1)$$

$$x(t) = \frac{(\mu_k - \mu_s)L}{K}\cos wt + \frac{\mu_k L}{K}$$

$$\Delta x = x_2 - x_1 = \frac{\mu_s L}{K} - \frac{(2\mu_k - \mu_s)L}{K} = \frac{2(\mu_s - \mu_k)L}{K} \qquad (2)$$

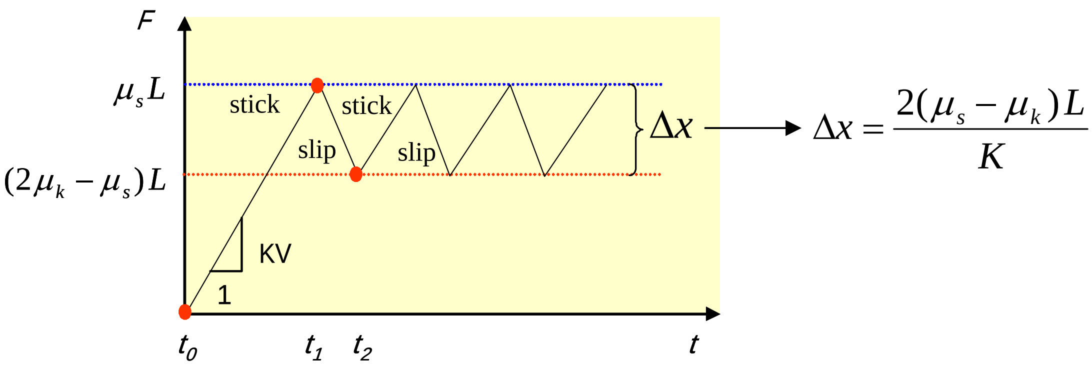


*Figure 3 – Schematics of calculated Stick-Slip phenomenon*

From the equation (2) we can know the factors that control the stick/slip are the discrepancy between static and kinetic friction coefficient, load and bending stiffness of tread block. Also If we assume that stick/slip noise is proportional to vibration amplitude, it is getting worse if the load is increase or discrepancy between static and kinetic friction coefficient is increase. Otherwise if the block gets stiffer, stick/slip noise gets improved.

## EXPERIMENTAL ANALYSIS

The tread rubber block movement measuring system is developed. Basically friction induced vibration is close related with block vibration. Thus acquisition of vibration and noise data is necessary in order to understand the stick/slip. But the tread block size is too small to measure it with accelerometer. (normal height of tread block is 0.8cm) So the laser vibro-meter is used for measuring block vibration. Figure4 shows the measuring rig. The size of rubber block is 3*3*0.8cm and normal passenger tire compound is used. 10Kgf, vertical force, is applied to rubber block. Smooth steel surface is used.

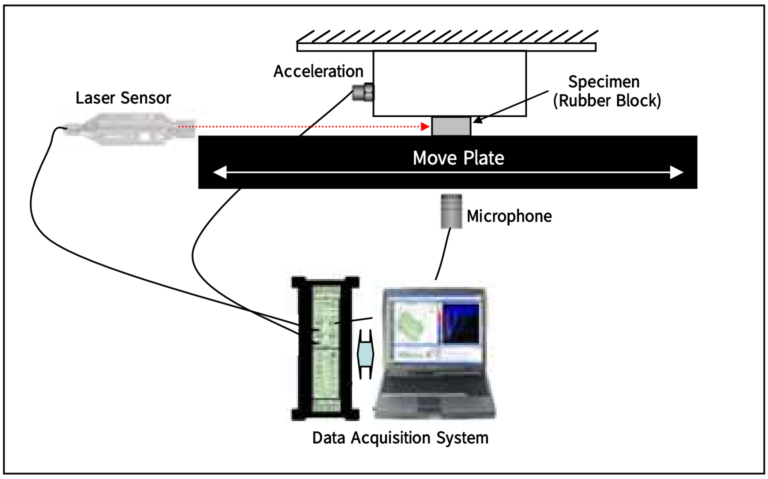


*Figure 4 – Tread Block Test Rig*

Measured block vibration is transformed to displacement data through integral. And it is compared with the analytical solution. Figure 5 shows the tread block vibration and it shows similar result with the analytical stick/slip model, Figure3.

