Enhanced Dynamic Response to Impact for Hot Rolling Mills

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INTRODUCTION

The speed regulator response is a fundamental characteristic of a drive system for rolling mills. Not only responding to minor speed adjustments commanded by the operator, mass flow compensators, looper regulators, tension control, or others, but also to the dynamic response to the impact of the product. This dynamic response is defined by the speed drop and how much time it takes to recover when the metal goes inside the stand. Having an acceptable dynamic response is essential to avoid cobbles and ensure quality requirements. This type of response is directly defined by the family of products to be rolled. Increasing the bandwidth of the automatic speed regulator (ASR) is the most common method to have a better dynamic response. Still, depending on the mechanical installation, it can also cause different torque instability issues. This paper proposes different methodologies to avoid these disturbances.

BACKGROUND

Rolling Mill Dynamic Response

The hot rolling mill subjects the drives system to an impact load every time the product hits the rolls. When the product hits the stand, the speed naturally drops, causing an accumulation of material between the stand being hit and the one upstream. Also, it will cause the material to buckle between the stands. Accumulating material and buckles between stands increases the risk of cobbling and possible mechanical damages. Depending on the product rolled, is the allowed dynamic response.
The lightest the product, the highest the dynamic response needed (lower number). JSC OEMK "Alexey Ugarov" is also the only integrated plant in Russia that carries out direct iron reduction and smelting in electric arc furnaces. Its capacity is 3.5 million tons of metallized pellets per year, at all four metallization plants.

Speed dynamic response (Impact Response) measurement

The dynamic response is how the drive responds to a perturbance, or in the case of a rolling mill stand, when the billet/slab hits the rolls. The dynamic response to the impact is measured by using the area caused by the speed error, comparing the rolling speed reference (without speed impact compensation or lead speed) to its feedback, until it gets inside the permitted steady state error. The shaded area on figure (1) is the area that measures the dynamic response of the drive system.

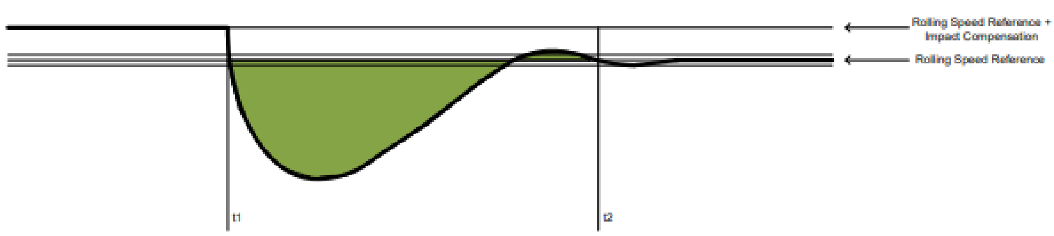

Fig. 1

$$Dynamic\ Accuracy\ Response = \int_{t1}^{t2} \left| n_{ref} - n_{fbk} \right| dt \ [\% * s]$$

$$n - speed\ in\ \%\ (100\%\ is\ top\ speed)$$

Some examples of acceptable responses for some of hot rolling processes are:

- Bar mill 0.1-0.5 %sec
- Large section Mill 1-2 %sec

DISCUSSION

PROBLEM DESCRIPTION

The main problem is the effect of torque instabilities caused by increasing the speed regulator bandwidth to get a better impact response. In an ideal world where the motor gearbox, pinion, stand, rolls, and speed sensor are perfectly constructed and installed, there is no reason to have torque instabilities. But in the real world there are imperfections that can cause speed variations which makes the ASR to respond immediately causing torque perturbances. Some of these imperfections are:

- Mechanical vibrations. - These vibrations may be produced by mechanical issues in the gear box, pinions, couple, motors, or even the rolls while running in idle. Such vibrations will cause speed deviations that makes the ASR react with torque spikes to avoid them.
- Speed sensor misalignment. - The speed sensor misalignment will cause the speed feedback to wobble. This may not be a real speed deviation, but the drive system will get it and react to avoid it.

