Performance Evaluation of Nonlinear Character Friction Control

Yong-Hee Cho*, Won-Sung Lee**, and Jung-Ha Kim***

* Graduate School of Automotive Engineering, Kookmin Univ., Korea
(Tel : +82-2-916-0991; E-mail: ychcho94@kookmin.ac.kr)

**Graduate School of Automotive Engineering, Kookmin Univ., Korea
(Tel : +82-2-910-4712; E-mail: wslee@kookmin.ac.kr)

***Graduate School of Automotive Engineering, Kookmin Univ., Korea
(Tel : +82-2-910-4715; E-mail: jhkim@kookmin.ac.kr)

Abstract: In this paper, we describe the nonlinear character for a friction control. The nonlinear character of friction control is inherent in mechanical system, which has gained more and more interest. The modeling and compensation of nonlinear friction are difficult tasks for precise motion control. This paper is performance evaluation of nonlinearities and mechanical compliance exists together with friction control system.

Keywords: Nonlinear Character, Friction Force, System Identification, Performance Evaluation

1. INTRODUCTION

The aim of this paper is performance evaluation of sorting system, which shoot ahead for thin-veneer sorting progress mechanism.

Handwork progresses of producing the floor material consist of sorting, moving, adhesion, inspection, and heat-pressing. Now, developed sorting veneer mechanism is using vacuum absorber. The absorption mechanism has restriction, which is making vacuum between absorber and veneer, therefore it is difficult for plant to apply.

For that reason, more efficient system is demanded such as sorting system using friction force. One side, friction force is regarded with eliminating target on mechanic system and braking system. Because friction force cause mechanical efficiency to restrict and difficulty to design control system.

In order to plant application of sorting system using friction force is demanded such as accurate design of instrument and performance evaluation of optimal control.

2. SYSTEM CONFIGURATION

2.1 Friction Configuration

The principle of model based friction compensation schemes is to apply a force or torque command equal and opposite in sign to the instantaneous friction force. An accurate friction model is needed for this purpose. As friction phenomena have not yet been completely comprehensive because friction modeling is not an easy task.

To understand friction it is necessary to investigate the topography of sliding surfaces in contact(Rolling contact may contain different characteristic). Any surfaces, even apparently smooth surfaces, are microscopically rough. The protuberant features can be considered as asperities.

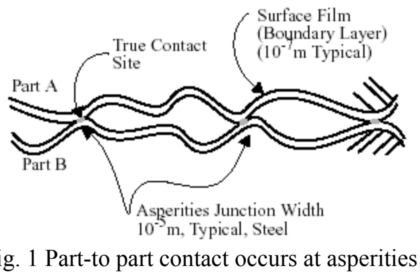

Fig. 1 Part-to part contact occurs at asperities

When two surfaces come the true contact, the true contact tasks place at points where asperities come together, as shown in Fig.1. Deformations of the contact points occur due to the load. As the load grows, the junction area grows.

2.2 Friction models

Static friction models are those that give the friction forces a function of velocity.

• *Coulomb friction:* the friction force opposes motion and does not depend on velocity and contact area,

$$F = F_C \operatorname{sgn}(v),\ F_C \text{ is Coulomb friction}$$

• *Viscous friction*: the friction force is caused by viscosity of lubricants,

$$F = k_v v,\ k_v \text{ is viscous } \textit{friction coefficient}$$

• *Static friction*: the friction force for zero velocity is a function of the external force,

$$F = \begin{cases} F_e & if \quad v = 0 \ and \ |F_e| \le F_s \\ F_s \operatorname{sgn}(F_{e)} & if \quad v = 0 \ and \ |F_e| \ge F_s \end{cases}$$

where υ is sliding velocity, F_e is applied force and F_s is static (break-away) friction force.

