# ANALYSIS TO KNOW CONTRIBUTING FACTORS FOR MILL CHATTERING PHENOMENON AND POSITION FOR DETECTING SENSOR IN 4-HI TANDEM ROLLING MILLS

**Dr.B.D.Patil** Department of Mechanical Engineering, Marathwada Mitra Mandal's Institute of Technology, (Affilated to Savitribai Phule University,Pune),Pune,Maharashtra, Email : bhuvan98222@gmail.com,
**Dr.Amit.S.Chaudhary,** Department of Mechanical Engineering, DIT (Affiliated to Savitribai Phule University,Pune), Pune, Maharashtra, Email: amit.bsl@gmail.com,
**Dr.Kishor.B.Waghulde**, Department of Mechanical Engineering, DIT (Affiliated to Savitribai Phule University,Pune), Pune, Maharashtra, Email: kishorwaghulde@gmail.com
**Dr.R.V.Bhortake**, Principal, Marathwada Mitra Mandal's Institute of Technology, (Affilated to Savitribai Phule University,Pune),Pune,Maharashtra, Email : principal@mmit.edu.in

## Abstract:

After performing intensive grade rolling or micro-alloy critical grade rolling in a finishing tandem-type mill, it was observed that vibrations are a common occurrence in the F2 and F3 stands. This occurrence is undesirable as it negatively impacts product quality and production efficiency. To address this issue, it is strongly advised to implement a sensor-based online monitoring system to detect chatter and make necessary adjustments before it reaches resonance frequency. Additional corrective measures include using hydraulic mechanisms like back-up balance, hydraulic liners, or work-roll bending. The findings from Finite Element Analysis (FEA), Fast Fourier Transform (FFT), and mathematical models have been validated to support these solutions.

**Keywords** : Vibration, Chattering, Resonance frequency, FEA, FFT

## Introduction :

In manufacturing of flat sheet product Cold rolling is the finishing and vital process. During the cold rolling of thin metal sheets, undesired mechanical vibrations, generally referred to as chatter, are often generated. It usually lowers the surface finish of the sheet and in some cases causes gauge variation. It may also cause severe damage to the rolling mill and strip rupture under extreme conditions. It has also been found that as mill speeds are increased the system goes to instability As the need for low-cost and high-quality products increases, prevention of chatter phenomenon becomes an important task in the rolling industry.

It has been frequently observed that chattering occurs in the F2 and F3 stands of the finishing tandem-type mill due to the high draft reduction in the early mills. To address this, a rolling load screw-down mechanism is used. However, the mill has limited hydraulic damping, leading to the frequent occurrence of chattering during hard grade rolling. There are three main types of chattering in various stands: torsional factor along the axis of the work roll driver shaft train, with a range of 5 to 25 Hz; vertical chatter with a third octave in the range of 128 to 250 Hz; and fifth octave chattering in the range of 500 to 700 Hz. Torsional chatter is observed in all stands, with the third octave seen in early stands and the fifth octave in late stands. Thinner critical grade rolling with a thickness of 2mm and below often exhibits this phenomenon. In the early stands, chattering leads to high thickness gauge variation and strip waviness, while in the later stands, center buckle and light dark horizontal lines can be seen on the strip surface.

Attempts to reduce the transfer bar thickness from the reversing rougher mill may cause an increase in the length of the transfer bar, resulting in higher temperature drop and mill speed. Since micro alloy materials are rolled at high temperatures (controlled by x-ray and temperature gauge at the mill exit), the mill model compensates the draft accordingly with the mill speed, leading to an increase in chattering, especially when the bite angle is high and the work-roll diameter is small. To maintain proper friction during rolling, it is essential to have properly ground rolls with exact surface smoothness. The ideal coefficient of friction is attained by implementing roll lubrication and anti-peeling measures on the work roll. Excessive or insufficient friction can render the system unstable. Therefore, frequency analysis of the chattering phenomenon allows for detection and suppression before it reaches a critical frequency.

