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미끄럼 저항 측정을 위한 로봇 시스템 개발

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The Development of Robot System for Assessing Slip Resistance

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Abstract : The main objective was to design and develop a prototype robot system for assessing slip resistance. The developed robot system will be able to be used for stochastic nature of friction in the whole workplace. The second objective was to evaluate its operating condition in the laboratory, using a dreg sled type slipmeter(BOT-3000) as reference device. It was found that COF(Coefficient of Friction) measured with robot system was similar to that of BOT-3000 when sliding velocity was reached at 0.2㎧. The robot system might be the more promising one than any traditional measurement devices. A further evolution of prototype devices, as well as the development of test methods for that's various applications, is to be started in forthcoming studies.
Key Words : slip resistance, stochastic nature, robot system

1. 서론

According to the KOSHA statistics in 2006, STF (Slip, Trip and Fall on the same levels) are the leading cause of industrial accidents of Korea, excepting for caught-in accident. The total number of casualties attributed to STF was 16,305 which account for 20.4% of all accidents. The number of STF accidents victims increase by 1,257 persons and fatalities decrease by 23 compared with 2005 respectively. The number of slip accidents victims account for 9,344 persons or 57.3%, trip account for 1,736 persons or 10.4% of all STF accidents[1)].

Conventional slip theory does not account for the stochastic nature of friction in the whole workplace.

By contrast, extreme value theory[2)] can explain stochastic nature of real workplace floor. Many devices for assessment of floor slipperiness have developed by many researchers[3)]. However very few devices are able to be used for the extreme value theory, since many devices just measures the discrete values of the slip resistance of whole workplace. In order to predict the slip potential for whole workplace, it may be required to develop an equipment that automatically and continually measures the steady-state dynamic COF. So we have developed two kinds of measuring devices. The first device was the portable slipperiness test equipment (PSTE). The second device was automatic robot system. The first was a preliminary test device of the second. The operating principle of PSTE was similar to that of the robot system. However, the PSTE was operated by means of manual pushing, while the robot system was operated with electric motor.

The PSTE and robot system in order to measure slipperiness of whole workplace are described and preliminarily evaluated in this study. The prototypes are capable of measuring such frictional properties of floor surfaces using one mode of operation, dynamic loading. BOT-3000 is used as starting point for designing a PSTE and slipperiness assessing robot system.

The main objective of this study is to design and develop a prototype robot system for assessing slip resistance and evaluate its operating condition in laboratory.

1.1. A survey of automatic slip assessing devices

Many devices have developed for the measurement of slipperiness of floor and footwear. Since most of them were manually operated and could not control normal force and velocity[3)], those devices couldn't be used for the whole workplace assessment of slipperiness. Some of them also had a poor usability and depended on experience of operator. So

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Table 1. Examples of automatic devices for assessing floor slipperiness and its test conditions.

Name of device	Average normal force(N)	Contact area(cm^2)	Contact pressure(kPa)	Horizontal sliding velocity(m/s)	Special remarks
AFPV	124-360	16	77-225	0.83	Poor usability
Tortus	2	0.6	30	0.017	Low controlled velocity
FSC 2000	24	2.5	100	0.2	Similar BOT-3000, long test distance
GMG100	93	11.7	80	0.2-0.3	In practice, at least, two operator needed

more automatically operated devices are needed to accurately and easily evaluate the slipperiness of whole workplace.

There are many automatic measurement devices in the world. Some of them are reviewed in Table 1. The test conditions of these devices are also summarized in the table. These types of devices are automatically driven with controlled velocity and/or normal force under the limited distance in site or laboratory.

1.2. Stochastic nature of friction

The probability of slipping has stochastic nature of the interface between floors and outsoles. Currently, many standards have the threshold value of COF. A surface may be considered as slip resistant if the mean COF between floor and outsole exceeds this threshold value. Since the slip accident, however, is commonly happen at the lowest friction site in workplace, the mean COF has little meaning to represent slip resistance of whole workplace.

Marpet[4] suggested that the safety threshold might not be compared with the average of entire measured data set, but be compared with the tenth percentile of all measured data set. Barnett[2] suggested novel theory of slip potential which provided a mathematically closed form equation and easily manipulated relationship among the probability of slipping, critical friction criterion, the distance traveled by walker, and three statistical parameters (average, spread and asymmetry of entire distribution of COF) that characterize the floor/footwear set.

Although mean COF may exceed the threshold, local COFs are able to be below the threshold. So, the continuous measuring device will be needed from stochastic nature of COF.

2. Materials and methods

We develop automatic slip and trip hazard assessing equipment which is consist of a high precision linear strain gauge, ultra mobile personal computer, slip measuring sensor, 48-volt DC power source, 2-D laser scanner, ultra sonic sensor, indoor GPS system, motor driving system and blue-tooth telecommunication system.

