Hair’s-Breadth Precision
Tension Control for Ultra-Thin Aluminium Strip

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In 2005 South America Aluminium producer Companhia Brasileira de Aluminio (CBA), located in Aluminio, Sao Paulo, put in train plans to extend its aluminium foil production capacity. The seven foil lines already operating were to be joined by Foil Mill No 8 and, when that was producing successfully, Mill No 9 would be established using the same design and technologies.

Today both mills are in operation and capable of producing foils down to a 5.5 \( \mu \)m thick – around one-twentieth of the thickness of a human hair – at production speeds of 2,000m/min, or equivalent to 120km/h. Rolling material like this places enormous demands on controls in terms of tension and speed, as well as precise fine-tuning of automation and drive systems. When Mill No 8 went into operation in April 2006 it was the fastest running AC-driven foil mill in the world. In July 2008 Mill No 9 began production. (See table 1).

In reducing mills, position control of the hydraulic screw is employed to increase the roll force to reduce material thickness to 0.1mm (100 \( \mu \)m). For foil rolling, however, especially below < 40 \( \mu \)m, increasing the roll force would not effect any change in material thickness.

Table 1: Foil mills 8 and 9 data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Foil Mill No 8</th>
<th>Foil Mill No 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum strip width</td>
<td>2,150mm</td>
<td>2,150mm</td>
</tr>
<tr>
<td>Max/min strip input thickness</td>
<td>0.6/2 x 0.01mm</td>
<td>2 x 5.5( \mu )m (1( \mu )m = 1 x 10^-6 metres)</td>
</tr>
<tr>
<td>Minimum strip output thickness</td>
<td>2 x 5.5( \mu )m</td>
<td>2,000mm</td>
</tr>
<tr>
<td>Maximum coil diameter</td>
<td>2,000mm</td>
<td></td>
</tr>
<tr>
<td>Min/max strip entry tensions</td>
<td>0.6/18kN</td>
<td>0.4/12kN</td>
</tr>
<tr>
<td>Min/max strip exit tensions</td>
<td>0.4/12kN</td>
<td></td>
</tr>
<tr>
<td>Maximum strip speed</td>
<td>2,000m/min</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: System configuration and technologies

Process Technologies Controller
- Reference Generation Drives
- Collier, Rollto, Mill-Drive Control
- Evaluation of losses
- Calculation of inertia
- Diameter calculations (Layer/Speed)
- Exact Calculation of AutoSlow Down
- Reference for speeds and torques
- Torque additions div/fid
- Fast optical links to Drives and DDA
- Programming according IEC 61131-3
- One Controller for Technology and Process

Main Drives Technology
- DTC® (Direct Torque Control) for high precision
- DC Busbar for Energy Savings
- Optical connections to controller and tools
- Maintenance/Analyzing Tool "Drive Windows"
- Standard Drive Concept for easy maintenance
because under high pressure the work rolls in relation to the thickness to be rolled are almost “flat”. Even when rolling 5.5 \(\mu\)m-thick material, it is necessary to double it (2 x 5.5 \(\mu\)m) to achieve sufficient thickness and tension values. Usually roll force is kept constant and by varying rolling speed and strip tension parameters alone is it possible to achieve additional reduction to the material (speed-tension-control).

In order to achieve high production rates, as foil coils have long rolling times, it is essential to have a maximal rolling speed applying the lowest tension possible. This is achieved by means of speed-tension optimisation.

Using automatic tension control

Depending on material and process parameters like rolling oil consistency and quantity, roll surface, etc, strip reduction occurs at the moment rolling speed reaches around 100-200m/min. It is vitally important at that point that speed and tension are controlled to ensure strip tension is not lost.

The automatic-gauge control’s reference values are almost constant and the drive has to react to all changes in the process with its own control algorithm. This is more demanding during the acceleration phase. To achieve highly sensitive tension control, and thus consistent thickness, it is necessary to deal in microns and in fractions of kN, not seen in reduction mills. (See Table 2 comparison.)