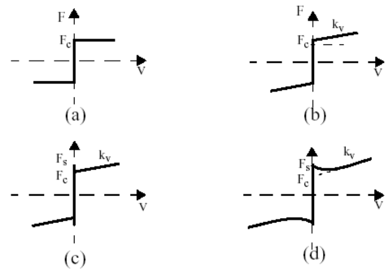

Fig. 2 a) Coulomb friction; b) Coulomb plus viscous friction; c) Static plus coulomb and viscous friction; d) Stribeck curve, show that the friction force first decrease continuously from the static friction level and then increases for high velocity

General static friction model: A more general description of friction than the classical models is the model in Fig. 2(d), which includes the Stribeck effect, i.e., for low velocities friction decrease continuously with increasing velocity. Therefore, a general static friction model is,

$$F = \begin{cases} F(v) & if \quad v \ne 0 \\ F_e & if \quad v = 0 \ and \ |F_e| < F_s \\ F_s \operatorname{sgn}(F_{e)} & if \quad v = 0 \ and \ |F_e| \ge F_s \end{cases}$$

where $F(v)$ is a function, which can be given either as look-up table or as a parameterized curve that fits experimental data. A very common form is,

$$F(v) = F_c \operatorname{sgn}(v) + (F_s - F_c)e^{-(v/v_s)^{\delta}} \operatorname{sgn}(v) + k_v v$$

where v_s is called the Stribeck velocity.

The static friction models only describe the steady state behavior between velocity and friction force. One drawing of the above models is discontinuity at zero velocity that allows the friction rate to take on an infinite number. The discontinuity does not reflect the real friction behavior in a good way and causes errors or even instability in the algorithms used to compensate the friction.

2.3 Sorting Mechanism using AC Servo Motors & Sensors

The sorting model that is developed could be seen Fig. 3 and Fig. 4. The major mechanism of the sorting model is made up using a different friction between a friction generation device and veneer to sort supply on by one.

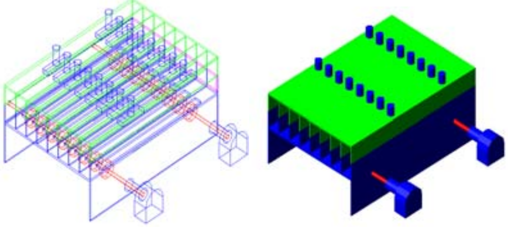

Fig. 3 Sorting Model

In the Fig. 4, the sorting roller (upper roller) is generated a friction by a rotation force and the highest veneer. Then it is sorted the highest one.

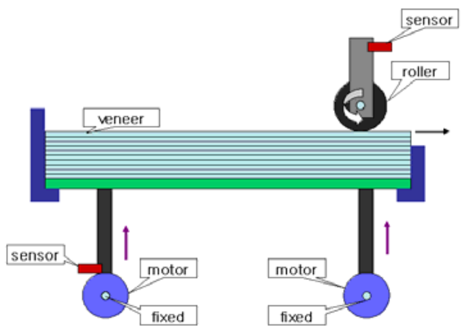

Fig. 4 Schematic Diagram of sorting mechanism

3. KINEMATICS ANALYSIS OF SORTING SYSTEM BY NORMAL FRICTION FORCE

3.1 Geometry of Friction Control Sorting System

In the Fig. 5, the sorting system, sorting roller must move vertical direction to get friction of veneer and sorting roller. And it contain axis with moving positive vertical direction to compensate normal friction force when veneer sorted by sorting roller. Normal friction force and sorting force are happened by sorting roller is contacted with veneer.

A main mechanism of sorting system is that F (rotation force of the motor to veneer contacted to tangent line) is bigger than F_f (maximum static friction force between motor and veneer contacted to motor) and smaller than F'_f (maximum static friction between veneer and veneer) then M (the highest veneer) can sorted. The numerical formula for sorting is described by:

$$\therefore F_{fs} \le F_f < F'_{fs} \qquad F_{fs} + F'_{fs} \le F < 2F'_{fs} \qquad (1)$$

In the other worlds, if it is known F_{fs} and F'_{fs}, and make F_f satisfied the formula, sorting can be possible. The friction what is occurred in the sorting system is very important parameter. So it is simulated that model what has relation the friction static friction force and Coulomb friction model.

