ALGORITHMS FOR SPEED AND STRETCH CONTROL
OF THE MAIN DRIVES OF A STRETCH-REDUCING
TUBE MILL

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Key words: Speed and stretch control, Stretch-reducing tube mill (SRM).

This paper shows the drive solution, the speed references calculation and the automatic control of all speeds range for the assembly of the 24 stands belonging to a stretch-reducing mill for seamless pipes. The correlation between the speed control and the stretching control of the rolled pipe is also shown. The experimental results are real data associated to the most recent project that has been executed at a seamless pipe plant in Poland and China.

1. INTRODUCTION

The concept of common drives of the stands of a Stretch-Reducing Tube Mill (SRM) using distribution and differential gear-boxes represents a flexibility limitation of the performances of the mill but using it we can sensibly reduce the costs of the drives [1, 2]. Therefore, when we are designing rolling mills of this type, we have to study carefully the necessity and the utility of choosing individual drives for each stand or common drives [3].

If we are using a common reducer driven using main and overlapping drives the rotating speed ratios are changing simultaneously at all stands by control of the rotating speed at both (or one of the two) motors and maintaining the ratios for the rotating speeds of the rolling stands as been established by designing of the gears. Thus, in this drive system we can change only the speed average or the stretching average, but not the distribution of the deformation values in the individual sequence of the stands [4, 5].

If we may give up the advantages of the individual speed control on the pipe deformation and if we except a larger slipping between the rolls and the rolled material (a current status at easier rolling programs) we could accept a common drive with distribution and differential gears [6 – 8].

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2. ELECTROMECHANICAL DRIVE SOLUTION

2.1. SPEED CONTROL

The 4-motor drive consists of two drive groups which are mechanically separated from one another and, therefore, allow effective Crop End Control (CEC) even with close sequences of tubes. For this purpose, the entry mill stand group features exceptionally high gear ratios to obtain particularly large elongations (Fig. 1). The roll speeds for stand position \( i \) are calculated as, in the entry side drive group.

\[
\text{Roll speed}(i) = \frac{grbm(i) \cdot isbm_1}{grbm_1} + \frac{grdm(i) \cdot isdm_1}{grdm_1}, \tag{1}
\]

and with respect to the drive group on the run-out side:

\[
\text{Roll speed}(i) = \frac{grbm(i) \cdot isbm_2}{grbm_2} + \frac{grdm(i) \cdot isdm_2}{grdm_2}. \tag{2}
\]
The basis speed curve is characterized by high gear ratios in the entry drive group to enable positive differential gear action also in this area, i.e. identical direction of rotation of both basic and differential drives.

During the steady-state phase of the rolling process, the basic drives of this system run at identical speeds while the differential drive units operate at exactly synchronized speeds. The speeds are related by the following term:

\[
\frac{isdm_1}{grbm_1} = cm \ast \frac{isbm_2}{grbm_2} + cd \ast \frac{isdm_2}{grdm_2},
\]

\[
\frac{isbm_1}{grbm_1} = icf \ast \frac{isbm_2}{grbm_2},
\]

whereby \(cm\) and \(cd\) are constants. The motors are synchronized automatically in the basic automation system.

### 2.2. STRETCH CONTROL

The motor speeds at changes in elongation are calculated with the rotational speed values resulting from the calculation of the changes in speed. This method ensures that the operator can effect a change in elongation by means of a change in speed, if necessary, if motor speed limits are reached with no change in speed. One input value \(ref\) – reference elongation factor – is used for this purpose.

- **Input range:** \(-100 \ldots +100\%\)
- **Standard:** \(0\%\) (in rolling program)
- **Calculation:** Conversion of the input value \(ref\).

The elongation factor covers a specific range of values depending on the product mix of the mill and on the calibration of the mill i.e. on the number of the active stands involved in the rolling process.

On theoretical and experimental basis a linear dependence of \(ef_{\text{max}}\) and the number of stands of the SRM has been defined with \(ef_{\text{max}}\) as internal limiting value, e.g. 20% in the actual project.

\[
ref = 1 + \frac{ef}{100} \ast \frac{ef_{\text{max}}}{100}.
\]

The following calculation results in a “pivoting” of the speed diagram with the pivot point \(pps\) (Fig. 2). One stand position is defined as the pivot point:

\[pps = pis.\]

From practical reasons the pivoting stand has to be the last stand belonging to the First drive group or the first stand of the second drive group (in our case stand 8 or stand 9).
This has the effect that the entry speed and thus the throughput of material remain more or less constant.

Each gearbox is assigned to one motor. A characteristic value which is determined together with the rolling program, determines the gear stage (0 or 1). The corresponding gear ratios are indicated in the Table 1.

Further calculation of new motor speeds: \( grbm_1 = 1 \) or gear ratio of the switching step chosen. The same is to be applied for \( grbm_2, grdm_1 \) and \( grdm_2 \).

