THE FORCE FEED FORWARD TECHNOLOGY

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The Force Feed Forward Technology
Background Information
In simple terms, a Hot Strip Mill (HSM) takes a cold slab of steel and converts it into a coil of sheet steel. The steel slabs are loaded cold into the reheat furnace at a thickness of 150 to 250 mm. Then, reduced to a coil thickness between 0.8 to 16 mm through rolling. Steel width varies according to customer demand, in general it is between 500 – 3000 mm wide. The drop out temperature of the steel from the reheat furnace is about 1200 C and the Downcoiler temperature is about 700 C. The thinner the steel gets, the harder it becomes to roll and the faster it loses temperature.

The hot strip mill is one of the more expensive processes in producing steel; in capital cost US$300-500 million for a new HSM. The yearly operational and maintenance cost of a HSM varies and differs from one mill to the other, generally, it is in the US$40-90 million depending on country and many other factors. Therefore, there is lots of efforts and technologies developed for the HSM to reduce operational and maintenance cost and improve productivity.

The product of the Hot Strip Mill is either sold as is or processed by other downstream processes. Examples are the pickling lines to clean the surface, coating lines or galvanizing, using a tempering mill to change mechanical characteristics and cold mills to reduce thickness further and change the mechanical properties.
The finishing Mill in a HSM is complicated, there are usually 5-7 of such mills in a Hot Strip Mill. The objective of the Finishing Mills is to reduce the steel from ~30 mm thickness to the final product thickness and to give its final shape and profile.

There are four rolls, the two driven Work Rolls and the two Backup Rolls that are free rotating. The gap between the two Work Rolls is set by electro-mechanical screwdowns or hydraulic cylinders or a combination of both. Most mills were built before the 1980's and have electro-mechanical screwdowns when they were built.

The problem with Electro-Mechanical screwdowns is that they use motor rotation that goes through gearing to convert that into vertical movement of the screw.
A conventional AGC system uses the force changes to indicate hardness or temperature changes in the steel. This signal is used to calculate how much of that force resulted in changes to the Finishing Mill stand stretch. That stretch is then applied to the screwdown motor to apply a gap position that will produce the desired thickness of steel out of that stand. This is a good system if you can have a fast reaction speed.

However, with the mechanical and electrical limitations of the screwdown system, response time would result in some delay time to set the gap at the proper position when a disturbance occurs.

A characteristic of the Hot Strip Mill rolling is that Rolls are not perfectly round, they have eccentricity in them after roll grinding. This would show as force changes to the Control system. The conventional AGC would react, thinking it is Temperature variations from the steel, to actually impress these changes in the steel.
The temperature variation is characteristic of all Hot Strip Mills due to Reheat Furnace skids. As the steel goes through from the input side of the furnace to the exit side of the furnace, it is put on skids in the furnace that are internally cooled which result in cooling of that area of the steel. There are usually 4-8 skids in each furnace.

With a Feedback System, the screw reaction is late resulting in some of the disturbances passing through the mill without correction.

The solution is to replace the electro-mechanical screwdowns with Hydraulic cylinders which are much faster to react. A feed forward system is another alternative only if tracking is done right. The Force Feed forward system fills is designed to fill that need.
The Force Feed Forward Gauge Control System for hot strip mills is a unique method of gauge control.

- Easy retrofit into Electric Screwdown and Hydraulic Actuators mills.
- The low cost, short non-disruptive installation make it an attractive alternative to other AGC upgrade projects.
- FFF System has been in operation in six hot strip mills in North and South America.
- Results in superior gauge performance.

The Force Feed Forward System is unique among the other Automatic Gauge Control System in that it is completely an anticipatory system. It depends on modeling of the physical characteristics of steel to predict what will happen based on simple inputs such as the first stand Force signal, thickness reductions in the mill, each stand feedback speed, actual gap position and a few others.

The system is fitted into Hot Strip Mills easily since it requires no mechanical / electrical changes in the mill. So the system can be installed while a mill is running in normal production.

The system has been proven in various old, new, big and small hot strip mills. In fact there are six mills around the world where FFF has been installed and we aim to add to that list.
There are six installations of The FFF system. The latest was just commissioned early this year in Iscor Vanderbijlpark. The results were extraordinary for these mills as Gauge Performance and mill stability improved dramatically.
Technical Description

- Force Feed Forward is a computerized Gauge Control system.
- Steel is sampled in F1 and divided into bits of 1/20th of a second.
- Each bit is tracked as it goes through each finishing stand.
- Control decisions are fed forward.
- Force Feed Forward System is completely predictive it has the ability to dictate the exact time of control output allowing proper compensation.

The FFF System is first and foremost a computer system. Because of the complicated nature of the models that are required, a reliable and fast processor runs the FFF system. Currently the FFF system runs in Compaq Alpha Computer under OpenVMS Operating system.

The FFF system samples the load cell of the first finishing stand 20 times per second, creating a force profile of the steel. Each bit of steel is tracked as it passes through the rest of the finishing stands.

Input conditions of the steel, the finishing mills and the force profile are fed into the FFF models to produce control decision that are fed forward anticipating when that a specific bit of steel requires the screw position change to produce the proper gauge.
One of the most difficult tasks in developing the FFF System was tracking steel as it passes through the finishing stands. Each stand has a different speed to compensate for the thickness reduction, further the overall speed of the stands increases as time passes to keep the steel bar entry temp nearly constant. Further, changes in screw positions results in changes in mass flow of steel which means speed changes.
The FFF AGC system works on the principal of mapping the steel force profile from the first finishing stand or F1 and getting other inputs fed into the FFF models in the Alpha Computer. Decisions on what to do at each screwdown motor are delivered to the controller of each stand in advance to accommodate for response time. The FFF does not move F1 screws to be able get the true Force map from that stand. Also, the FFF system changes the each stand speed because changes in screwdown position results in changes in the steel of the speed and delivers the changes to the controller in advance.