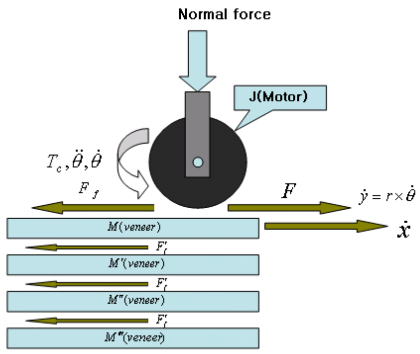

Fig. 5 FBD of Sorting System

We must make sorting system simple to analyze because it's friction is complicated.

3.2 Conditions for Sorting

Fig. 6.shows a simple model for a single veneer sorting and it is described free body diagram of single veneer. This is the mathematical model about the sorting system.

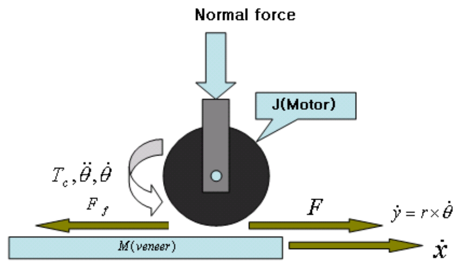

Fig. 6 FBD of single veneer

Each equation of motion are related to veneer and motor. And they are expressed in stated in state variables.

Veneer

$$m\dot{x} = F_f, (x = \dot{x}_a) \qquad (2)$$

Motor (considering viscos friction in a motor)

$$J\ddot{\theta} + b\dot{\theta} = T_m - rF_f, r \text{ (Radius): constant, } (y = \dot{\theta}) \qquad (3)$$

$$J\dot{y} + by = T_m - rF_f$$

Generally Friction is nonlinear and has various model equations according to specified case.

4. EXPERIMENTAL VALIDATION

In this research, we used the PC-based DAQ System for a performance evaluation and friction phenomenon as following Fig.7.

4.1 Measurement description

In this research, we used three motors and MMC(Multi-Axis Motion Control) board to system control. First motor used to contact of tangential direction between veneer and roller. Second motor used to control the position of rollers. Third motor sued to compensate of roller position.

Also, it uses to get of normal friction force of veneer. And, it moves vertical direction of positive.

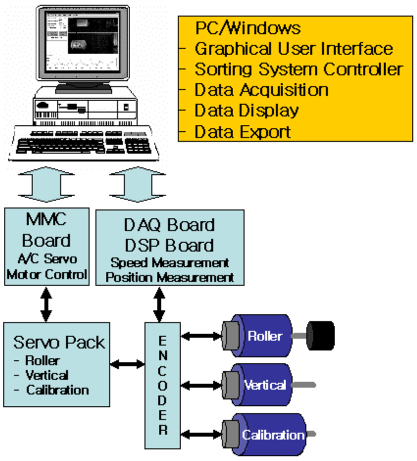

Fig. 7 PC-based Validation

MMC board is designed by the Open-Architecture structure of PC-Base slot.

Table. 1 is a specification of MMC board. These values are important to measure the system.

Table 1 Specification of MMC board

Item	Specification
CPU	TMS320C3X
MOTION	PTP, CIRCULAR INT., STRAGHR INT., SPLINE INT.
INTRERFACE	PC/AT/INDUSTRIAL
SAMPLING RATE	1msec
ANALOG OUTPUT	±10V, @12-BIT RESOLUTION
PULSE OUTPUT	Max. 3.75MHZ, 50% Duty Cycle
MOTION RANGE	32-bit, ±2147483647
SOURCES	+5V@2A, +12V@0.5A, -12V@0.5A, -5V@0.3A

MMC board is consist of MMC-BDPV41, S/W, 40pin flat cable for input and output, 40 pin flat cable for AMP connecting, 24V 4pin cable. Accessories are axis cable, limit sensor modulation, I/O modulation etc.

It is used by measurement tools such as measurement PC, Transducer, DAQ H/W and S/W, sensors for sensing sorting veneer's velocity, encoder for sensing motor velocity, linear displacement transducer for sensing normal friction force between sorting veneer and sorting roller.