<table>
<thead>
<tr>
<th>Gear stage</th>
<th>( grbm_1 )</th>
<th>( grdm_1 )</th>
<th>( grbm_2 )</th>
<th>( grdm_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

If only the stand group on the inlet side is occupied by roll stands and the drives on the run out side are not used to drive guide stands etc. the following applies:

\[
isbm_2 = \frac{ismm_1}{grbm_1} \times grbm_2, \ \text{and} \ \ cm = 0, \ \ cd = 1.
\] (6)
Final calculation of new motor speed:

\[
\text{osdm}_1 = \frac{vx}{\text{grbmdm}_1} + \frac{\text{isdm}_1}{\text{grdm}_1} + \text{my} \times \text{cf} \times \text{grdm} \times (\text{pis}) - w \times \text{cf} \times \text{grdm} \times (\text{pf}) \times \text{grdm}_1.
\]  

(7)

\[
\text{osbm}_1 = \frac{\text{grmb}_1}{\text{grbm}_1} + \frac{\text{isdm}_1 - \text{osdm}_1}{\text{grdm}_1} \times \text{grbmdm}_1.
\]  

(8)

\[
\text{osdm}_2 = \frac{w \times \text{osdm}_1}{\text{grdm}_1 - z \times \text{osbm}_1} / \text{grbm}_1 / \text{cf},
\]  

(9)

\[
\text{osbm}_2 = \frac{\text{osbm}_1}{\text{grbm}_1 / \text{cf} \times \text{grbm}_1}.
\]  

(10)

Accordingly:

\[
\text{osbm}_1 = \frac{\text{osbm}_2}{\text{grbm}_2 / \text{cf} \times \text{grbm}_1}.
\]  

(11)

After every calculation of a motor speed, limit values are checked and corrected accordingly.

The change in inlet and outlet speed can be calculated with the basic equation:

\[
is = g \times aj + ios,
\]  

(12)

with:

- \(is\) – inlet or outlet speed after change in elongation [m/s];
- \(g\) – gradient relationship of inlet or outlet speed [(m/s)/%] (in Rolling program);
- \(aj\) – adjusted input value P [%];
- \(os\) – inlet or outlet speed at default settings of the motors [m/s].

Fig. 3 shows the complete range of speeds for the stretch-reducing mill stands and the allowed range to be adjusted manually by the operator if required.
If only the stand group on the inlet side is occupied by roll stands and the drives on the run-out side are not used to drive guide stands, the following applies:
\[ osdm_2 = 0, osbm_2 = 0. \]

