Numerical and Experimental Approach for Roll Grinding Process

Lihong Yuan, Veli-Matti Järvenpää, Seppo Virtanen and Hessam K. Shiravani

Department of Engineering Design
Tampere University of Technology
P.O.BOX 589, 33101 Tampere, Finland
{lihong.yuan, veli-matti.jarvenpaa, seppo.virtanen, hessam.kalbasishirani}@tut.fi

Abstract

This paper presents a study of a vibration problem in a roll grinding machine. The rolling contact between a metal roll and the grindstone may cause the pattern formation on the roll surface during the grinding operation. A self-excited vibration excitation or so-called regenerative chatter excitation is present in the process. The chatter vibrations are described by a mathematic model including time delay effects. The numerical results of frequency responses are illustrated and they are consistent with the on-site measurements in a workshop of a roll factory.

1 Introduction

In paper machine industry, a roll grinding machine is used to finish or maintain roll surface. Excellent surface finish should be homogenous one with silky sheen, free of scratches and any other blemishes. Precision roll provides more efficient roll operation and better paper quality. To understand the dynamic behaviour of grinding machine towards these aspects is very important. A typical grinding machine consists of work piece-roll (metal) and grinding wheel (stone) which keep contact interaction during the process. The contact vibration problem of such kind of system is studied in this work. In order to ensure the finishing the entire surface of on roll, technically there are always overlaps between the revolution paths related the width of the grinding wheel. Therefore the retard effect may cause vibration and the consequence is the generation of pattern formation occurred on the surface of the roll (Figure 1).

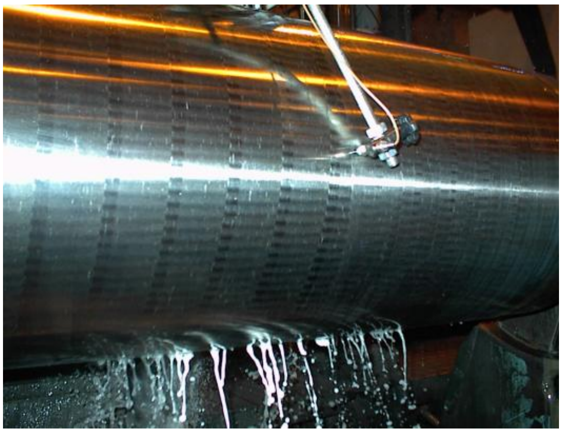


Figure 1: Pattern deformation generated on the roll surface with overlap.

In this roll grinding process, there are additional time delay effects, which are originated from the overlap of the grinding path on the surface of the roll (the work piece) ground by a cylindrical grindstone. Generally, the grinding system may be unstable due to the delay effect and this chatter growth rate problem has been analyses widely in literature [1-9]. The grindstone's rotational speed is high and the roll is rotating very slowly due to the requirements of the finishing process. The contact zone between the roll and the grindstone is assumed as an insignificantly small area. In the mathematic model, the roll is described as a simply supported continuous beam element expressed in an eigenvector basis and in a rotating coordinate frame. The contact between the roll and the grindstone is described by contact dynamics formulation and the normal and tangential forces of the contact are based on the wear theory. In this work, the double delays will be involved in the model. Based on the above considerations an experiment is set up on a grinding machine of a real factory. The responses of an industrial roll grinding machine are measured by using Pietzo-electric displacement sensors, rotation speed laser and accelerometers. The corresponding results should verify the simulation ones in tolerance ranges. This provides a more precise view to observe the dynamic behavior of the system and suggest ways to control the whole process in order to minimize chatter's detrimental effects. The main objectives of this work are to detect uncontrollable situations, identify causes, determine process limits and suggest reasonable actions in order to control and optimize the system.

In this work, measurements and dynamical analysis of the grinding process of paper machine rolls are studied. The measurements have been carried out in real factory workshop with various rotating speed. A mathematic model describing this system is illustrated. Numerical and experimental results will be given. The effects from the parameters of interest in rolling contact will be discussed.

