Understanding Mill Vibration Phenomena

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Abstract

Third octave mill vibration remains a difficult problem to solve in the aluminium and steel rolling industry, often reducing mill productivity by limiting the maximum speed of the mill. This paper describes the typical resonant modes of the mill stand that can become excited during third octave vibration. Eigenfrequency predictions from a computer model of a mill stand are presented and compared to experimental measurements, distinguishing between the third and fifth octave chatter modes. The interaction between third octave vibration modes and the entry strip tension will be discussed, demonstrating how the vibration becomes self-exciting and unstable. A simple model of the self-exciting behaviour is presented.

Introduction

The simplest type of mill vibration is found in all mills and is a forced vibration, typically due to roll eccentricity and is experienced at roll rotation frequencies. These frequencies are usually lower than any of the resonant frequencies of the mill stand and so gauge variation is a result of the stiffness of the mill and the material being rolled. In some cases it is possible for this vibration to be worsened by excitation of torsional resonances of the main, unwind and rewind drives[1].

Natural resonances of the rolling mill that involve translational motion of the rolls typically occur at frequencies greater than 50Hz. Of the large number of resonant modes of the mill that could become excited during rolling, only a few of these modes cause damage to the metal being rolled or the rolls. Excitation of these specific modes are the typical cause of the phenomena of third octave gauge chatter and fifth octave roll and strip chatter marking, respectively. This paper describes these modes of vibration and presents a simple model to help understand the self-exciting nature of the third octave gauge chatter vibration.

Eigenfrequency Modelling

To provide a better understanding of mill vibration phenomena, a finite element model was created to predict the resonant modes of vibration, or eigenfrequencies, of any rolling mill. This Mill Stand Vibration Model simply requires input of physical dimensions and elastic properties of the materials making up the mill stand frame, rolls, bearings and hydraulic actuators. To capture effects of roll and frame bending, these components are modelled as multiple beam elements, each with 3 degrees of freedom. Hertzian contact is assumed between the work and back-up rolls. The stiffness of the strip is calculated automatically using a roll gap model, based on the mill geometry, alloy and rolling schedule. The model also includes 1-d springs to account for hydraulic connections and discrete masses to account for interconnecting drive shafts and chocks. The model is asymmetric (top to bottom and operator to

[1] Octave refers to the musical octaves where the third musical octave is 128-256Hz and the fifth musical octave is 512-1024Hz

drive side). The model automatically assembles global mass and stiffness matrices, before calculating the eigenvalues or natural resonant vibration frequencies of the structure.

For each mode an Energy Ratio is calculated for either the in-bite contact or the contact between the backup and work roll. This ratio, expressed as a percentage, is the potential energy in the contact divided by the total strain energy in the whole system for that mode. The Energy Ratio has proved useful to identify modes more likely to produce gauge chatter vibration or backup roll marking (fifth octave chatter). The model does not use a commercial FE environment, instead it is a standalone analysis tool with a user-friendly interface.

Third Octave Gauge Chatter Vibration

Third octave(a) gauge chatter is known to involve vibration of the rolls, chocks and housing frame at frequencies ranging from 100 to 300Hz. The onset of vibration is sudden, reaching large amplitudes that produce significant exit gauge variation which interacts with the rolling load via entry tension resulting in very unstable, self-excited behaviour.

Figure 1 shows a typical gauge chatter vibration mode that is observed at a frequency around 100Hz. This mode involves simple vertical translation of the rolls (the top two rolls in antiphase to the bottom two rolls) and significant motion of the housing frames. Also shown in Figure 1 is a different mode that is responsible for a less common, higher frequency gauge chatter problem that involves significant roll bending with less involvement of the housing frame.

