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A Review on Chatter Analysis in Cold Rolling process

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Abstract

Chatter is a self-excited vibration that occurs between the tool and the work piece, in manufacturing industries and resulting in a poor surface finish, high-pitch noise and accelerated tool wear which in turn reduces machine tool life, reliability and safety of the machining operation. Chatter is major obstacles in achieving desired productivity and becoming a common limitation to productivity and part quality in manufacturing sector. Due to this reason, from many years, it has been a very important topic of industrial and academic interest in the manufacturing research. A lot of previous research and various techniques proposed by several researchers to solve the chatter problem. Researchers have studied how to detect, identify, avoid, prevent, reduce, control, or suppress chatter. This paper reviews the state of research on the chatter problem and classifies the existing methods developed to predict the chatter where the objective is to avoid chatter occurrence during the rolling process in order to obtain better surface finish of the product, higher productivity and tool life, that passively or actively, will modify the system behavior. A great deal of research has been has been performed on the chatter problem. However, at this moment, it is difficult to explain why a certain mill produces coils with and without chatters while working under same conditions. However, chatter phenomenon can be controlled if certain mill parameters like rolling speed, reduction, work roll bender, roll surface finish and lubrication are controlled properly.

Keywords: Chatter; Stability; Frequency; Amplitude; Vibration

Abbreviations: PLTCM: Pickling Line Tandem Cold Mill; TCM: Tandem cold rolling mill; CPT: Center Plus Trimmer; TCM: Tandem Cold Mill

Introduction

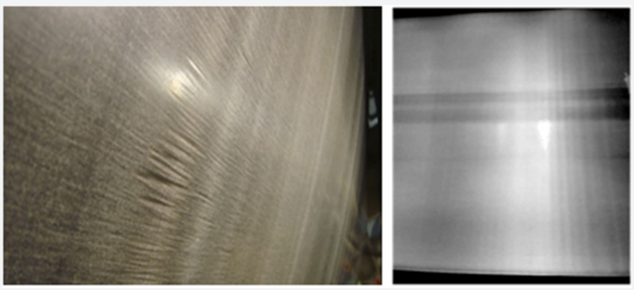

Figure 1a & b: Chatter mark (light dark bands) on sheet.

An undesirable mechanical vibrations defect occurs during common process of cold rolling operation known as chatter. This happened due to numerous discrepancies occurring during manufacturing process, such as roll vibration, variation in strip tension and negative damping [1]. Chatters lead to thickness variation (across the width), surface damage and undesirable noise at work place. The final product quality gets tremendously affected by chatter marks on the surface of rolled strip and until now it is difficult to discover the generation mechanism and methods to identify chatter marks [2]. Chatter marks have been recognized as a main restriction on productivity and economic benefits. Chatter marks generate during the start and the finish periods of the rolling process and damage the surface quality [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 Figure 1a &1b.

The factor which may be associated such as strip tension variation due to roll vibration, friction and cooling during process. According to the frequency of vibrations, generally there are three kind of vibration consider during cold roll forming which may influences chatter marks [4] such as:

a. Low frequency torsional vibration (5-20Hz) which is associated with drive train and small thickness variation.

b. Third octave mode vibration (100-200Hz) which produces large thickness variation and strip rupture and

c. Fifth octave mode vibration (500-700Hz) which results in transverse bending of the backup and work rolls.

Among these chatter, both third and fifth octave mode of chatter are related to vertical vibration of rolls. Third octave mode chatter is more severe and has unacceptable surface finish variation and pronounced tension fluctuation between stands due to the delay in the phase of strip. This result in strip rupture and pronounced vibration problem.

Chattering is the big distress in still industries production. Previous research work had been done in order to find out the causes of chatters, possible remedies either through mathematical modelling (i.e., analytical study) or finite element analysis (i.e. simulation study) or experimental study. The rolling process using one degree of freedom system of vibration and evaluated the resonant frequency of fifth octave chatter vibration were discussed, in which, the work roll was considered as mass element and work-backup roll contact was considered as spring element and the back-up roll was considered to be rigidly fixed [4] Chatter simulation model by using two degrees of freedom was further observed [5]. The four degree of freedom (motion of two work roll and two back up roll) in addition to one degree of freedom system in order to appreciate the vibrations of rolling system was estimated numerically to deal with the chatter problem [6].