Measurement sources are divided into two analog input measurement and pulse count of encoder. Unfortunately, measuring analog signals with a data acquisition board is not always as simple as wiring the signal source leads to the data acquisition board. Knowledge of the nature of the signal source, a suitable configuration of the data acquisition board, and an appropriate cabling scheme may be required to produce accurate and noise-free measurement. By far the most common electrical equivalent produced by signal conditioning circuitry associated with transducers is in the form of voltage.

In this paper, used DAQ board with specification below and Fig. 8. shows a block diagram for the PCI-MIO-16E-1.

Input Range of ADC : Unipolar…………………..0V~+10V
Bipolar………………………..± 5V
Bipolar………………………..± 10V
Input Mode of ADC: Ground-referenced single-ended
Non-Referenced Single-Ended
Differential
Analog Input: Number of channels………..16 Single-Ended
8 Differentials
Type of ADC……Successive Approximation
Resolution……………..………………12 bit
Max Sampling Rate………...……1.25 MS/s
Timing I/O: Number of Channels…...…2Counter/Timers
Resolution Counter/Timer…………....24bit
Base Clocks Available
Counter/Timers……20MHz,100MHz
Base Clock Accuracy…………….. ±0.01%
Min Source Pulse Duration…………..10ns

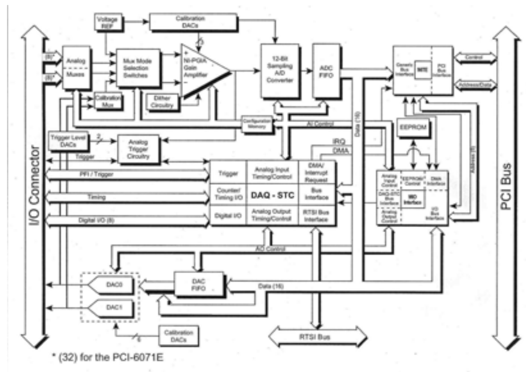

Fig. 8 PCI-MIO-16E1 of Block Diagram

4.2 Experimental validation

Fig.9 shows the loaded veneer's sorted amount and roller position of vertical direction at fixed rolling velocity. Between roller and contacted veneer must originate suitable normal friction force then sorting system can sort one by one.

The more loaded veneer can be sorted easily though contacted low normal friction force. And, it can compensate the roller position vertical direction 3~9mm to sort veneer from 10 pieces through 100 pieces.

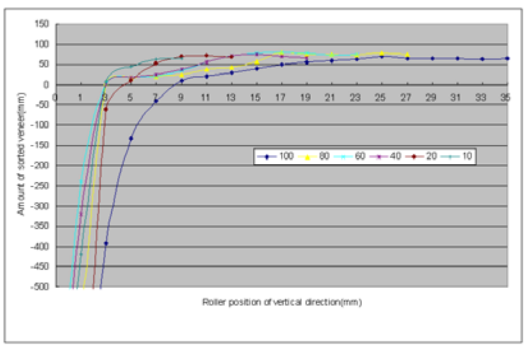

Fig. 9. The sorting amount as number of veneer at 360rpm

Through Fig. 10~13 show relationship between roller position of vertical direction and amount of sorted veneer at changed veneer velocity from 50rpm to 2000rpm with occurring normal friction force between roller and veneer. And Fig.14 show of theirs at average velocity of low (50~200rpm), middle (300~700rpm) and high (800~2000rpm).

Zero value of Y-axis means that one veneer is sorted perfectly without disturbing under veneer.

In the Fig. 14, the normal friction force increase when veneer is sorted by high-velocity zone of roller.

The positive value means that there are Rolling-phenomenon between roller and veneer. The other way, negative value means Slip.

As a result of this, it is easy to occur Slip-phenomenon and become smaller normal friction force.