It measures the DCOF(Dynamic Coefficient Of Friction) of a whole workplace. This robot system can be adjusted to modify its driving modes while maintaining a constant 0.1 and 0.2 $^{m}/s$ forward speed. It can also be programmed to perform a SCOF(Static Coefficient Of Friction) measurement, mimicking a pedestrian's outsole contact with the floor surface during average walking speed.

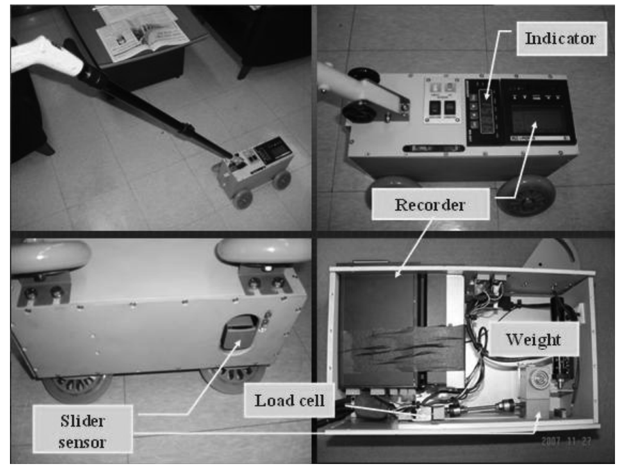


Fig. 1. Portable slipperiness test equipment.

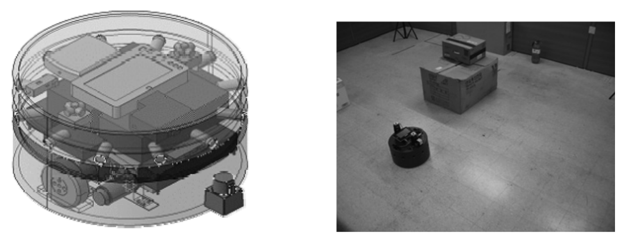


Fig. 2. Slip resistance measuring robot system.

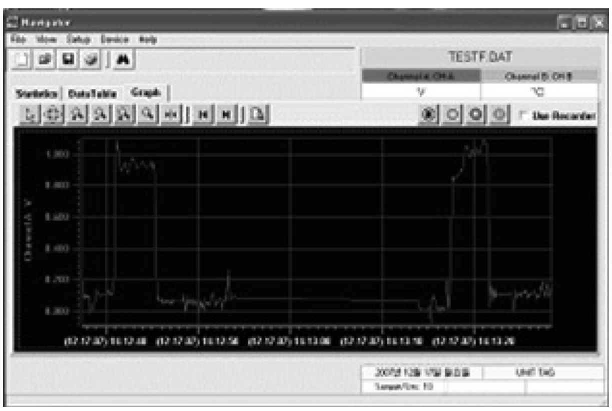
The PSTE, developed in this study, is a portable, drag sled type slip tester as shown in Fig. 1. The frictional force of this tester is measured on the device horizontally moved with respect to tested floor. The normal force (100 N up to 200 N) of PSTE can be adjusted to find the best fit condition. PSTE, consisting of digital indicator, sensor unit, weight, fiber optical sensor and servo motor systems, is introduced as assessment device for slip potential. This new test device is designed to measure dynamic friction properties of dry and contaminated floor surfaces during simulated heel contact, which is considered the most critical phase of locomotion from the slip and fall point of view.

The overall dimensions of PSTE are 300 mm×120 mm× 180 mm, and its weight is 6.9 kg. The applied normal force can be altered using the linear motor. Digital recorder(Datachart 1250) is used to acquire the frictional force data of floor. The gathered data is transfer to the flash memory and analyzed with DC1250 Navigator software. The Neolite is used as sensor slider material which is standard simulated out sole.

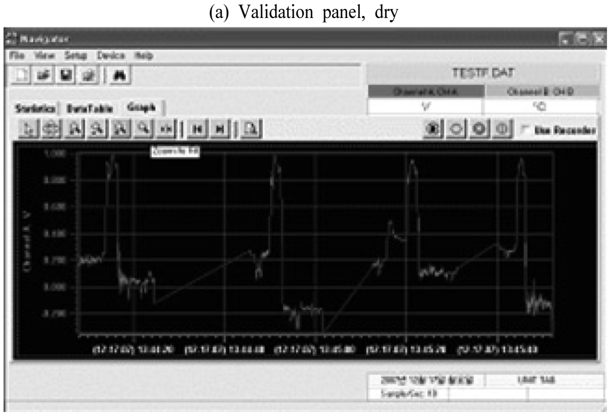
Two kinds of floor are selected for calibration of PSTE as standard reference floors : validation panel(DCOF : 0.97±0.03), stainless steel plate (DCOF : 0.9±0.1). The floors are measured under two surface conditions including dry and wet. Wet floor is very common in all the building, especially after daily floor cleaning.

The robot system, developed in this study, travels across the floor and simulates foot traffic on the floor as shown in Fig. 2. Variations in COF is continuously measured, and then specific trouble spots are defined from measured COF data set.