Increasing the ASR bandwidth will make the drive system react faster against the deviations previously described. The torque spikes caused by the fast response may result on future mechanical issues on the drive system. The following graphs show the torque instability triggered by these kinds of issues:

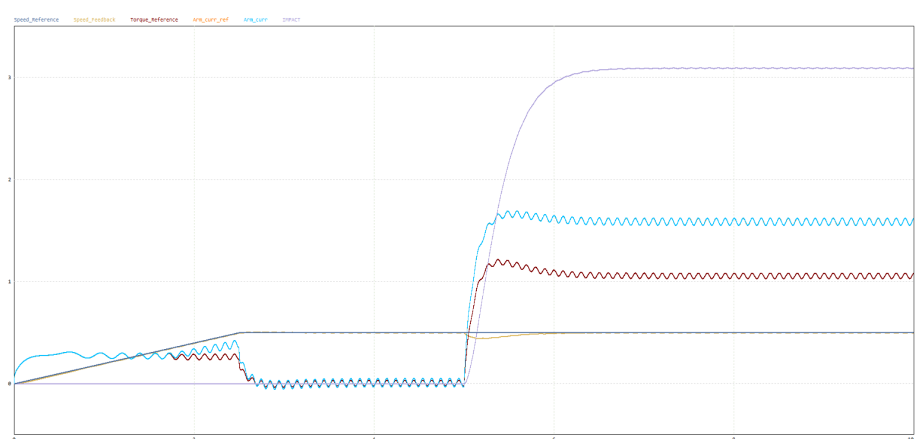

Fig. 2

Figure (2) shows a simulation of a motor accelerating with a speed regulator response of 5 rad/sec and 2.5 seconds later it has a disturbance like a material impact, similar to the ones suffered by hot rolling mills. Also, another disturbance is added as an oscillation of the speed feedback, simulating a misalignment of the speed sensor. This is low response for a mill with a low inertia. The torque oscillation is of +/-3.5%. But the dynamic response to the impact is above 3%sec. The picture shows that the speed drops 7% and it takes about 1 sec to stabilize again.

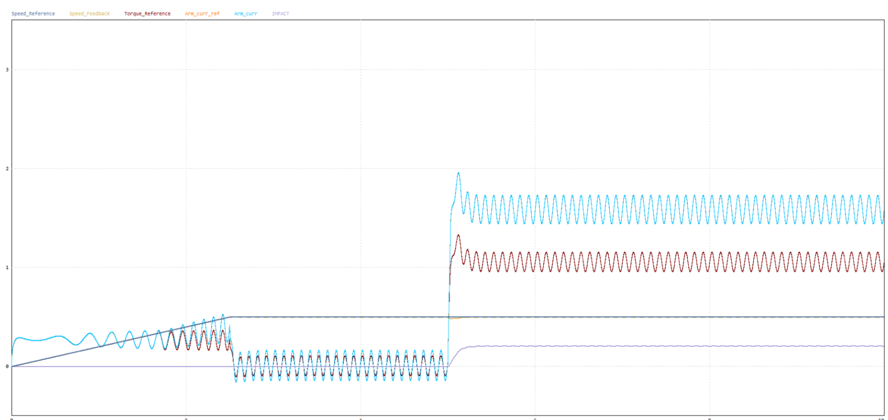

Fig. 3

Figure (3) shows a simulation of a motor accelerating with a speed regulator response of 20 rad/sec. The conditions for these simulations are the same as in Figure (2). Figure (3) shows a dynamic response of 0.2%sec, but the torque oscillation rises to +/-12% while running in idle.

Figure (3) shows a better response for the impact, but oscillation may cause further damage in the long term to the mechanical equipment. Figure (4) shows the same problem on a real mill.