2 Formulation of Problem

The vibration problem in the grinding machine can be modeled as a lumped spring-mass system as in Figure 2. The double time delays from both roll and grinder are also considered [10-12].The equations of motion of the dynamic system are given by,

$$m_1\ddot{x}_1 + c_1\dot{x}_1 + k_1x_1 = -k_n\gamma\{(1-\alpha)\varepsilon_{nom} + x_1 - x_2 - \alpha\gamma[x_1(t-\tau_1) - x_2(t-\tau_2)] - (1-\gamma)[x_1(t-\tau_1) - x_2(t-\tau_2)]\} \tag{1}$$

$$m_2\ddot{x}_2 + c_2\dot{x}_2 + k_2x_2 = k_n\gamma\{(1-\alpha)\varepsilon_{nom} + x_1 - x_2 - \alpha\gamma[x_1(t-\tau_1) - x_2(t-\tau_2)] - (1-\gamma)[x_1(t-\tau_1) - x_2(t-\tau_2)]\} \tag{2}$$

The coefficient k_n is contact stiffness. The time delay τ_1, τ_2 are related to the rotation speed of the roll and grinding stone. The overlap rate α of grinding path is in percentage. The coefficient γ indicates the elasticity of materials between the contact surfaces. The coefficient ε_{nom} is nominal cutting depth.

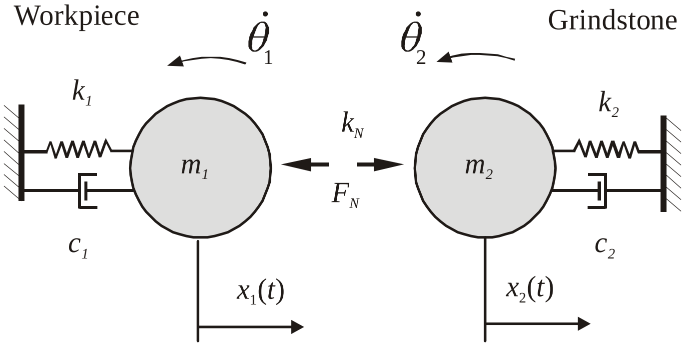


Figure 2: Equivalent spring-mass system.

3 Methods and analysis

Firstly, the response in frequency domain can be obtained; secondly the clasical stability theory can be carried out in a simplified model.

3.1 Frequency response

The frequency response of the system can be obtained by adding excitation force. The steady state solutions in matrix take the form

$$\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = \left(-\omega^2 \mathrm{M} + i\omega C + \mathrm{K}\right)^{-1} \begin{bmatrix} -1 \\ 1 \end{bmatrix} k_n \gamma (1-\gamma) \varepsilon_{nom} \tag{3}$$

where $\mathrm{M} = \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}$, $C = \begin{bmatrix} c_1 & 0 \\ 0 & c_2 \end{bmatrix}$, $\mathrm{K} = \begin{bmatrix} k_1 + B & A \\ A & k_2 + B \end{bmatrix}$

and where

$$A = -k_n\gamma - k_n\gamma^2 \alpha e^{i\omega\tau_1} - k_n\gamma(1-\gamma)e^{i\omega\tau_2}$$
$$B = k_n\gamma - k_n\gamma^2 \alpha e^{i\omega\tau_1} - k_n\gamma(1-\gamma)e^{i\omega\tau_2}$$

3.2 Classical stability analysis

For simplicity, the motion of the roll is only considered. The model with one-degree freedom can be written as

$$m_1\ddot{x}_1 + c_1\dot{x}_1 + (k_1 + k_n\gamma)x_1 - k_n\alpha\gamma^2 x_1(t-\tau_1) = 0 \tag{4}$$

Performing variable transformation $\tau_1 = \omega t$ and Laplace transform, the corresponding characteristic equation is obtained

$$\omega^2 s^2 m_1 + \omega s c_1 + (k_1 + k_n\gamma) - k_n\alpha\gamma^2 e^{2\pi s} = 0 \tag{5}$$

Substituting the characteristic complex roots $s = \sigma + jn$ into above (5), and let both real and imaginary parts of the equation be zero. Based on control theory, we know that when the real part is positive $\sigma > 0$, the system is unstable; it is negative, the system is stable. Moreover, the imaginary part *n* is related with the wave number of the pattern deformation generated on the surface of the work piece [13].