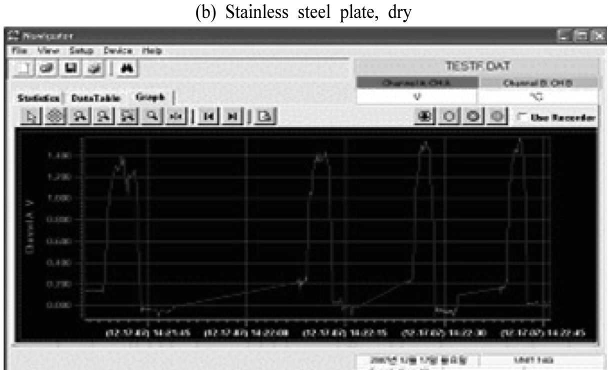
The robot system is assessed on the VCT(Vinyl Composite Tile; Rz=5.36 μm) under the wet condition as shown in Fig. 2. The tested floor is cleaned with ethyl alcohol 50% solution, and then dried in air. The distilled water is used as contaminant. The roughness parameter(Rz) of floor is measured with roughness checker(Surtronic Duo).



(a) Validation panel, dry



(b) Stainless steel plate, dry



(c) Stainless steel plate, wet

Fig. 3. The preliminary test results of PSTE for dry and wet floor surfaces.

3. Results and Discussion

The objective of this study is to design and develop a prototype robot system for assessing slip resistance and evaluate its operating condition in laboratory, but not yet in the field.

Fig. 3 show the preliminary test results of PSTE which are typical examples of frictional force graph. This test is performed under the dry and wet conditions with two different reference surfaces.

The DCOF over the time of contact between slider and floor is calculated from the classical equation by Amontons and Coulomb, DCOF = frictional force/normal force[5]. The PSTE give good agreement with validation panel value (DCOF: 0.97±0.03), but it give somewhat higher DCOF than that of stainless steel plate (DCOF : 0.9±0.1), especially under the wet condition. The results indicate that poor squeeze film simulation is happen in the slider-floor interface. The slider configuration of PSTE may also induce poor performance under the wet condition. So we must develop more appropriate slider sensor configuration which have minimum contact area between slider and floor. Hence, a convex slider configuration is selected as basic slider for PSTE in hereafter.

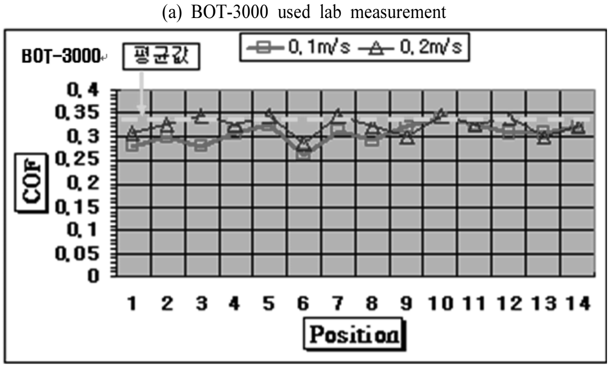
Fig. 4 shows the test environment and lab test results of BOT-3000 and robot system.

The BOT-3000, used in this comparing study, is a towed-sled-type device, similar to the Tortus Floor Friction Tester, and it measures low-speed DCOF with undetermined contact time between slider and floor surface as shown in Fig. 4(a)

In Fig. 4(b), the effect of the applied velocity on the DCOF is drawn versus the sliding distance. The dashed line is mean value measured with BOT-3000 and solid line is local value measured with robot system. It is found that friction coefficient is increased when the applied velocity is slightly increased. However such result doesn't agree with the other studies[6]. Unfortunately, it isn't conducted an experiment on sliding velocity over 0.3 $^{m}/s$, because the robot system don't move faster than that velocity. Therefore such variation cannot be confirmed with this result.

The results of robot system also show a slightly increasing trend with sliding distance. Visual inspection of the slider surfaces indicate that the observed trend is caused by mechanical wear and contamination of dust on the floor surface.

(a) BOT-3000 used lab measurement



(b) results of robot system and bot-3000

Fig. 4. The test situation and lab test results of BOT-3000 and robot system.

So rubber sensor must be conditioned frequently in this robot system.

The results indicate that this robot system may be the more promising one than PSTE for the further development

This system allows an operator to exam and/or monitor the floor. Thereby, this robot system may potentially reduce the likelihood of an excessively slippery condition developing. It also allows a user to perform "before and after" type testing of floor cleaners and treatments.

4. Conclusions

Numerous devices base on different operating principles have been developed to measure the COF between floor surface and outsole. But very few equipment are able to be used for evaluation of slip hazard of whole workplace. So robot system, which continually measures the dynamic coefficient of friction of whole workplace, was developed.

A prototype portable slip test equipment and robot system, designed for whole workplace testing, have been described and is preliminarily evaluated in this study. The robot system may be the more promising one than PSTE for the further development.

A further evolution of these prototype equipments, as well as the development of test methods for that's various applications, is to be started in forthcoming studies.

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