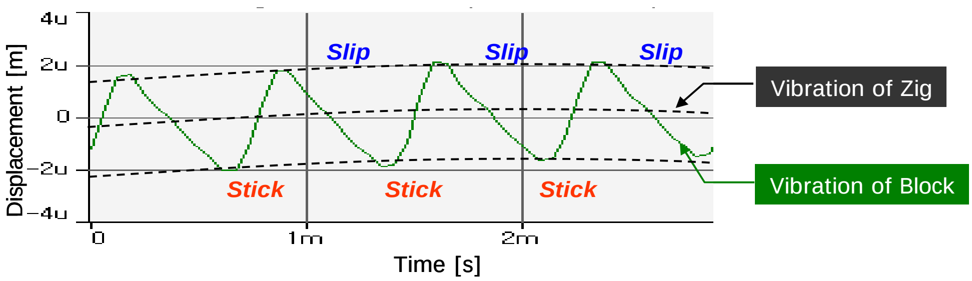


*Figure 5 – Schematics of tested Stick-Slip phenomenon*

Block displacement and near field noise is analyzed though FFT. Figure 6 shows the frequency analysis result. During acceleration period (0~0.5s) stick/slip frequency increases with respect to speed. However during the constant speed the frequency increases a little. Figure7 shows the block displacement changes with respect to time. We can divide it into 3 parts. 1st part is unstable step. Just as the speed is constant, the stick/slip amplitude and frequency changes much. 2nd part is quasi stable step. In this step, the amplitude decrease and the frequency increase a little. And 3rd part is stable state. Both frequency and amplitude are unchanged at this state. Therefore we need to study stick/slip at this stable state to compare exact characteristics of this phenomenon. The peak frequencies of stick/slip vibration and noise are between 1500 Hz and 1700 Hz. And also harmonics of this peak is observed. The other study also shows the peak frequency of the tread block occurs between 1 kHz and 2 kHz. And it is similar with in the range of the shear eigen-frequency of the tread [6],[9]