4 Measurement set up

The physical model of the roll grinding system measurements[14] is illustrated in Figure 2. For the roll there are two types of sensors: two laser sensors and two inductive displacement sensors; all of these are on the sledge of the grindstone, moving horizontally along the roll during grinding. The first laser sensor is a so-called Doppler velocity laser (LDV) and it measures the horizontal velocity of the cross-section of the roll. The second laser measures the vertical displacement of the cross-section (V-direction). The inductive sensors measure the displacements in the same directions as the lasers. At the end of the roll there are two types of sensors for measuring the rotational speed of the roll: one is a pulse sensor and the other one is a wheel sensor. For the grindstone, one pulse rotational speed sensor is located at end of the drive. One accelerometer is on the sledge of the grindstone the in U-direction. All the electrical signals from the sensors go into corresponding amplifiers and oscilloscopes and finally are input into a computer. The computer displays the measurement data and additional analysis and data processing can be carried out after the measurements are finished.

The whole machining process was performed as normal cutting. The operator is able to adjust the speed of the grindstone, workpiece roll , and cutting feed of the stone in order to excite the roll during measurements. Figure 4 illustrates one 3-D plot with the response in time and frequency domains. There are two resonance frequencies about 13Hz and 22.5 Hz.

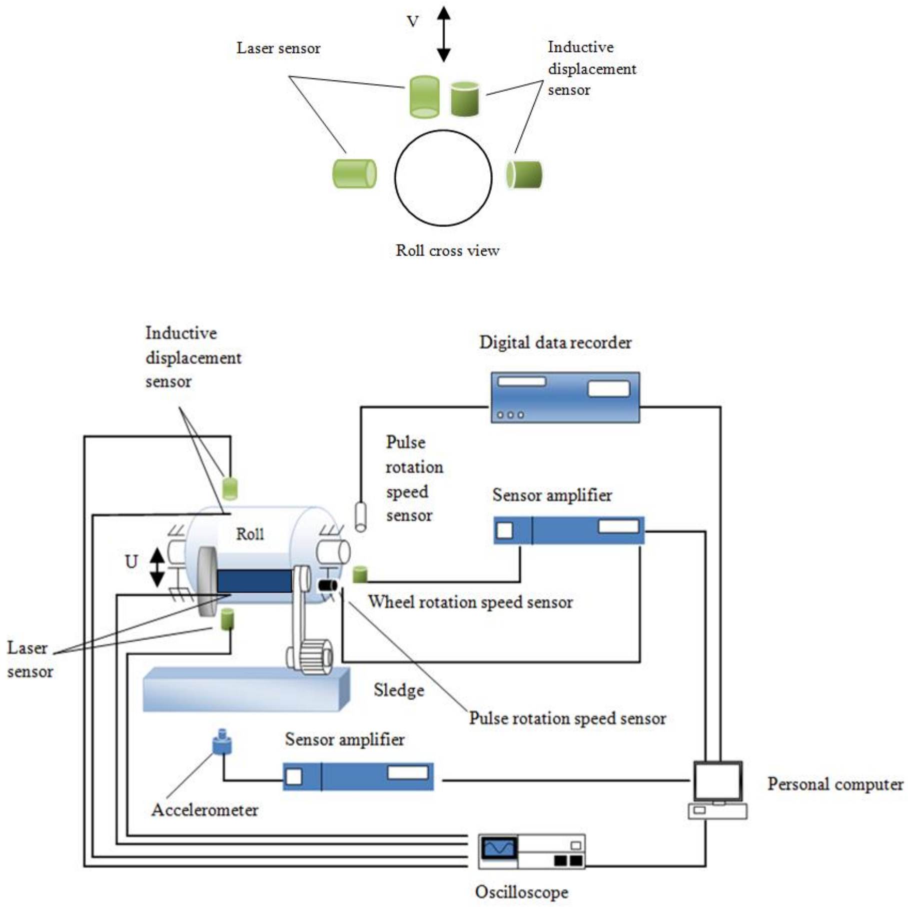


Figure 3: Measurement illustration of grinding machine

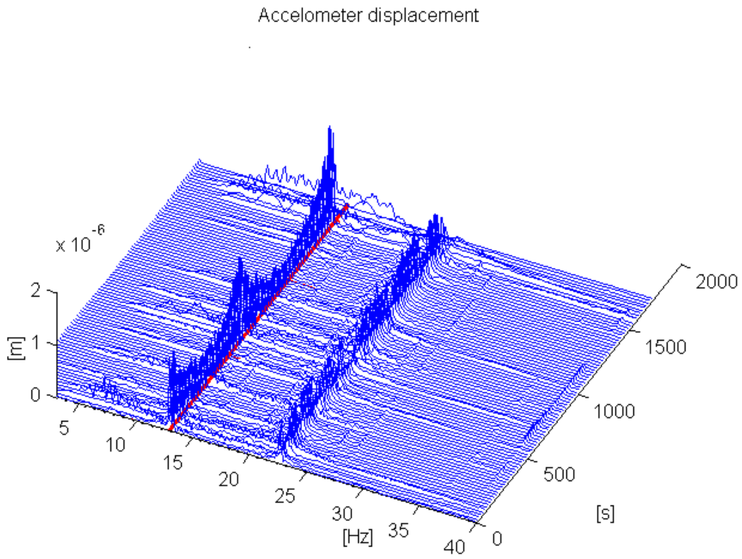


Figure 4: Response in time- and frequency- domain

5 Numerical results

The simulations have been carried out by Mathcad programming. The numerical results based on parameter values in Table 1 are illustrated in following text. The relevant observations have been discovered.

Parameter	m_1	c_1	k_1	m_2	c_2	k_2	k_r	α	γ
Value	3983.3	4268	3.6557x10^7	329	344.2	36x10^6	4.26x10^6	0.2	0.9
Unit	kg	Ns/m	N/m	kg	Ns/m	N/m	N/m		

Table 1: Parameter values of grinding system for the computations

The frequency responses are computed according to the equations (3). The numerical results are in figure5. The amplitude of the stone with much less mass is much bigger than the one of the roll. Both cases (up and down) have two renounces at about 13.2 Hz and 22.39 Hz, which is consistent with the measurement in figure 4. The case (down) has satellite beak due to the time delays. The time delay from roll is 2s; the other one from grinder is 0.1s.