A numerical solution to show the effect of friction condition in rolling bite on mill chatters (five stand four high mills), an optimum range of friction in fifth stand in order to achieve higher critical speed was presented [7]. The numerical solutions were validated with the experimental results obtained in NKK corporation production mill. The computer simulation have been used to study chatters and showed the variation of natural frequency with variety of factors viz. friction, rolling speed, tension, reduction and strip width. The stability criterion for rolling mill was derived analytically using the factors causing negative and positive damping [8].

However, up till now, to remove chatter completely remains unsuccessful. Hence, it is a great challenge to reduce chatter from strips without affecting production capacity. In this literature review, we are trying to explore different sources of chatter, methods to control the chatters and relationship between chatter and process parameters on previous based research work.

Sources of chatter in rolling mill

Table 1: Chatters reasons.

S.No	Reasons of Chatters
1	Due to problems in drive systems: Misalignment of gears (Excitation proportional to speed)Tooth engagement, Gear defects
2	Roll ripples/ Unbalance or eccentricity of rolls/ Speed of rolls
3	Periodic grinding of rolls
4	Friction conditions lead to excitation
5	Excitation due to slackness/ process interruptions
6	Influence of varying tensions in the mill, Inter-stand tensions
7	Coupling of mechanical and electrical behaviour of various drive system will lead to harmonic vibrations
8	Causes of self-excited vibrations: Rough roll (a) Relative movement between strip and roll (b) Lubricating performance of temper fluid (c) Stability of friction state while operation
9	Variations in rotating frequencies of transmission parts (Reasons particularly for torsional chatter)
10	Influence of mechanical system: Shocks will open up the roll gap and lead to torsional chatter (Oscillations of drive systems)
11	Influence of electrical system: Changes in each electrical factor will affect the drive system
12	Influence of lubrication in driving parts
13	Excessive roll bite lubricity (Chattering may happen due to skidding of work roll on the strip during roll bite also called as 'Negative forward slip'). This negative slip occurs due to excessive roll-bite lubricity and/or excessive entry tension
14	Excessive roll bite friction
15	Coupling of adjacent stands by strips
16	Improperly ground work rolls
17	Defective work-roll bearings: (Radial loads, when applied to bearings through roll bending or unbalance or eccentricity of the rolls).
18	Inter-stand coupling
19	Chatter-affected strip entering the mill stand
20	The causes for the fifth octave mode chatter are as follows: (a) General Mill vibrations and operating conditions: (b) Surface damage on backup roll

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The process defects, chatter in roll forming operation, May occurred due to various un-circumstances such as friction, velocity and roll force fluctuation during operation process Table 1. Mainly there are different sources of chatter [9,10] such as:

a. Friction coefficient

b. Strip entry velocity

c. Strip width and thickness

d. Forward and Backward reduction ratio.

To establish the exact relationship of process parameter with chatter on actual mill model is complicated. Previous literature review has been observed that the numerical spring mass systems are relatively similar to process model in the shop floor [11,12]. Such as, consequence of rolling speed, strip width, friction coefficient, with vibrational amplitude of rolls and tuned dampers.

Friction co-efficient: The friction coefficient (μ) is a nonlinear function of the relative velocity. Hence with the rapid raise in the relative velocity between the working rolls and the strip, the force of friction varies gradually from the maximum force of friction to the force of kinetic friction. However, if the relative velocity increases continuously, when the coefficient of kinetic friction reaches its minimum (μm) then temperature is rapidly raised, due to relative motion between two surfaces. This results in the heat scratch and sticking problem with a partial oil film rupture. During rolling operation, the friction coefficient is depends on lubrication flow and it will directly affect the roll vibration. Usually, vibration decreases with the increase of the friction coefficient. The higher friction coefficient leads to higher rolling forces and will increase the rolling stiffness and chatter frequency (Figure 2).

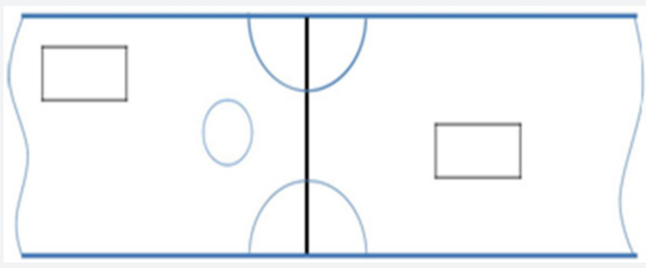

Figure 2: Hot rolled coil after welding, notching and punching.

Strip entry velocity: As speed has a very strong effect on chatter development and all other effect may be measured by evaluating their effects on limit speed. The variation of Strip entry velocity is one of the significant causes of chatter development since it is directly proportional to the rolling force and produces the variable components of back tension due to this reason variable stretches are developed between two stands (Table 2).