### 3. MEANING OF SYMBOLS FOR SPEED AND STRETCH CONTROL

<table>
<thead>
<tr>
<th>Field</th>
<th>Symbol</th>
<th>Measuring Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td>( cd )</td>
<td>constant</td>
<td>Value determined when drawing up the rolling program.</td>
</tr>
<tr>
<td></td>
<td>( cm )</td>
<td>constant</td>
<td>Value determined when drawing up the rolling program.</td>
</tr>
<tr>
<td></td>
<td>( vx )</td>
<td>real</td>
<td>Value determined when drawing up the rolling program.</td>
</tr>
<tr>
<td></td>
<td>( pps )</td>
<td>integer</td>
<td>Position number of the pivot stand</td>
</tr>
<tr>
<td></td>
<td>( pis )</td>
<td>integer</td>
<td>Position number of the initial pass stand</td>
</tr>
<tr>
<td></td>
<td>( pfs )</td>
<td>integer</td>
<td>Position number of the final stand</td>
</tr>
<tr>
<td></td>
<td>( grbm_1 )</td>
<td>real</td>
<td>Gear ratio of basic drive motor 1</td>
</tr>
<tr>
<td></td>
<td>( grbm_2 )</td>
<td>real</td>
<td>Gear ratio of basic drive motor 2</td>
</tr>
<tr>
<td></td>
<td>( grdm_1 )</td>
<td>real</td>
<td>Gear ratio of differential drive motor 1</td>
</tr>
<tr>
<td></td>
<td>( grdm_2 )</td>
<td>real</td>
<td>Gear ratio of differential drive motor 2</td>
</tr>
<tr>
<td></td>
<td>( grbm(i) )</td>
<td>real</td>
<td>Gear ratio at stand position “( i )” of the basic drive</td>
</tr>
<tr>
<td></td>
<td>( grdm(i) )</td>
<td>real</td>
<td>Gear ratio at stand position “( i )” of the differential drive</td>
</tr>
<tr>
<td></td>
<td>( cf )</td>
<td>constant</td>
<td>Correction factor with unequal speed ranges of the basic motors ( cf = \frac{issm_1/grbm_1}{issm_2/grbm_2} )</td>
</tr>
<tr>
<td>2.1</td>
<td>( isbm_1 )</td>
<td>rpm</td>
<td>Speed of the basic motor 1 of the inlet side drive group</td>
</tr>
<tr>
<td></td>
<td>( isbm_2 )</td>
<td>rpm</td>
<td>Speed of the basic motor 2 of the outlet side drive group</td>
</tr>
<tr>
<td></td>
<td>( isdm_1 )</td>
<td>rpm</td>
<td>Speed of the differential motor 1 of the inlet side drive group</td>
</tr>
<tr>
<td></td>
<td>( isdm_2 )</td>
<td>rpm</td>
<td>Speed of the differential motor 2 of the outlet side drive group</td>
</tr>
<tr>
<td>2.5</td>
<td>( ref )</td>
<td>%</td>
<td>Reference elongation factor depending on the number of equipped stands on the SRM</td>
</tr>
<tr>
<td>Outputs</td>
<td>( osbm_1 )</td>
<td>rpm</td>
<td>Speed of the basic motor 1 of the inlet side drive group</td>
</tr>
<tr>
<td></td>
<td>( osbm_2 )</td>
<td>rpm</td>
<td>Speed of the basic motor 2 of the outlet side drive group</td>
</tr>
<tr>
<td></td>
<td>( osdm_1 )</td>
<td>rpm</td>
<td>Speed of the differential motor 1 of the inlet side drive group</td>
</tr>
<tr>
<td></td>
<td>( osdm_2 )</td>
<td>rpm</td>
<td>Speed of the differential motor 2 of the outlet side drive group</td>
</tr>
<tr>
<td>Calculation symbols</td>
<td>( w )</td>
<td>real</td>
<td>1/cm</td>
</tr>
<tr>
<td></td>
<td>( z )</td>
<td>real</td>
<td>cd/cm</td>
</tr>
<tr>
<td></td>
<td>( zgrbm )</td>
<td>real</td>
<td>( z*grdm(pfs) )</td>
</tr>
<tr>
<td></td>
<td>( grbm(pfs) )</td>
<td></td>
<td>grbm(pfs)</td>
</tr>
<tr>
<td></td>
<td>( y )</td>
<td>real</td>
<td>( y=(isbm2/grbm2<em>grbm(pfs)+isdm2/grdm2</em>grdm(pfs))/(isbm1/grbm1<em>grbm(pis)+isdm1/grdm1</em>grdm(pis)) )</td>
</tr>
<tr>
<td></td>
<td>( my )</td>
<td>real</td>
<td>( max(x*ref,1) )</td>
</tr>
</tbody>
</table>
4. EXPERIMENTAL RESULTS

Experimentals results from SRM Hengyang–China and Huta-Andrzej–Poland are shown in Table 2 and Figs. 4, 5 and 6. The calculated speeds and stretches have been confirmed in practice as the experimental diagrams (Fig. 4 and 5) are confirming.

Table 2

<table>
<thead>
<tr>
<th>Motor Speeds (rpm)</th>
<th>MD1</th>
<th>DD1</th>
<th>MD2</th>
<th>DD2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>970.74</td>
<td>503.42</td>
<td>970.74</td>
<td>913.10</td>
</tr>
<tr>
<td>ref = 100%</td>
<td>1076.64</td>
<td>473.76</td>
<td>1142.83</td>
<td>683.37</td>
</tr>
<tr>
<td>ref = -100%</td>
<td>864.83</td>
<td>533.07</td>
<td>864.83</td>
<td>683.37</td>
</tr>
<tr>
<td>Inlet and Outlet Tube Speeds [m/s]</td>
<td>Inlet</td>
<td>Outlet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nominal</td>
<td>1.13</td>
<td>7.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ref = 100%</td>
<td>1.16</td>
<td>8.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ref = -100%</td>
<td>1.10</td>
<td>5.89</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4 – Speed diagram SRM Heng Yang.

Fig. 5 – HMI speed diagram mask SRM Huta Andrzej.
5. CONCLUSIONS

Calculating with the required accuracy of the stand’s speeds and defining the range of speed regulation for the stretch-reducing mill stands allows important achievements on the quality of the seamless tubes manufactured on the mill and also an important increase of the output of the mill.

The Crop End Control which has as result an increase of productivity of about 3%, the Average and Local Wall-thickness Control which improves the quality of the tubes are based on this calculations and control.

The calculation of the speeds according to the algorithm described in this paper and the control system for the main drive speeds have been tested successfully first on the Stretch-reducing Mill of the BENTELER C-ny in Paderborn – Germany in 1998. Based on this experience this solution was applied in other 6 seamless tube mills in NOVA HUT – Czech Republic –1999; HUTA ANDRZEJ- Poland –2000; TUBOS REUNIDOS – Spain – 2001, TAGMET - Russia - 2002; HENGYANG – China and again TUBOS REUNIDOS – Spain in 2006 in projects developed under coordination of the SMS-MEER Company from Germany.

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REFERENCES