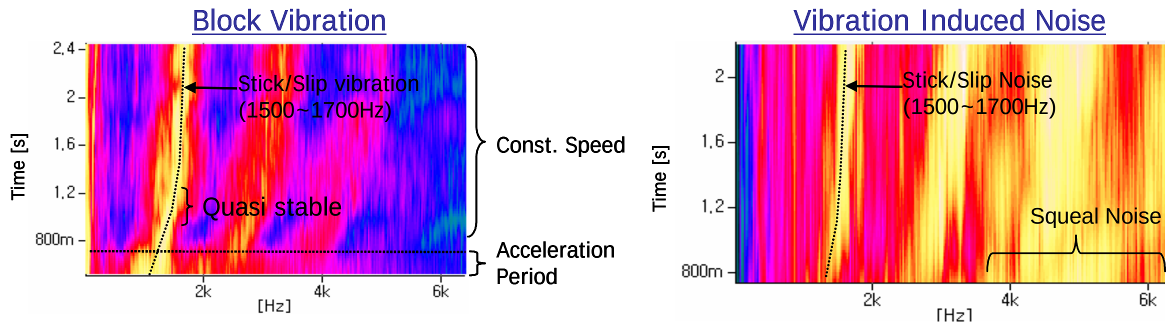


*Figure 6 – Frequency Analysis Result*

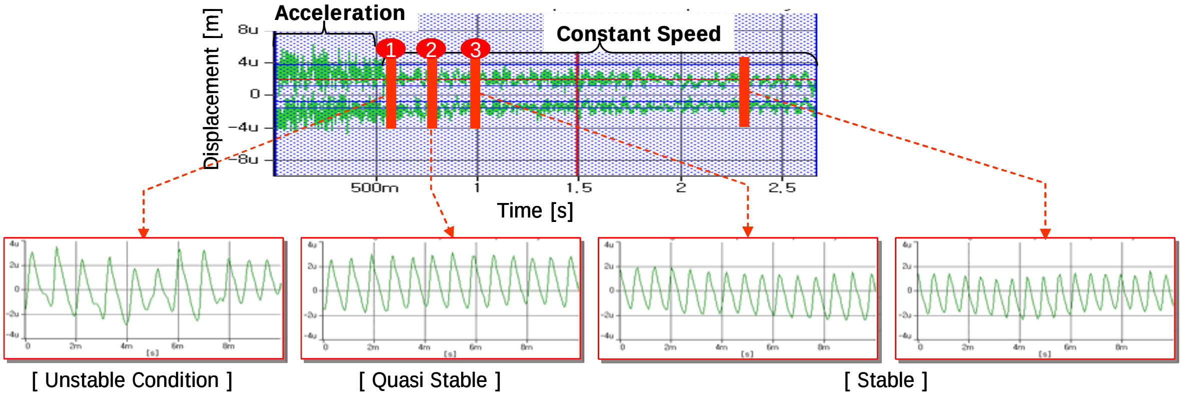


*Figure 7 – Time variant characteristic*

Stick/slip phenomenon occurs always at all slip speed theoretically. However test result shows that this phenomenon occurs very irregularly at low speed like 1cm/s or 5cm/s. Kinetic friction coefficient is measured with respect to the slip speed to study this phenomenon. Figure 8 is the kinetic friction curve. And it shows a peak around 10 Cm/s. This speed is called as critical speed and stick/slip occurs over the critical speed.

[10] At the speed 20 Cm/s stick/slip is observed clearly. Tread compound and road surface is maybe the factors that control this critical speed and it is an important factor to study stick/slip.

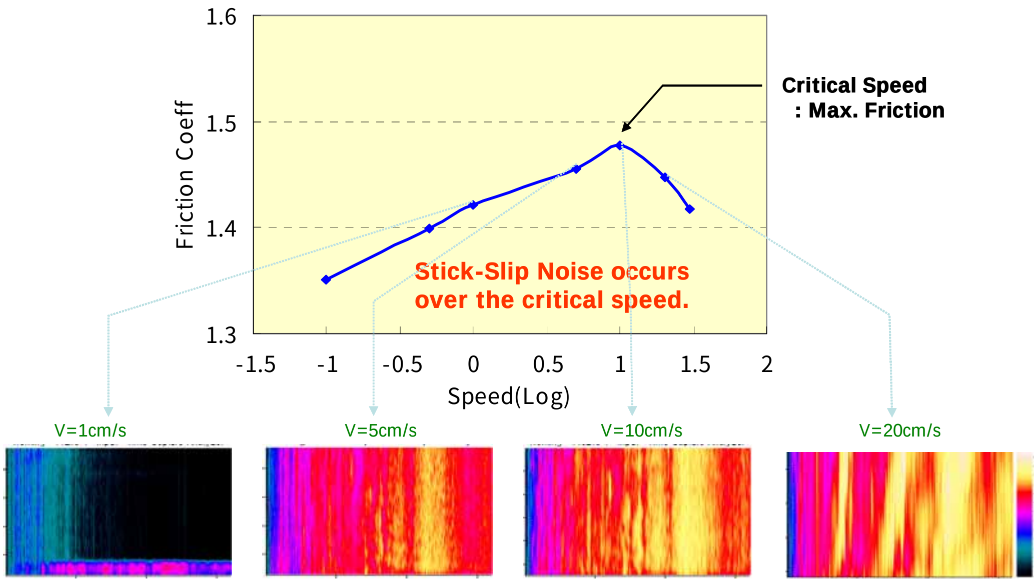


*Figure 8 – kinetic friction curve and critical speed*

## CONCLUSIONS

This is the briefly review the tire stick/slip phenomenon. To understand tread rubber block movement, measuring system is developed and test result is compared with simple analytical model. The peak frequencies of stick/slip vibration and noise are between 1500 Hz and 1700 Hz. Test result shows that stick/slip occurs very irregularly at low speed like 1cm/s or 5cm/s. From the kinetic friction curve with respect to time, the peak is observed around 10 Cm/s(this is called critical speed) and stick/slip occurs over the critical speed.

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