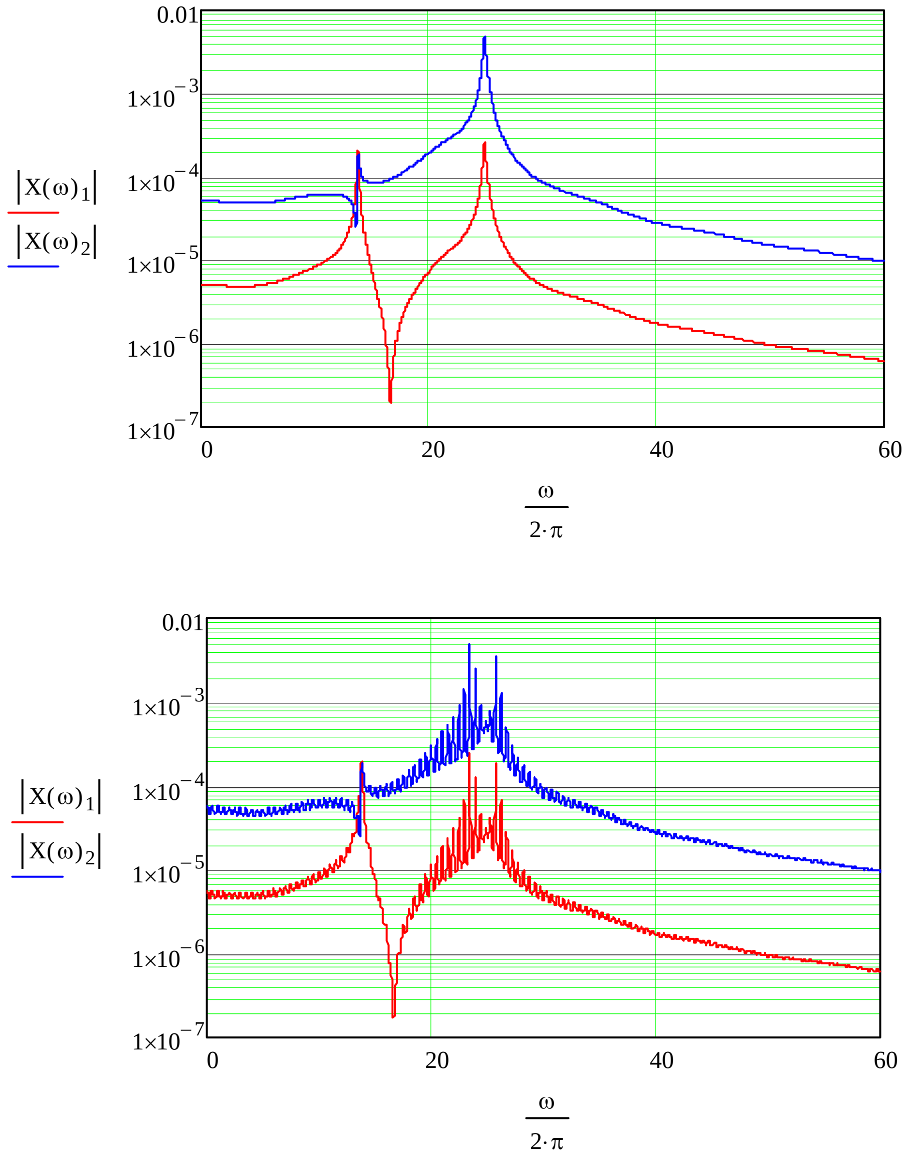
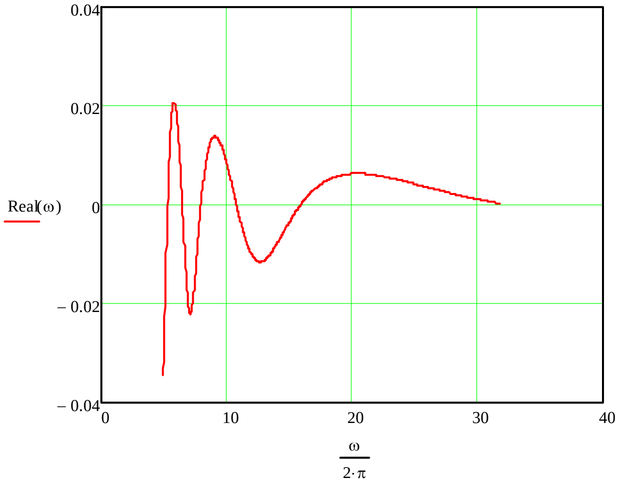


Figure 5: Frequency response without time delays (up); frequency response with time delays (down).

The stability analysis is calculated from equation (5). In Figure 6 when real part σ is positive then the system should be stable; when real part is negative it becomes unstable. Then the stability regions are alternatively changing stable and unstable with excitation frequency. Furthermore because the imaginary part *n* is related with the number of the pattern deformation of the roll surface, we can judge how the wave number is moving with the excitation frequency.