Up to the exit of the last finishing stand, the FFF has no real feedback on how good it performed. Therefore, a feedback loop exists indicating to the FFF the actual thickness deviation of the steel from the aim gauge. The FFF feeds back that signal to the last two stands if necessary to adjust the its feed forward predictions.

A second feedback loop exist from the Finishing Temperature measurement. The FFF makes predictions on the temperature and then compares that to the actual Finishing Temperature. The changes drive long term learning changes.
The FFF System comprises of different levels of control, Level 2, the highest is the most intelligent level where all the FFF models reside. This is basically the Online and Backup Alpha Computers.

The next level of control is the PLC which interfaces to existing mill controllers to do the I/O between the Alpha Computers and Level 0 which is all the sensors and electrical motors in the field.
FFF Installation & Maintenance
Typically, the FFF would not require any Level 0 changes. However, in some cases, the mill existing Level 0 sensors are inadequate for Advanced AGC control. For example, the sensor that measures the gap position has to have a certain accuracy and free of backlash. In some installations of the FFF, Hatch engineered and installed an LVDT to measure the screw position accurately instead of using the existing rotary encoders which were driven through various gearings and shafts.
Level 1 installation is again dependent on the Hot Strip Mill existing control equipment. Hatch has installed PLCs from various control vendors. In one of the FFF installations, there was a need to install a remote I/O. The connections between the remote I/O and the PLC was done via fiber optic cable.

The communication between the PLC and the Alpha computers is varies in each installation. Lately the trend is to use TCP/IP Ethernet or Ethernet/IP.

What is worthy of mention is that the FFF system can be enabled or disabled by a turn of a switch from the operators desk. This is very useful during commissioning when debugging the system and the IO.
Level 2 Installation

- Simulated control for data gathering is done in a “shadowing” mode, with actual control still by the old system.
- The Force Feed Forward System then systematically takes over control of selected coils.
- A gradual assumption of control of the entire product range is accomplished smoothly.

Level 2 installation is common to all FFF systems being a VAX (in the old days) or an Alpha Computer that runs the FFF models.

In the early days of commissioning, the FFF system is installed in the mill in shadowing mode; getting data from the mill sensors and producing control decisions without actually being connected to the outputs.

Gradually, different modules of the FFF are turned ON until control of the whole Finishing Mills AGC is done by the FFF. This is done in the order of 2-4 weeks after completing the equipment installation.
The three components of Level 2 are the PC’s, the two Alpha Computers and the Network Hubs.

The PC’s act as an interface to the Alpha’s to display the various FFF menus monitoring the system and reporting on system performance.
Maintenance

- The Force Feed Forward is maintenance free, Models are not driven by product dependent sets of gain or compensation tables.
- The Force Feed Forward equations, models, and algorithms are complete and permanent descriptions of the physical properties of steel and its behaviour during hot rolling.
- System performance therefore continues at extremely high levels without intervention by technicians or engineers.
- The adaptive subsystems employed automatically keep pace with drifting mill conditions, sensors, equipment, etc.

Since the FFF models represent the true physical behaviour of steel and the mill, the FFF Level 2 is maintenance free once it is tuned for the specific Hot Strip Mill.

The FFF system performance does not deteriorate with time as with many other AGC since it does not depend on lookup tables or fixed sets of gains. The problem with that is that mill conditions change according to tens of variables. There are adaptive learning modules in the FFF which drive a number of tuning variables to change according to drifting mill conditions. Examples include variation of cooling water flow would generate variations from the predicted finishing temperature to the actual finishing temperature. This will drive some factors to change to compensate for that change in cooling water.

The Level 1 and Level 0 require the usual maintenance to replace any defective sensors or PLC IO cards.
FFF Performance
Performance

- In actual operations, gauge performance in the range of 97 - 99% within 1/4 ASTM A568M standards.
- Mill stability has been improved due to less required mill speed corrections.
- Steel width control has been improved due to less sudden mill speed variations.
- Improved Head End Gauge.
- Improved Tail End Gauge.

The FFF system performance has produced excellent results in the various installations;

The Steel Thickness deviation has been in the range of 97-99% within the 1/4 ASTM tolerance which exceed all customer requirements for tolerances. In the later FFF installations, the 1/8 ASTM performance is also very good ~ 90%.

On top of that, since the FFF puts out mill speed corrections to its screwdown movements, which means a more stable mill. This would mean also that width variations due to sudden speed changes is reduced.

Finally, head end and tail end gauge performance is improved because of the specific modules within the FFF system for correcting head end and tail ends.
The ASTM standard for Carbon Steels and High-Strength-Low-Alloy Steels (HSLA). There are another standard which is used to measure thicker coils specifically ASTM A635M.

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<thead>
<tr>
<th>Width Range (mm)</th>
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<th>ASTM A568M - Carbon Steel</th>
<th>ASTM A568M - HSLA</th>
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<tbody>
<tr>
<td></td>
<td>&lt; 2.00</td>
<td>2.00-2.50</td>
<td>2.50-4.50</td>
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<td></td>
<td>±1/4 ASTM</td>
<td>±1/4 ASTM</td>
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<td>300 - 600</td>
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<td>&gt; 1800</td>
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<tr>
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This is a sample of how the FFF handles skid marks. Although there were temperature variations of up to 50 C, there were very little effect on the thickness deviation.
One of the features of the FFF is that it redistribute the load of the mill stands so that the later stands do less work. This is desired to produce less force variations which means better shape and profile of the steel.
THANK YOU
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