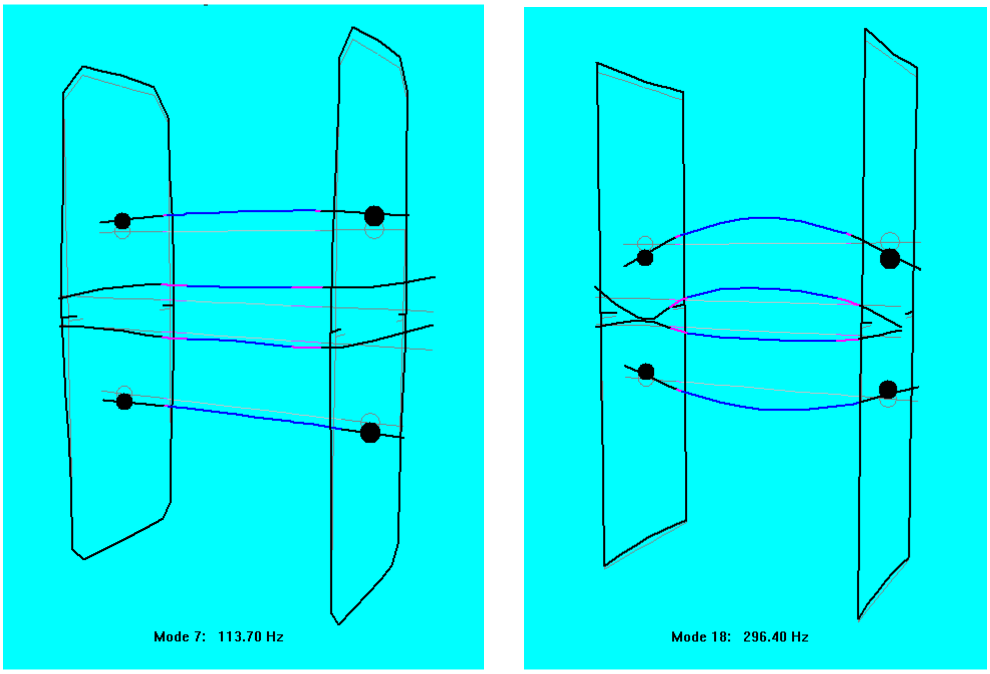

Figure 1: Prediction from the Mill Stand Vibration Model showing a typical gauge chatter vibration mode at 114Hz (left). A less common gauge chatter mode at 296Hz is shown (right) involving significant roll bending.

The model has helped to understand several mill vibration problems and Figure 2 shows a comparison between the predicted and measured mode frequency during rolling. Each datum in Figure 2 represents a different mill with different mill geometry and dimensions, showing excellent agreement between prediction and measurement over a wide range of frequency.

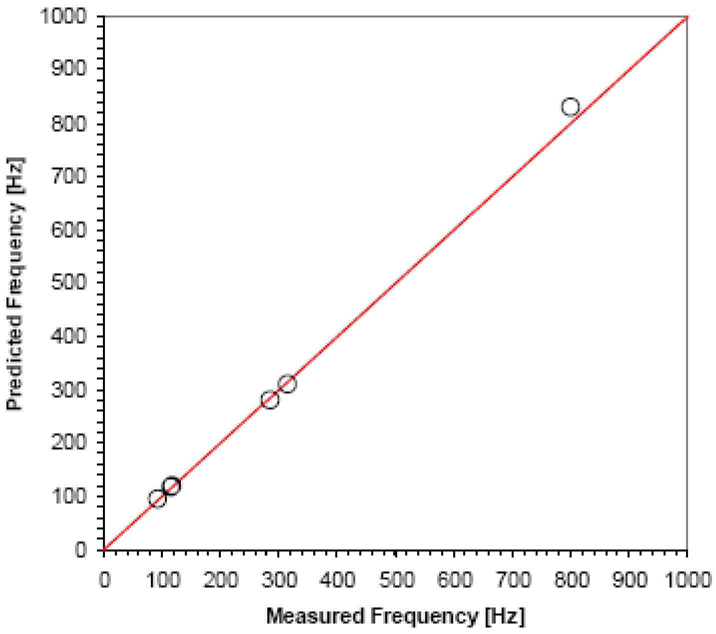

Figure 2: Comparison of predicted and measured mill vibration frequencies for cold mills with different millstand geometries. The straight line represents the condition of predicted frequency being equal to measured frequency.

A change in exit gauge will perturb mass flow through the mill resulting in a change to entry strip velocity. In turn this results in a change to entry strip tension which affects exit gauge. This mechanical feedback loop that exists within every mill stand has been described elsewhere[2] and is at the heart of the third octave gauge chatter vibration. The resulting gauge variation can be several percent of nominal gauge at frequencies that are too high for the mill gauge control system to either sense or respond to. When gauge chatter vibration occurs, the strip has to be scrapped.

It is possible to model the self-exciting feedback loop, either as a time simulation model or in the Laplace domain. Figure 3 shows a typical prediction from a time simulation model for two stands of a tandem cold mill. The results show a sudden onset of mill vibration, producing significant load variation in each stand, and a coupling of the two stands during vibration.