Table 2: Remedies for chatter reduction.

S.No	Chatter	Remedies for Chatter Reduction
1	To avoid resonance	Through supply of low power non-synchronous frequency: (A) Providing predetermined looseness to the bearing of one of the roll so that it will oscillate at a frequency different than that of other roll and thereby, avoiding the natural frequency of stand structure (B) To provide source of mechanical vibration to a stand (C) Applying non-synchronous pulsating rhythm to a hydraulic fluid supplied to hydraulic component of the stand, e.g., hydraulic cylinders employed to control strip gauge [13,14]
2	To reduce third octave chatter	(A)By increased damping: (I) Use of tuned dampers located over top backup rolls (II) Pressurization of roll-balance cylinder (B)Using backup rolls of different diameters in different stands (C) Lower viscosity backup-roll-bearing lubricants (D) Changes in the drafting schedule after work-roll change
3	To reduce fifth octave chatter	(A)Critical material has to be scheduled as soon as possible after backup roll changes in the final stand [because only a few customers will have critical standards against the slightly undulating waves]. (B) Modulation of the mill speed (C) Proper selection of backup roll diameter with respect to work roll diameter (D) Utilization of hardest permissible backup roll (E) Utilization of smooth work roll`

Strip width and thickness: Strip width and thickness is one of the major sources to develop chatter marks on flat strip. Generally for the same thickness wider sheet has more stability then smaller sheet. When strip width doubled from 1.14m to 2.286m with friction coefficient μ=0.1then speed stability limit was changed from 4.5m/s to 6m/s i.e. Speed limit increased 1.33 times and also frequencies increases from 134Hz to 175Hz.

Forward and backward reduction ratio: Occasionally, when negative damping system become unstable and strip back tension and front tension start fluctuating causes the variation of the rolling force and change the friction as well as the gap between the rolls. If the back tension is increased further then third octave mode chatter occurs and reaches its maximum amplitude within a few seconds [13].

Possible remedies for chatter reduction

Influence of tuned dampers: A tuned mass damper is a device which is mounted in the structure to reduce the amplitude of the mechanical vibration and it may also prevent the damage or outright structure failures. Tuned mass damper is included in the chatter prevention system and it has effected

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due to the changes of the natural frequency of the stand and this frequency change with rolling speed, strip tension, strip width and strip thickness and reduction. The important things are that location of this tuned damper should be such that it could place according to system mode shape. To prevent the vertical and horizontal vibrating motion of mill rolls, by introducing a source of low power vibration to the rolls i.e. non-synchronous with the frequency of the roll vibration [14]. The low power non-synchronous frequency can be supplied to a stand in a variety of ways, such as, the bearings at the end of one roll in a stand can be provided with a predetermined looseness relative to the other roll bearings. This allows the “loose” roll to assume a mechanical motion and frequency that is not that of remaining rolls, which having normal bearing clearances i.e., loose roll assumes a motion that distorts the harmonic motions of the others rolls, which is at a frequency different from the oscillating frequency of the other rolls.

Plant overview of chatters

Criteria for stability in tandem mill: A numerical simulation model performed a parametric study for friction coefficient at last stand and the rolling speed and came up with the plot showing regions for occurrence and non-occurrence of chatters. The simulation results were compared with the production mill results and validated [7]. The Pickling Line Tandem Cold Mill (PLTCM) is divided into three sections viz.:- (I) Entry (II) Center plus Trimmer (III) Tandem cold mill.

Entry section

This section consists following elements: (A) Pay-off Reel (B) Leveler (C) Dividing shear (D) Welder (E) Trimmer. The Input coils for PLTCM are Hot Rolled coils and these are output of two sources. First one is Hot Strip Mill (HSM) and the second one is LD-3. The specifications for input coil are: (HR coil thickness=2-6.5mm; HR coil width= 900-1580mm).

Pay-off reels are cylindrical in shape on which the coil is mounted. There are 2 pay-off reels-POR#1 and POR#2. POR#1 and POR#2 are corresponding to upper line and bottom line. Process of mounting hot rolled coils on POR’s is automated. Leveler rolls are applied after the pay-off. The function of these leveler rolls is to maintain the flatness of the input coil. It also helps in breaking the scale on the coil surface that is accumulated due to hot rolling operation.