Heidari and Forouzan (1) studied the relationship between the rolling parameters and the rolling mill vibration. The rolling parameters are optimized to achieve the maximum rolling velocity to satisfy surface quality requirement of the strip steel. V.Panjkovic and Gloss Gerald (2) studied that chatter in this mill is primarily caused by frictional conditions in the roll gap, with occasional contributions from residual chatter marks on work rolls. These frictional conditions seem to be linked to the thickness and properties of the oxide formed on the rolls. Yan Xiaoqiang, ZhangYan (3) determined the abnormal vibration source based on the tested signals and simulation study from the chatter marks observed on the surfaces of the steel strip and the backup rolls. X.Yang et al.(4) developed a dynamic model of the cold rolling mill to study and to predict the dynamic behavior of the mill in the rolling process. Paton and Critchley (7) found that the fluctuation of the tension force in the rolling process would lead to the self-excited vibration of the mill. The results were obtained through the experimental measurement and theoretical analysis on the vertical vibration of two tandem cold rolling mills. J. Gasparic (8) noted that the presence of chatter marks on the surface of work rolls could lead to vibrations in a rolling mill. The mill vibration could be easily excited whenever the ratio of the operating speed to the wavelength of roll marks were close to that of mill natural frequencies. G.L.Nessler and J.F.Cory (9) believed that the diameter difference between the upper support roll and lower support roll was related to chatter mark generation, and avoiding the ‘induced speed’ could effectively reduce the vibration. Yarita et al. (10) suggested that the poor lubrication between the working rolls and the steel strip were also responsible for the serious vibration of the rolling mill.In W.L. Roberts' research (11), it was revealed that the occurrence of chatter marks on the steel strip surface increased when the number of marks on the work rolls and support rolls were both integral. This phenomenon was particularly evident at specific rolling speeds known as the 'induced speed.' By using the FEM to analyze the characteristic of roll bend vibration.

Researchers have extensively investigated methods for detecting, identifying, avoiding, preventing, reducing, controlling, or suppressing chatter. This paper provides a comprehensive review of the current state of research on the chatter problem and categorizes the existing approaches developed to predict chatter. The primary goal is to prevent chatter during the rolling process, leading to improved surface finish of the product, increased productivity, and prolonged machine life, through passive or active modification of the system behavior.

## Problem identification and Objective

An undesirable mechanical vibrations defect occurs during common process of cold rolling operation known as mill chatter. This happened due to numerous discrepancies occurring during manufacturing process, such as roll vibration, variation in strip tension and negative damping Chatter early diagnostics and mill speed automatic control vibration monitoring system development.

[1] Chatter in the rolling process results in thickness variation across the width, surface damage, and undesirable noise in the workplace. The presence of chatter marks on the rolled strip's surface significantly impacts the final product quality, and until now, the generation mechanism and effective identification methods for chatter marks have remained elusive.

[2] The emergence of chatter marks represents a significant limitation on productivity and economic gains. These marks tend to develop during both the initial and final stages of the rolling process, causing harm to the surface quality of the product.

[3] And appear on rolled strip as periodic pattern of light-dark band.

Physical appearance of chatter mark on rolled sheet has been showed in **Fig**.1 and Fig.2

**Figure 1** Chatter marks on Work roll

**Figure 2** Chatter marks on strip

According to the frequency of vibrations, generally there are three kind of vibration consider during cold roll forming which may influences chatter marks such as:

1. The occurrence of low-frequency torsional vibration (5-20Hz) is typically related to the drive train and leads to minor thickness variations.
2. Third-octave mode vibration (100-200Hz) induces significant thickness variations, potentially causing strip rupture.
3. Fifth-octave mode vibration (500-700Hz) results in the transverse bending of the backup and work rolls.

Additionally, third-octave chatter corresponds to the resonance vibration of the top backup roll within the roll stack.3rd octave frequency resembles musical notes of 128-250 Hz hence its name. Just before chattering scratches of roll appears on the strip surface. This is due to roll lubrication between the strip and rolls are not sufficient. Metal to metal contact takes place due to lube oil thickness gets lowered than surface roughness of work roll and strip.

Non-synchronized motion of any two rolls leads to an increased load distribution between them, resulting in gauge variation. If the two work rolls collide, strip pinching occurs, causing tearing across the width of the strip. Chatter-induced strip gauge variation typically ranges from 0.21mm to 0.12mm. The coefficient of friction varies between 0.02 and 0.03. However, by increasing the roll lube and employing an anti-roll peeling mechanism, the coefficient of friction can be reduced to 0.01-0.02. Therefore, in practical applications, improving roll bite lubrication is crucial to prevent chattering.

When the mill operates at high speeds in the later stands, typically above 600rpm, resonance vibrations can occur between the work roll and the back-up roll, leading to the phenomenon known as 5th octave chatter. The frequency of this vibration falls within the range of 500-700Hz, corresponding to the 5th musical octave. The back-up roll is fixed, and the contact with the work roll acts like a spring, contributing to the occurrence of chatter marks. These marks often get imprinted on the back-up roll's surface, appearing as dark black and white regions, aligned with the rolling direction.