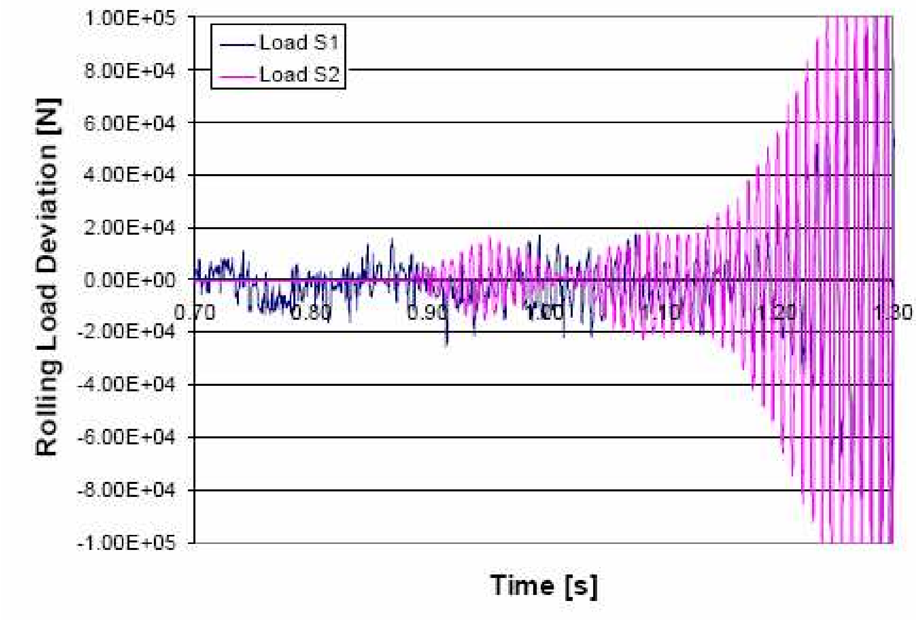

Figure 3: Predictions from a time simulation model showing the rapid onset of third octave chatter involving both stands of a simulated two stand cold tandem mill.

Using a Laplace domain approach and applying a criterion for instability, it is possible to calculate the critical rolling speed, $V_{critical}$ [ms-1], at which the feedback loop becomes self-exciting and the onset of mill vibration would occur, as follows:

$$V_{critical} = \frac{-2 L M_{eq} \zeta \omega_n^{3}}{\frac{dF}{dT_i} E W}$$

where L [m] is the length of the entry strip, Meq [kg] is the equivalent mass of the vibration mode, ζ [dimensionless] is the damping ratio (damping of the system as a fraction of the critical damping), ω [s-1] is the resonant frequency of the vibration mode, dF/dTi [dimensionless] is the sensitivity of the rolling load to a change in the entry tension, E [Nm-2] is the elastic modulus of the strip and W [m] is the strip width.

Fifth Octave Chatter and Backup Roll Marking

Fifth octave chatter marking initially requires a source of forced vibration which commonly excites avery specific resonant vibration mode of the mill stand. The sources can be within the mill or the roll grinder. Typical frequencies of the mill vibration mode are between 500 and 1000Hz. The markings usually form around the backup rolls and also print onto the strip surface causing surface quality issues. It is usually possible to measure very slight surface undulations on the backup roll, associated with the markings. Further observations are described elsewhere [3].

Once the markings have begun to form on a backup roll, the marks themselves can excite the vibration mode at certain roll speeds and the problem becomes self-exciting. This causes the markings to build up in severity in an exponential manner, such that a product quality issue can build up within about a day, after some weeks of problem-free service. Nevertheless the timescale for the formation of roll marks is much longer than for the third octave gauge chatter. An example of severe fifth octave marking around the barrel of a backup roll is shown in Figure 4.

Back-up rolls must be changed frequently on mills that suffer from this problem, before the onset of marking. A high frequency of back-up roll change results in loss of productivity, excessive cost and shortened overall lifetime of the back-up rolls themselves.

The Mill Stand Vibration Model provides a good prediction of the mill resonance that can be responsible for marking the backup rolls. Figure 5 shows predicted resonant frequencies for a cold rolling mill stand that was also studied by experimental modal analysis with the assistance of AMTRI. The results are described elsewhere and show good agreement between the model and experiment, both in mode shape and frequency[1],[4]. The typical modal shape shows the two work roll barrels moving in phase, mostly rigidly, between the two back-up rolls, in a largely vertical plane. It is this particular motion, when excited, which can result in the marking of the back-up rolls due to surface damage. The operator-side roll necks are bending significantly, largely within the clearance in the chocks. The lower coupling and drive-side work roll chock are also in motion.