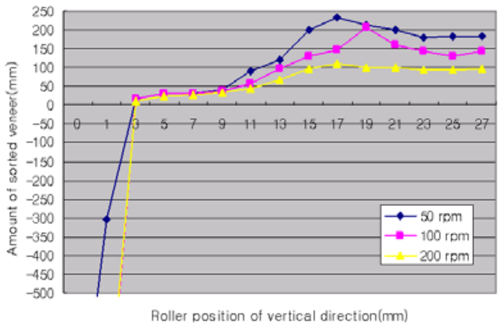

Fig. 10. The sorting amount of veneer as roller velocity

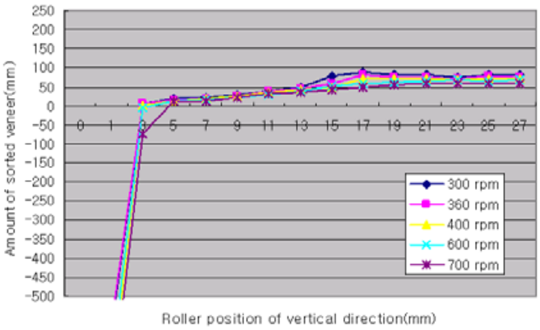

Fig. 11. The sorting amount of veneer as roller velocity

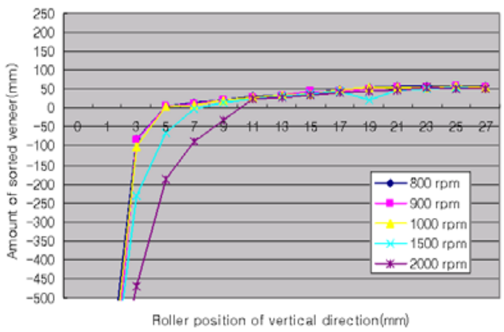

Fig. 12. The sorting amount of veneer as roller velocity

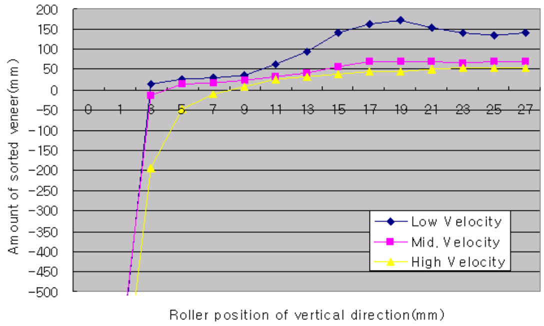

Fig. 14. The sorting amount of veneer as roller velocity

By this token, normal force has some connection with friction force. And, it is important factors rolling velocity and normal friction force with friction control.

5. CONCLUSION

Friction is important in all motion control systems. There is currently much research on friction in many different fields, which is generating much knowledge and insight. This can be used to increase our understanding of friction phenomena and design better friction compensators. This paper has performance evaluation of nonlinear characteristics friction sorting models for friction and techniques for friction compensation. There are two promising methods for friction compensation, normal force and sorting roller's velocity. Development of dynamic models for friction and adaptive friction compensation schemes are interesting research areas which have good application potential for motion control.

REFERENCES

[1] National Instrument, *Measurement Studio Component Works Manual*, 1996.

[2] SAMSUNG Electronics, *Multi-Motion Controller User Manual*, 2000.

[3] M. S. Ko, "Research about Development of an Automatic Sorting System Driven By Control Friction," *Graduate School of Automotive Engineering Kookmin University, Master's thesis*, 2003.

[4] Julian Andrew de Marchi, "Modeling of Dynamic Friction, Impact Backlash and Elastic Compliance Nonlinearities in Machine Tools, with Application to Asymmetric Viscous and Kinetic Friction Identification," *A Thesis Submitted to the Graduate Faculty of Rensseler Polytechnic Institute in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy*, 1998.

[5] C. B. Baril. "Control of mechanical Systems Affected by Friction and Other Nondifferentiable Nonlinearities,". *PhD thesis, Technion, Israel Institute of Technology, Haifa, Israel*, 1993

[6] P.-A. Bliman. "Mathematical Study of the Dahl's Friction Model ," *European Journal of Mechanics. A/Solids, 11:6*, pp. 835-848, 1992.

[7] K. J. Åström. "Control of Systems with Friction," *In The Fourth International Conference on Motion and Vibration Control, MoViC,* pp. 25--32, Zurich, Switzerland, 1998