After the tension leveler completes its work, there is an instrument called dividing shear. Both at head end and tail end of the coil, there is a certain length of coil with variation in the coil geometry than rest of the coil. In order to get rid of this variation, dividing shear cuts off that particular length of an input coil depending upon the coil grade. The dividing shear is applied both on upper line and bottom line. The data related to the length of the scrap on head and tail end of every coil is already saved in the system depending upon the geometry (thickness, width) and grade of the coils.

Two coils of POR#1 and 2 are welded together. Tail of the leading coil gets welded with the head of the trailing coil along the width. The purpose of welding two coils is to keep the line continuous. Welder is typically of flash butt type with oil dripping facility. The oil being used is of grade VG-150. There are certain restrictions on geometry of two coils getting welded together. One of the two coils should not differ in width by more than 200mm than the other. Also the thickness difference between two coils should not be more than 1mm. Mathematical expression can be given as: and also, depending upon the grades (i.e., material composition) of the coil, there are certain sets of pairs which can’t be welded together. In order to eliminate the weak zone i.e. the edge portion of weld pool, two semicircular holes of certain diameter are notched at both sides of the coil as shown in Figure 2. Also, a circular hole is punched in front of weld pool line for the rolling system to take into account the change of coil from that point. Consequently, appropriate length is cut off before the rolling so as to change the rolling pressure according to the geometry as well as material properties of the coil.

Central section/pickling section

This section has following elements: (A) Entry loop car (B) Tension leveler (Stretching machine) (C) Pickling tank: 4 different tanks are there having different concentrations of Hydrochloric acid within them (D) Rinsing tank (E) Dryer (F) Inspection Delivery loop car#1 (F) and Trimming Delivery loop car#2

The looper acts as a buffer in the mill and helps the mill to run continuously. After entry loop car, the strip goes to tension leveler. The tension leveler breaks the scale which is helpful for pickling operation. Tension leveler has two sections. First section breaks the scale by causing the strip to undergo angular deformation. Two rolls with backup rolls are set at certain vertical offset to complete the angular deformation. The second section of tension leveler helps to take care of the shape that was distorted while scale breakage. The strip undergoes around 2% of elongation. Once the scale is broken at tension leveler, the strip undergoes picking operation in pickling tank. Hydrochloric acid (HCl) is used for scale removal. There are four different tanks of HCl with increasing concentration in the direction of movement of the strip. The fourth tank has 10-11% concentrated acid. The purpose of varying concentration is to ensure removal of easily removable scale early and highly sticky scale at the end where the pickling effect is maximum. Pickling is followed by the rinsing operation. There are four rinsing tanks that use de mineralized water to remove the acid layer. Water is sprayed on the strip through nozzle. Now, the moisture also needs to be removed in order to avoid surface defects after rolling. Thus, the dryer comes into action where the strip is fed through hot air blow. The completely dried strip is then fed to delivery loop car#1 which acts as buffer. The strip is trimmed along its width depending upon customer requirement and then inspected

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visually. The output of this is sent to delivery loop car#2. This, in short, covers the central section of PLTCM.

Tandem cold rolling mill (TCM): (actually where the rolling operation takes place)

This is five stand six high cold rolling mills where the hot rolled coil is converted to fully hard cold rolled coil. Work rolls, intermediate rolls and back-up rolls are used in each of the five stands. As shown in the schematic structure of TCM, the strip is subjected to two weld point detectors named 4-WPD and 5-WPD. Both the detectors help in improving the positional control (as an explanation, with certain number of rotations of a particular roll, the weld point should travel certain amount of distance logically). 4-WPD allows ±100mm whereas 5-WPD allows ±3mm error. There are two pairs of steering rolls which help in central positioning control (CPC). Error of ±5mm is allowed here. There are two pairs of bridle rolls also. The purpose is to control the tension in strip according to rolling requirement. The principle used for controlling the tension is differential speed i.e. the drive in these rolls will adjust their speeds so as to achieve required tension in the strip. As mentioned earlier, two hot rolled coils of different thicknesses as well as grades are welded together so as to maintain the continuity of mill. Thus, at the welded portion, the properties of the running strip will vary and the rolling force required will also vary accordingly. Therefore, something called 'flying gauge control' is used to take into account this variation. X-ray gauges are used to measure the thickness of the strip before and after first stand as well last stand. Two X-ray gauges are provided in order to increase the accuracy of thickness measurement at the exit (after fifth stand). Feedback devices are installed to control the thickness. For thickness measurement within 2nd, 3rd and 4th stand, mass flow continuity concept is used. The mill is also facilitated with tension and velocity measurement devices installed in it. Automatic tension regulator (ATR) is device that works on pneumatic logical control (PLC) in order to control tension within the stands.