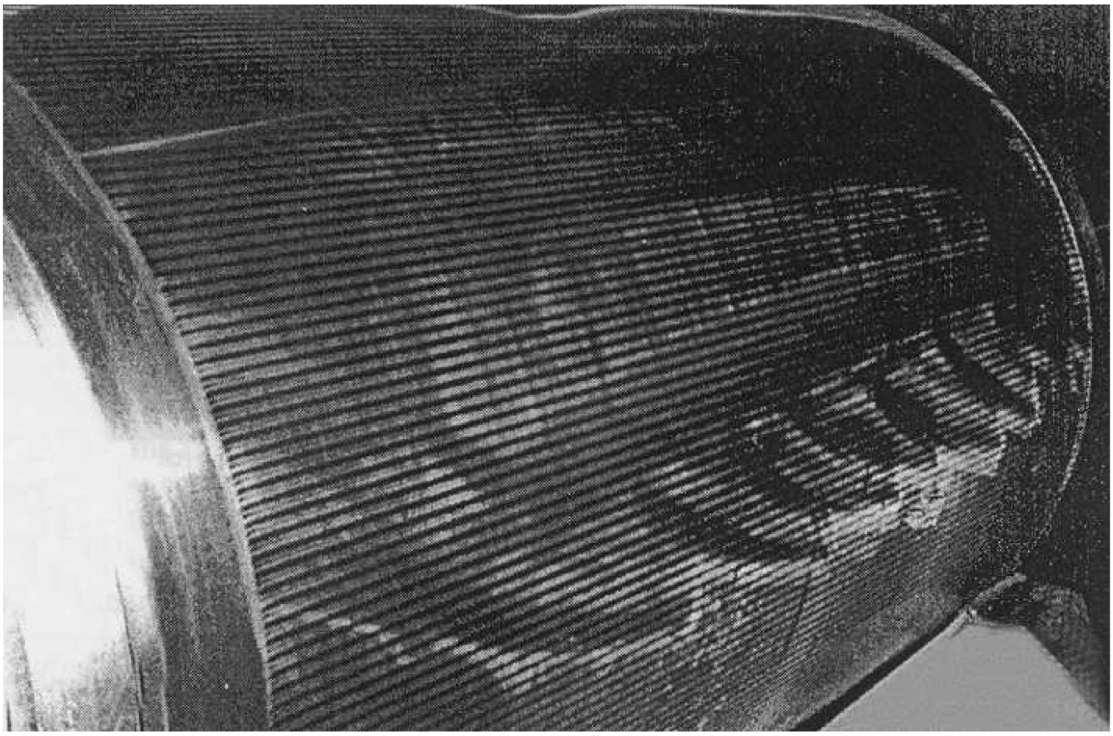

Figure 4: An example of severe fifth octave chatter marks on a back-up roll barrel. The marks are linear and parallel to the roll axis with a regular spacing around the roll circumference.

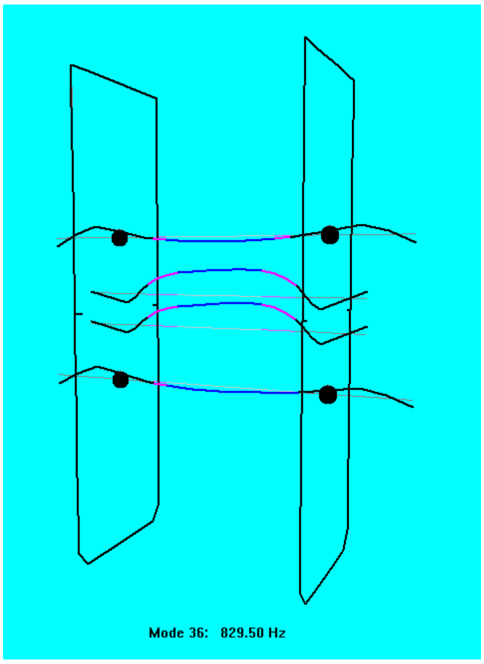

Figure 5: Prediction from the Mill Stand Vibration Model showing a typical fifth octave vibration mode shape for a cold rolling mill

Conclusions

Computer simulation of complex engineering problems can add significant understanding to the problem and clarify thinking in the area. This, together with careful experimental measurements, has resulted in the solution of many mill vibration problems.

Typical mill stand vibration modes responsible for third octave gauge chatter have been presented. Higher frequency modes tend to involve more roll bending depending on the dimensions of the mill stand.

A simple model describing the main features of the self-exciting behaviour of third octave chatter has been presented. The model predicts the importance of rolling speed and other factors in the stability of the self-exciting loop.

It has been shown that the vibration mode responsible for fifth octave chatter involves the work rolls moving as a pair between the backup rolls causing damage to the backup roll surface resulting in the observed markings.

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