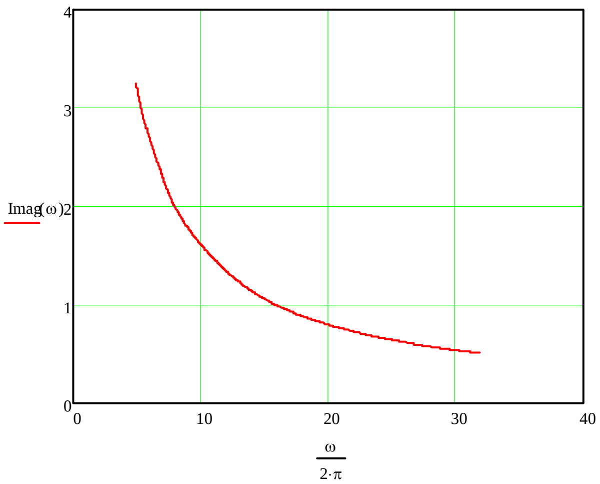


Figure 6: Real part of characteristic root versus rotating angular velocity of stone (up); Imagine part of characteristic root versus rotating angular velocity of stone (down).

6 Conclusions

The measurement in the workshop has been successfully carried out and the results are illustrated with renounce frequencies. The frequency responses of numerical analyses are obtained and consistent with the measurement results. Moreover the stability analysis has been given in a one-degree case. The pattern deformation on the roll surface can be more deeply investigated in the future work. Subsequently this study provides the guidance for further design of suppression and control the vibration for grinding machine.

Acknowledgments

This work is financially supported by Academy of Finland.

References

[1] I. Inasaki, B. Karpuschewski, H.S. Lee, Grinding Chatter-Origin and Suppression, CIRP Annals-Manufacturing Technology, ScienceDirect, Vol. 50, Issue 2, 2001.

[2] J.F.G. Oliverira, E.J. Silva, C. Guo, F. Hashimoto, Industrial Challenges in Grinding, CIRPAnnals-Manufacturing Technology, 58(2009)663-680, Elsevier.

[3] G. Stepan, *Modelling Nonliear Regenerative Effects in Metal Cutting*, Philos. Trans. Royal Soc. London A, Vol.8 No.4., 2001.

[4] Y. Altintas, M. Wech, Chatter Stability of Metal Cutting and Grinding, CIRP Annals-Manufacturing Technology, Vol. 53,Issue 2, 2004, Elsevier.

[5] Y.Altintas, M. Eynian, H. Onozuka, Identification of Dynamic Cutting Force Coefficients and Chatter Stability with Process Damping, CIRP Annals-Manufacturing Technology, 57(2008)371-374, Elsevier.

[6] J. Gradisek, A. Baus, E. Govekar, F. Klocke,I. Grabec, Automatic chatter detection in Grinding, International Jounal of Machine Tools and Manufacture, Vol. 43,Issue 14, 2003.

[7] E. Govekar, A. Baus, J. Gradisek, F.Klocke, I. Grabec, A New Method for Chatter Detection in Grinding, International Journal of Machine Tools and Manufacture, Vol. 42, Issue 15, 2002.

[8] B.I. Epruenau, E.H. Dowell and F. M. Montoya, *Pattern formation and linear stability analysis in centreless grinding*, Proceesind of institution of Mechanical Engineers,PartB: jounal of Engineering Manufacture, Sage, Vol211, 1997,.

[9] A. Sueoka, T. Ryu, M. Yoshikawa, M. Kondou, T. Tsuda, *Pattern Formation Generated in a Winder System of Tactile Machine, J*SME international journal, Series C, Vol.41, No.3, 1998.

[10] R.A. Thompson, *On the Double Regenerative Stability of Grinder: the theory of Chatter Growth*, Jounal of Engineering for Industry, Vol.108/75, 1986.

[11]L. Yuan, *Analysis of Delay Phenomena in Roll Dynamics*, doctor thesis, TUT, 2002.

[12]L.Yuan, E.Keskinen and V.M. Järvenpää, *Stability Analysis of Roll Grinding System with Double Time Delay Effects*, IUTAM Symposium on Vibration Control of Nonlinear Mechanisms and Structures, edited by H. Ulbrich, Springer, 2005.

[13] A. Karttunen, V.H. Raimo, *Stability Analysis of Rotating Nipped Rolls with Memory*, proceeding of the 10th Finnish Mechanics DAYS, 2009.

[14] A. S. Kobayashi, Handbook on Experimetnal mechanics, VCH publishers, Inc., 1993.