In contrast, the work roll surface is less susceptible to marks, but the back-up roll can experience flattened regions known as "fluting marks." The main cause of such marks is typically attributed to backlashes in drive motors, pinion gear, spindle couplings, and intermediate couplings. Consequently, it is essential to avoid prolonged rolling at very high speeds.

The detection of 5th octave frequency can be challenging because it falls beyond the audible range of operators in the cabin. Therefore, it is recommended to employ a vibration monitoring system to detect and alert operators, allowing them to reduce the operating speed and prevent the detrimental effects of 5th octave chatter.

**Experimental analysis of mill chattering**:

In this research, two distinct experiments were carried out to identify the primary component contributing to the resonance occurrence of 3rd octave chattering. Four piezoelectric accelerometers were affixed to the chocks of the work roll, back-up roll (B/u), and mill housing. These cylindrical accelerometers measured acceleration parallel to their axes. Placed vertically over the flange of the chocks on the operator side of the mill, one accelerometer was also positioned on the top of the mill housing.

In the first experiment, vertical acceleration of the top work roll, top B/u roll, and mill housing was observed while inducing horizontal vibration in the B/u roll. The second experiment involved monitoring vertical vibration of the top/bottom work roll and mill housing while measuring horizontal vibration in the top work roll. Figures 3 and 4 illustrate these experimental setups.

**Figur**e.3

**Figur**e.4

To identify the most suitable location for installing the acceleration sensor to detect chatter, a thorough study of vibrations at different positions in the mill was conducted. The observations from the two experiment combinations are summarized below:

In the first experiment, the 3rd octave chatter frequency closely matched the vibration frequency of the B/u roll and mill housing. The Acceleration Peak Time (APT) was at the 26th second. Horizontal vibration of the upper B/u roll was detected 5 seconds before APT, and the top work roll detected it 3 seconds before APT.

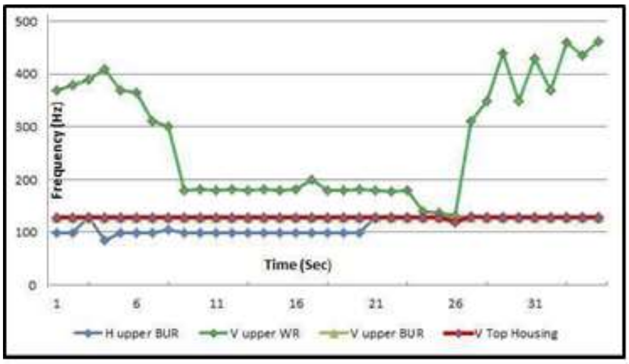

**Figure** 5: Variation of prominent frequency of the acceleration signals over time

When chatter occurred (at the second 26 in Fig. 5), the mill operator promptly reduced the rolling speed to prevent strip rupture. However, this led to a temporary instability in the system due to the sudden decrease in rolling speed. Immediately after the speed reduction, a slight decrease in the chatter frequency from 141 Hz to 137 Hz was observed in Fig. 5 due to the changing rolling conditions. The frequency of the 3rd octave chatter detected in this experiment was approximately equal to the vibration frequency of the backup roll.

Figure 6 demonstrates the ratio of the amplitude of the chatter frequency to the RMS value of the amplitude in the frequency spectrum over time for each signal. Prior to analyzing the acceleration signal, a low-pass filter with a cutoff frequency of 500 Hz was applied to the recorded data.

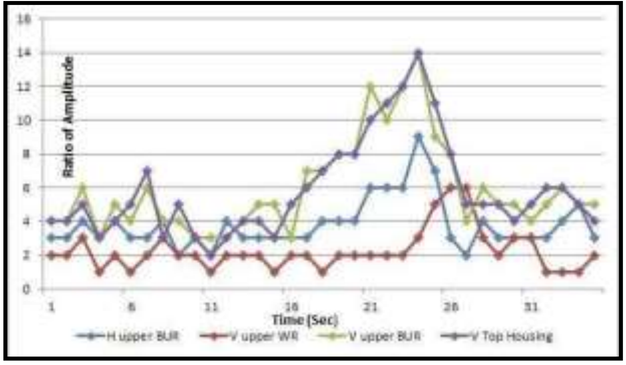

**Figure** 6 Ratio of amplitude of chatter frequency to RMS value of amplitude in frequency spectrum

The figure demonstrates that the amplitude ratio increases significantly when chatter occurs, varying between different signals. The signals for the vertical vibration of the upper backup roll and the vertical vibration of the top housing exhibit larger ratios. Another crucial observation from the figure is the time when the ratio starts to increase. The signals for the vertical vibration of the upper backup roll and the vertical vibration of the top housing show a shorter time before the Acceleration Peak Time (APT) when the ratio starts to rise. Hence, it can be concluded that these signals are more sensitive to rolling chatter.