Electrical drive is used to rotate the work rolls. However, intermediate rolls and back-up rolls rotate due to friction effect. The rolling force is applied through hydraulic unit. In the fifth stand, the amount of rolling force is same for all the coils irrespective of material and geometry since the percentage reduction is less. However, the rolling force varies with coil grade in remaining four stands. Rolls are made up of forged steel containing 4% chromium. The hardness of work rolls is maximum and that of back-up rolls is minimum. Synthetic oil in water is used as lubricant which takes care of friction and heat both. The concentration of synthetic oil in this mixture is maximum (3%) for first stand and minimum for last stand.

Modelling of rolling system

One degree freedom: The natural frequency for 3rd and 5th octave mode chatters was estimated with the use of one degree of freedom system [4]. The assumption in the third octave mode chatter is that back-up rolls are considered as mass element and the contact between work-backup rolls is considered as spring element in the vibratory system. However, the assumption in the fifth octave mode chatter is that back-up rolls are considered as rigidly supported and the contact between work-backup rolls is considered as spring element in the vibratory system. Two degrees of freedom: A four high mill can be modelled with two degrees of freedom assuming motion of top (or bottom) work roll and that of top (or bottom) back-up roll if symmetry is assumed. Four degrees of freedom: If motions of two work rolls and two back-up rolls are considered without considering mass of housing, rolling process can be modelled with four degrees of freedom [13,14].

Conclusion

Due to its complication, the chatter problem is still not completely solved, even though variety of research has been performed on chatters through analytical studies or experimental studies or numerical analysis. A lot of significant advances have been made over the years. Advances in computers, sensors and actuators have increased understanding of the phenomena, and developed and improved strategies to solve the chatter problem. However, at this moment, it is difficult to explain why a certain mill produces coils with and without chatters while working under same conditions. However, chatter phenomenon can be controlled if certain mill parameters like rolling speed, reduction, work roll bender, roll surface finish and lubrication are controlled properly.

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References

1. Yun I, Wilson W, Ehmann K (1998) Review of chatter studies in cold rolling. International Journal of Machine Tools and Manufacture. 38(12): 1499-1530.
2. Collinson S (1999) Knowledge management capabilities for steel makers: A British-Japanese corporate alliance for organizational learning. Technology Analysis & Strategic Management 11(3): 337-58.
3. Iwadoh S, Mori T (1992) Effect of Work Roll Materials and Progress of Manufacturing Technology on Cold Rolling and Future Developments in Japan. ISIJ international 32(11): 1131-1140.
4. Roberts WL (1988) Flat processing of steel: Dekker.
5. Heidari A, Forouzan MR, Akbarzadeh S (2014) Effect of Friction on Tandem Cold Rolling Mills Chattering. ISIJ International 54(10): 2349-2356.
6. Yarita I (1978) Analysis of chattering in cold rolling for ultra-thin gauge steel strip. Trans Iron Steel Inst Jpn 18(1): 1-10.
7. Kimura Y, Sodani Y, Nishiura N, Ikeuchi N, Mihara Y (2003) Analysis of chatter in tandem cold rolling mills. ISIJ International 43(1): 77-84.
8. Tlusty J, Chandra G, Critchley S, Paton D (1982) Chatter in cold rolling. CIRP Annals-Manufacturing Technology 31(1): 195-199.

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9. Quintana G, Ciurana J (2011) Chatter in machining processes: A review. International Journal of Machine Tools and Manufacture 51(5): 363-376.

10. Wiercigroch M, Budak E (2001) Sources of nonlinearities, chatter generation and suppression in metal cutting. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 359(1781): 663-693.

11. Ezugwu E, Fadare D, Bonney J, Da Silva R, Sales W (2005) Modelling the correlation between cutting and process parameters in high-speed machining of Inconel 718 alloy using an artificial neural network. International Journal of Machine Tools and Manufacture 45(12): 1375-1385.

12. Minis I, Yanushevsky R (1993) A new theoretical approach for the prediction of machine tool chatter in milling. Journal of engineering for industry 115(1): 1-8.

13. Bemporad A, Bernardini D, Cuzzola FA, Spinelli A (2010) Optimization-based automatic flatness control in cold tandem rolling. Journal of Process Control 20(4): 396-407.

14. Wang AC, Chang KW, Dunlap LD, Luo J, Stewart DF, et al. (1998) Interruption of rolling mill chatter by induced vibrations.

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