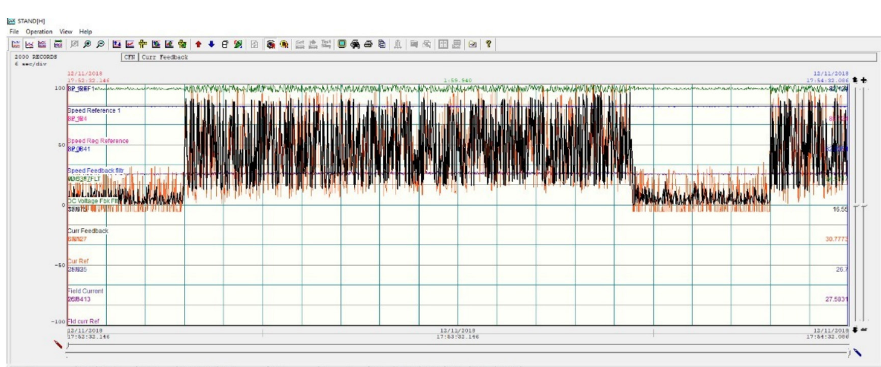

Fig. 4

Consequently, the problem to solve is how to get the required dynamic response to the impact caused by the metal, and at the same time reduce the torque spikes caused by the mechanical and speed sensor installation imperfections.

ANALYSIS

Problem Analysis and proposals

When mechanical problems exist and are not solved, the speed regulator response is key on the behavior of the mill. Vibration will cause speed error deviations and the drive will react to it. Reducing the response decreases the variation but reduces the dynamic response. To have a good dynamic response, it is common that the automation control systems of rolling mills use the lead speed method.

Lead speed is giving an extra speed reference to the rolling speed command while running in idle, and when the load increases, this extra speed is taken by the automation system. This way the speed reference goes back to the rolling speed. This is a common method in Hot Strip Mills, Long Product Mills, and in some Plate Mills. The response of the speed regulator is inversely proportional to the need of lead speed. In other words, the faster response, the lower need for lead speed, and vice versa.

The problem of using lead speed is detecting the real load and not capturing high torque situations caused by instabilities or increasing speed of the stand. A missed detection will cause the speed to drop late after the product impacted the stand, reducing the speed when the drive system already recovered. When this happens, the following issues may be encountered:

- Buckles between stand N and Stand N-1
- The head of the product will be rolling for a moment with an over speed
- Sudden speed drop after the material is inside the stand

Figure (5) shows a delay on the speed drop. If the speed recovers before the speed drop, it loses a lot of sense to use the lead speed method even though it still helps to decumulate material, but nothing else.

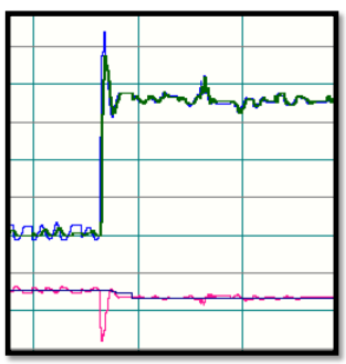

Fig. 5

Using feedforwards techniques

Using a feedforward means sending a signal to the actuator that will add to the regulator output. Usually, a feedforward is a theoretical reference according to the situation of the plant. Feedforwards signals helps the regulator's integrator to work efficiently, trying to keep it around zero, resulting on a faster response. Using Feedforwards methodologies has proven to be efficient and reliable for diverse kinds of control systems. In the strict case of the problems being analyzed in this paper, the feedforward acts as a torque signal that is added to the ASR.

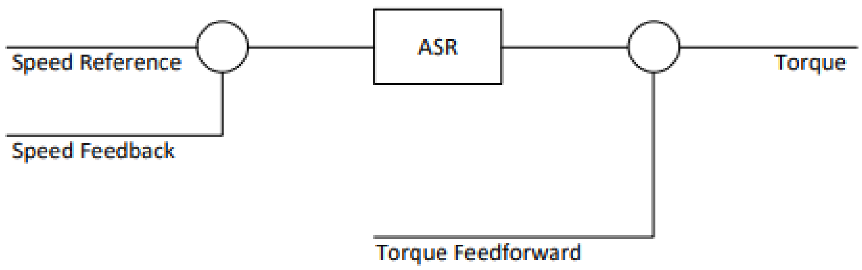

Fig. 6

Using load cell feedback

If the mill stand have a load cell to measure the force applied, then it is possible to use this information to create a feedforward signal. Knowing the force applied, using the roll radius, back and forward tension and other metallurgical and physical parameters, it is possible to calculate the theoretical torque that the motor should be subjected. This theoretical torque calculation can be sent to the drive system and then added to the output of the speed regulator. This way, the ASR should only correct for small speed deviation. Figure (7) shows a simplified control scheme for using the load cell feedback.