The ratio of losses to minimum tensions shows that precise tension control is essential. This must be complemented by a sensitive and fast-reacting drive system, as well as a precise computing of values by the integral automation system. The latter employs sophisticated software to fine tune process parameters like friction and loss compensation.

State of the art low voltage AC drives

While in the past foil mill drive systems have been based on DC technology because they lent themselves more readily to accurate speed and tension control, more recently there has been a move towards AC, as used in CBA Mills 1 to 7. AC technology has continued to evolve and ABB’s design for the new foil mills is based on state of the art low voltage AC drives and direct torque control (DTC). This offers equal or better control performance than DC technology, while reducing the maintenance burden. (See Table 3.)

AC-drive main motors combine ACS800 technology with IGBTs (insulated gate bipolar transistors) in a multi-drive configuration and are all on the same DC bus. This saves not only power on the incoming unit but also requires a smaller power feeding transformer. By using IGBTs in the incoming supply it is possible to run the system in a regenerative mode so that braking energy becomes available to the network. In the case of a network power failure emergency resistor-braking is possible to slow down the drives and avoid tons of material being wasted. (See Table 3.)

The ACS800 technology solution includes the most modern direct torque controlled AC drive and uses actual data to improve efficiency and control. The ACS800 technology offers better control performance than DC technology, while reducing the maintenance burden.
The so-called filling factor, the addition to the diameter of a number of layers (factor < 1). A further fine tuning was necessary for the coil diameter calculation; at a certain speed diameter calculation is switched over from layer counter to speed comparison. It is especially important to check both values for plausibility during acceleration. To ensure reliable diameter calculation for the auto slow down function, additional diameter measurement performed by a laser is taken into account.

A chart recorder display showing a part of the acceleration phase from 20-1,200m/min with reduction of foil material from 2 x 18 to 2 x 9 micron gives some idea of the system’s precision. Even during mill acceleration, as soon as the material begins to reduce, the coiler has to speed up to maintain strip tension. The ratio of the losses plus torque dv/dt compared to tension torque demand is only 1:1.27, ie, almost same compensation as tension torque has to be applied.

To maintain an efficiently optimised system it is desirable for friction curves, inertias and parameters to be checked periodically so that process deviations over time can be incorporated. The user friendly interactive graphic windows in the program and application-related HSI screens support the operator in the task of maintaining a fine adjustment of the plant.

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### Table 3: Main drives data

<table>
<thead>
<tr>
<th>Machine</th>
<th>Power (kW)</th>
<th>Max speed (rpm)</th>
<th>Arrangement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncoller</td>
<td>2 x 250</td>
<td>1,212</td>
<td>Clutch between motors</td>
</tr>
<tr>
<td>Mill stand</td>
<td>2 x 1,000</td>
<td>1,318</td>
<td>Fixed coupling</td>
</tr>
<tr>
<td>Upcoler</td>
<td>2 x 250</td>
<td>1,212</td>
<td>Clutch between motors</td>
</tr>
</tbody>
</table>

### Compensation for mechanical losses

The next step was to calculate exactly the compensation needed to counteract static mechanical losses, ie friction, caused by the entire drive train over the total speed range. (This also affects the rolling oil being used.) Drive train friction losses and motor torque/speed curve parameters reside in the program database to enable computing time to be optimised. Various motor configurations have been considered – for example, a one or two motor arrangement, or wide or narrow spools – as they result in different loss measurements. Exact measurement of the total inertia of a mechanical arrangement to determine additional torque during acceleration phases was performed prior to first strip being rolled.

Adjustments were carried out to establish the correct value for the appropriate motor values, based on a very fast motor software model. It calculates new drive set-ups every 25 micro-seconds and reacts immediately to process demands. A high-end type AC800PEC controller is used for the computing of the set point values.

The real-time software runs the programming languages IEC61131. Software performs all the compensation and calculations necessary for the precise control of tension and speed, and this is communicated to the drive using fibre-optics.

Prior to the measurement of losses all motors are given an identification run to enable the software motor model to be fine tuned. Optimisation of the drive parameters is achieved using the motors fast reversing modes to determine the special amplifying factors that are vital when starting the mill up and during acceleration phases.