Fig. 21 illustrates the variation of the Root Mean Square (RMS) value of acceleration over time for each signal, with a low-pass filter applied at a cutoff frequency of 500 Hz to the recorded data. It shows the acceleration values during system stability and instability. At stability (before and after chatter occurrence), the upper work roll exhibits high amplitude vibration, with a small increase during chatter. The upper backup roll vibrates less than the upper work roll when the system is stable but experiences severe vibration during chatter, particularly in the vertical direction. The top housing exhibits slow vibration at the time of stability but significant vibration during chatter.

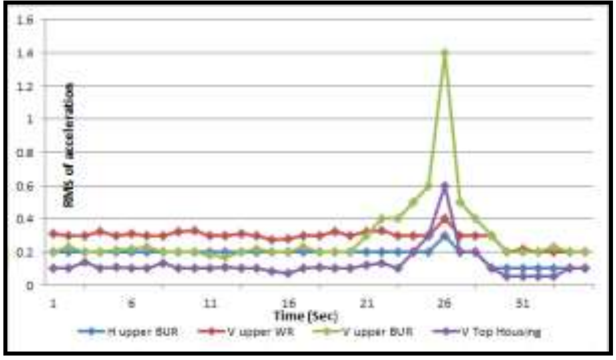

**Figure** 7 RMS value of acceleration signals

From Figures 5 to 7, it can be concluded that the upper backup roll is highly sensitive to rolling chatter, and the top housing is relatively sensitive to chatter as well. Therefore, the upper backup roll and top housing are suitable positions for installing acceleration sensors to detect chatter.

In the second experiment, both the top and bottom work rolls are detected 2 seconds before APT and their vibration frequencies match the 3rd octave chatter frequency of the mill housing. The significant frequencies are roughly 163 Hz for the vertical oscillation of the upper work roll, about 87 Hz for the horizontal oscillation of the upper work roll, approximately 400 Hz for the vertical vibration of the lower work roll, and around 139 Hz for the vertical vibration of the top housing. It's important to highlight that in the second experiment, the chatter frequency is observed at 139 Hz.

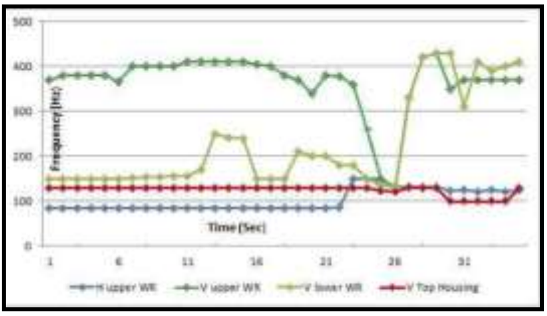

**Figure** 10: Variation of prominent frequency of the acceleration signals over time

Fig. 11 presents the amplitude ratio of the chatter frequency to the RMS value of the amplitude in the frequency spectrum over time for each signal, following a low-pass filter application with a cutoff frequency of 500 Hz. The 26th second corresponds to the APT. The signal for the vertical vibration of the top housing shows the largest ratio at APT, indicating that the top housing is highly sensitive to rolling chatter.

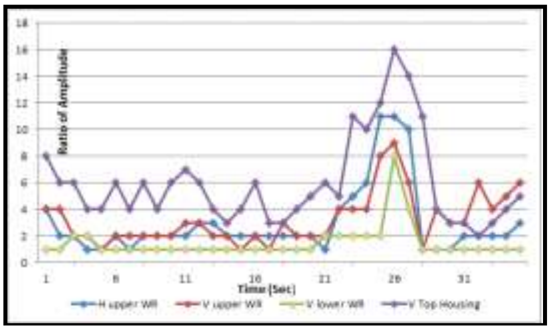

**Figure** 11 Ratio of amplitude of chatter frequency to RMS value of amplitude in frequency spectrum

Figure 12 displays the variation of the RMS value of acceleration over time for each signal, with a low-pass filter applied at a cutoff frequency of 500 Hz to the recorded data. The RMS value varies between different signals. The top housing exhibits the minimum value during stability but experiences significant growth during chatter. Conversely, the lower work roll exhibits the maximum value of acceleration during system stability and minimal growth during instability.