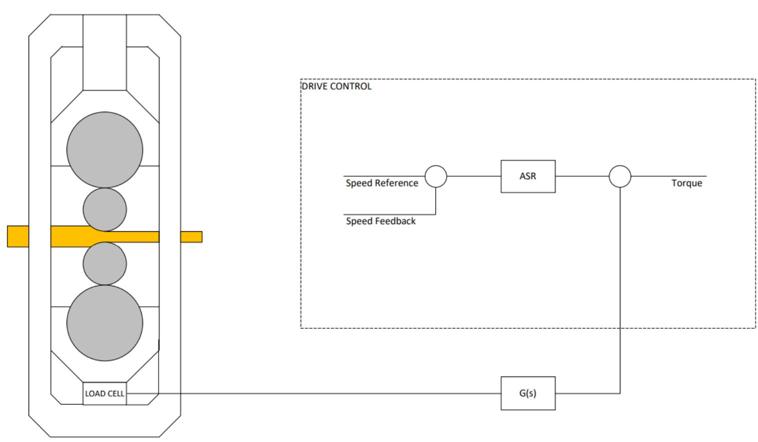

Fig. 7

Using drive internal drive information

Not every rolling mill works with load cells to measure the force applied. For instance, it is common that long product mills do not have this kind of instrumentation. Another way to calculate a feedforward is by calculating the theoretical torque reference by watching the speed regulator output and the speed feedback. The algorithm consists of an observer and the torque calculation. The observer will watch the speed regulator output and the speed feedback, and the torque calculator will use this information to calculate a feedforward signal. As an advantage it does not need the force or any other information coming from the mill stand. The theoretical torque is added to the speed regulator output as feedforward helping it to react faster to a disturbance. Figure (8) shows a simplified diagram of this solution.

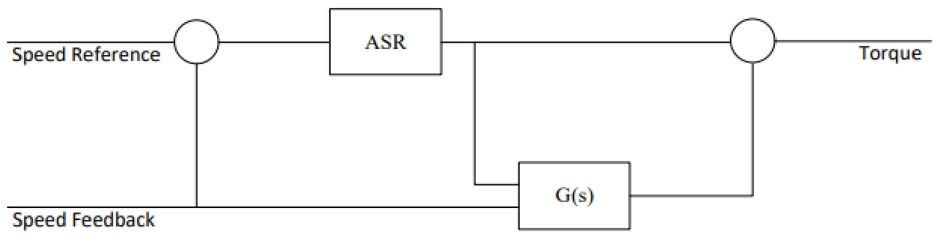

Fig. 8

Simulations

To explain this, refer to figure (9). The left image shows a simulation using only the speed regulator when the product impacts the stand. On the other hand, in the right picture the feedforward is used. The left image demonstrates how the speed regulator output takes full responsibility of the torque reference that the motor needs to maintain the speed, while the right image shows how the speed regulator output starts rising as well as the feedforward. Since both of them are adding, the speed regulator starts decreasing the output until both signals are balanced and the system is stable. In both cases, the speed regulator response is the same, but the right picture shows a much more aggressive dynamic response, resulting on a faster recovery of the impact.

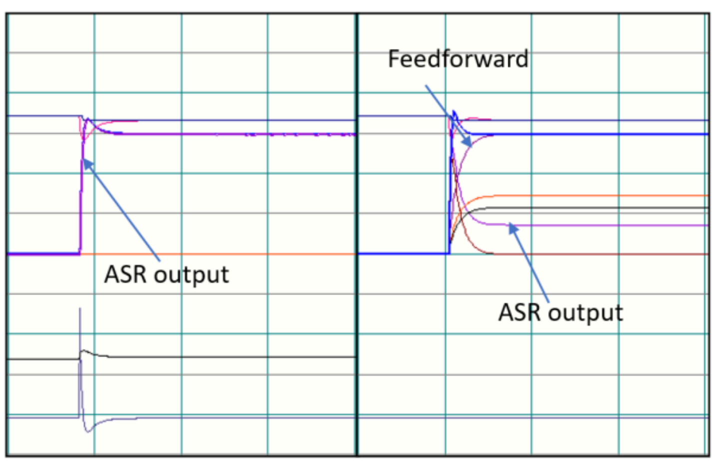

Fig. 9

For the next simulation, refer to the case described in figures (2) and (3). Both scenarios are subject to the same disturbance. In this new simulation, the case has the next characteristics: Speed regulator with a response of 5 rad/sec (the same as figure (2)) but using the feedforwards. The results are shown on figure (10).