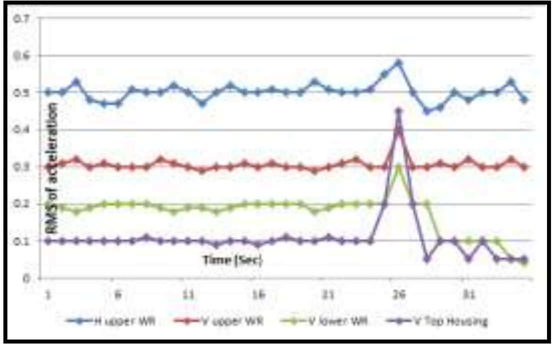

**Figure** 12 RMS value of acceleration signals

Based on Figures 10 to 12, it can be concluded that the top housing is more sensitive to chatter compared to the work rolls. Considering the results of both experiments, the upper backup roll and top housing demonstrate high sensitivity to chatter, making them suitable positions for installing permanent acceleration sensors to detect chatter.

In both experiments, the 26th second marks the occurrence of the Acceleration Peak Time (APT), while the highest amplitude ratio signal is observed during the vertical vibration of the upper backup roll and mill housing.

## Conclusions

This article presents an analysis of the vibrations in a two-stand tandem mill. The study involved the utilization of vibration monitoring and chatter detection systems to examine the behavior of the rolling stand. By utilizing empirical data, several analyses were carried out to quantify the relationship between rolling instability and the vibrations of different components within the mill stand. The results highlight the crucial role of signal processing in effectively interpreting vibration data, affirming its efficiency for such applications. The study demonstrates the highly sensitivity of the upper backup roll to rolling chatter. This component significantly contributes to the occurrence of chatter phenomena, particularly the third octave chatter that aligns with its vibration frequency.

Furthermore, the research shows that the upper backup roll is capable of detecting chatter several seconds before it becomes evident. Additionally, the top housing displays relative sensitivity to chatter effects. Consequently, both the upper backup roll and the top housing exhibit greater sensitivity to chatter when compared to the work rolls. These locations are suggested as suitable positions for the installation of permanent acceleration sensors dedicated to chatter detection. The implications of these findings are substantial, as they can serve as an effective tool for optimizing the operation of rolling mills, leading to enhanced production rates and product quality. The research strongly recommends integrating these insights into the refinement of automatic warning systems within tandem rolling mills, thereby contributing to improved operational efficiency and product quality enhancements.

## REFERENCES

[1] Heidari and M.R. Forouzan, Study on the Relationship between Chatter Mark Vibration and Rolling Skid for a Twenty-high Roll Mill Based on the Measured Torsional Strain of the Main Drive Shaft, Journal of Advanced Research (2012), p. – 2
[2] V. Panjkovic, R. GlossGerald, Journal of Materials Processing Technology, Vol.212 (2012), p. 954.
[3] Yan Xiaoqiang, ZhangYan, Research on Vibration reason of reversing cold mill, Journal of Vibration and Shock, Vol. 29, 2010, No.9, 231-235.
[4] Yang X., Tong C.-N., Yue G.-F., Meng J.-J. Coupling dynamic model of chatter for cold rolling. Journal of Iron and Steel Research International, Vol. 17, Issue 12, 2010, 30-34.
[5] Y.K. Sun: Modeling and control of the hot and cold rolled strip mill (Metallurgical Industry Press, Beijing 2010).
[6] Kimura Y., Sodani Y., Nishiura N., Ikeuchi N., Mihara Y. , Analysis of chatter in tandem cold rolling mills. ISIJ International, Vol. 43, Issue 1, 2003, p. 77-84.
[7] Paton and Critchley, The effect of friction and inelastic deformation on chatter in sheet rolling, The Royal Society publishing, 08 June 1994, p. – 1-5.
[8] J.Gasparic, Vibration analysis identifies the causes of mill chatter, Iron and steel Engineer,Vol.68,1991, 27-29.
[9] Nessler.G.L, Cory. J.F., Cause and solution of fifth octave backup roll chatter on 4-h cold mills and temper mills, Iron and Steel Eng., No. 10, Nov. 1989, pp. 23-27.
[10] Yarita. I., Furukawa. K., Seino.Y., An analysis of chattering in cold rolling for ultra-thin gauge steel strip, Trans. of the Iron and Steel Inst. of Japan, Vol. 18, No. l, Jan. 1978, 1-11.
[11] Roberts.W.L., “Four-h mill stand chatter on fifth octave mode”, Iron and steel Eng., Vol. 55, No. 4, April 1978,41-47.
[12] Mohammad Reza Niroomand, Mohammad Reza Forouzan and Ali Heidri, Experimental analysis of vibration and sound in order to investigate chatter phenomenon in cold strip rolling, The International Journal of Advanced Manufacturing Technology,Vol.100,2019,673-682.