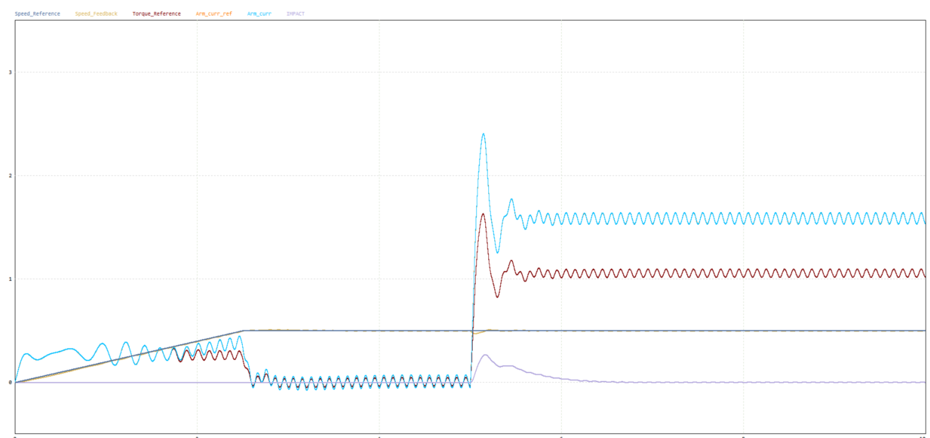

Fig. 10

The figure (10) shows a dynamic response of 0.25%sec and behaves much steadier compared to figure (3). This steady behavior while running in idle, reduces the potential future mechanical problems.

Response on the mill

The feedforward methodologies described on this paper have been tested on different rolling mills. The figures below show a real response on a rolling mill. The figure shows how the speed regulator output was reduced to stabilize the feedforward. Figure (11) shows a trend of a bar mill. The dynamic response is 0.23%sec, and no lead speed was used.

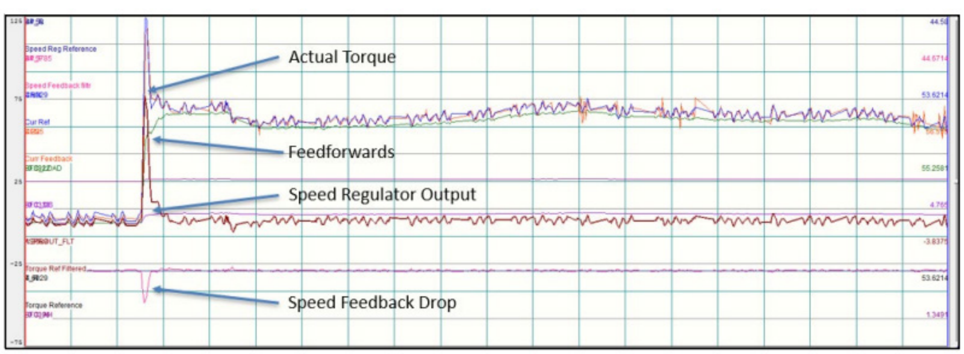

Fig. 11

Figure (12) shows the before (left) and after (right) implementing the feedforward configuration on a bar mill stand. In this case the stand suffered of instability while running in idle and while being loaded. The issue was a combination of the gearbox and the stand. After installing the feedforward, the system started working steadier. The torque reference is shown in figure (12). The speed regulator response of the drive was lowered to 5 rad/sec, which is commonly unacceptable, but with the feedforward, the dynamic response was below 0.3%sec. At the end, the operator did not need to add lead speed to this stand. The speed response is shown in figure (13).

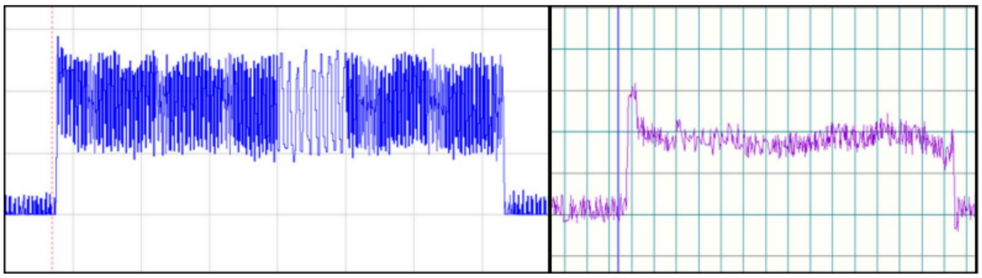

Fig. 12

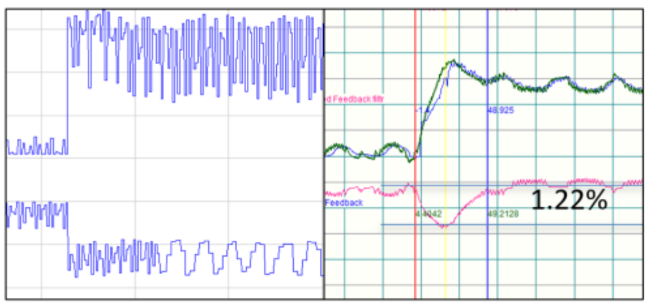

Fig. 13

Figure (14) and (15) shows the before and after on a large section mill, where it helps to keep the drive with positive torque while running in idle, helping the drive to avoid unnecessary current cross overs. The objective was accomplished, giving steadier behavior.

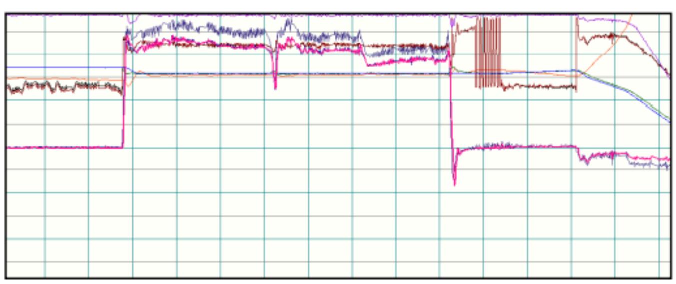

Fig. 14

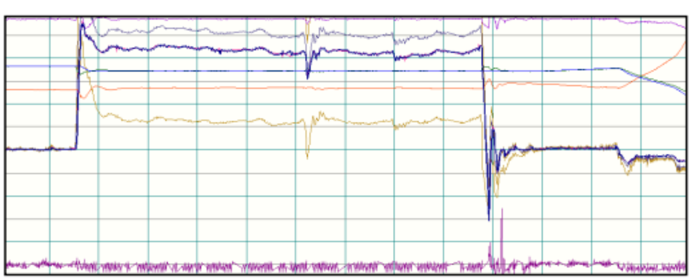

Fig. 15

CONCLUSIONS

Feedforwards methodologies have proven to be efficient and reliable for different industrial processes. In almost every control system of every part of the steel transformation chain, this methodology is used to achieve the quality of the product. Using feedforwards to help the drive systems behave steadier and react faster to any disturbances such as the ones on rolling mills when the product hits the stand is not the exception.

Without question, feedforwards result on a more efficient operation and a clear relief for any regulator of the control system. A good feedforward system may increase the response from 2 to 4 times of the system without increasing the regulator response. This way, for example, in the case of PI regulator, the proportional regulator will hit smoother for small deviations, and the integral gain will not be increased to values where instabilities may appear.

The results achieved in the rolling mills shows that it is possible to decrease the speed regulator response and still have an acceptable dynamic response to the impact caused by the material hitting the rolls. These results show a steadier behavior on the motor while running in idle, reducing the vibration on the gearbox, motor, and the stand. Less vibration means less risk of further damages, and at the same time a significant cost reduction in mechanical maintenance.

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