Process Optimization for Hot Strip Mill*

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Synopsis
In order to search for suitable technological schedule of hot strip mill, there is proposed an economo-mathematical model, in which production cost is a function of technological parameters such as threading speed, thickness of transfer bar and extract temperature from reheating furnace. The optimization of these parameters is performed to produce high quality strip with minimum production cost. The optimization code was applied for a hot strip mill in Bulgaria and also for one in Japan. The economical situation for production of hot strip differs much from each other in these two countries, and the type of hot strip also differs, but the code could output proper solutions. With the use of the code, a new rolling schedule, in which the transfer bar thickness decreased with length of strip, proved the possibility to reduce production cost and improve gage accuracy.

I. Introduction
During the last 10-15 years the hot strip mill technology, automatization and the equipments have developed very remarkably in all countries especially in Japan. The main subject in the operation hot strip mill today is a production of better quality strip at higher production rate with lower operation cost.3,5) This will be achieved by an effort of energy saving,1 4> because of enormous increase in energy cost.3,5) Surely a very large number of achievements have already been made with the optimization of heating processes1) and by the applications of direct rolling processes,1-3) of hot and reverse charge,4) and of schedule-free rolling.2) It is important to keep in mind that hot strip mill (HSM) problems are reciprocity contradictory to each other. Moreover, there are many possibilities to realise the rolling technology and to choose the HSM equipment and layout. In such situation, it is necessary to employ optimization technique in order to decide the suitable technology schedules.

Some efforts have been done to formulate the approach to choose the controlling method of HSM, considering the reheating furnace, roughing and finishing groups as a united complex and to realise a HSM economo-mathematical model as an instrument to search for the proper technology version. Here, the authors could show that the proposed optimization concept was valid in both cases of Bulgarian and Japanese technological and economical situations, and moreover, they could propose a new rolling schedule where the transfer bar thickness decreases from top to tail end on the basis of the concept.

II. The Idea for Optimization of HSM Operation

1. Essence of the Approach
In order to produce hot coils in proper conditions, it is necessary to solve many problems as follows:
(a) Which is better, to roll or to cast slabs?
(b) At what condition is a slab heated in a reheating furnace?
(c) How is the rolling schedule in roughing and finishing group realized?
(d) In what condition is the hot strip cooled to the target coiling temperature?

Each of the techniques to realize HSM operation is considered as sub-processes subordinated to one common object which is to produce high quality strip with minimum production cost. The technological pivot of the optimization is that the hot coil must be produced in the fixed condition idealized by metallurgical point of view with minimum cost. The flowchart of the optimization of the operation conditions of HSM is shown in Fig. 1.

2. Control Variables
Control variables in this approach are slab discharge temperature (T_sl), slab thickness (H_sl), thread speed at the exit of finisher (V_th), and bar thickness at the entrance of the finishing group (H_b).

3. Restrictions
Many restrictions are taken into account. They are the target finishing temperature that is the most important technological demand, flatness restrictions, maximum possible V_th in the concrete mill for size of every rolled product, load restrictions such as rolling force, torque and power, and restrictions in changing of T_sl and H_sl for each slab in a group of slabs.

4. Concept Realization According to Fig. 1
In order to search for the optimal technological version for a concrete mill it is necessary to have its actual speed-temperature-reduction schedules and the mill specification (Box 2 in Fig. 1). For the first step, the optimization begins with changing bar thickness H_b and V_th along “i” loop in Fig. 1. As it was remarked, the search for the optimum begins with the increase of V_th and H_b (in Boxes 3 and 4) by a step. The increasing of V_th and/or H_b gives a possibility to reduce the temperature decrease
in the finishing train and to increase the finishing mill productivity. The pass schedule \((E_{f1} \sim E_{f7}; E\) representing the reduction, \(f\) the finishing stand and \(1 \sim 7\) stand numbers) and the bar entry temperature into the finishing group \((T_{sl})\) are calculated in Box 5 for new threading speed \(V_{th} + \Delta V\) and bar thickness \(H_b + \Delta H.\) \(T_{sl}\) is determined by a function of the final strip thickness \(H_s,\) the target finishing temperature \(T_{fr}, V_1\) and \(H_b.\) \(TT_{sl}\) also depends on the strip width \(B_s\) (respectively that of bar and slab) due to load limitation (Box 9).

After this, the required slab discharge temperature \(T_{sl}\) can be established by a function of the bar entry temperature \(T_{th}, H_b\) and \(H_s\) via determination of the roughing reduction schedule (Box 6).

The production cost \(PC\) is calculated by the HSM economo-mathematical model for every speed-temperature-reduction schedule (Box 7). That will be described later.

If \(PC\) is reduced for the new \(H_b\) and \(V_{th}\) (Box 8), the loop "i" continues till at least one of the rolling conditions reaches its limitation in Box 9. If it is possible to increase \(V_{th}\) more, the optimization can continue by changing of \(H_b\) only (Box 9).

When the optimization in loop "i" is saturated, next stage of optimization begins in loop "j" with reducing slab thickness (Boxes 10 and 11). In many cases, it is much effective to reduce the slab thickness even simultaneously with reducing slab weight. All the HSM speed-temperature-reduction schedule \((T_{sl}, H_b, V_{th}, E_{f1}, E_{f7})\) is calculated again for the new slab thickness (Box 12). On the j's loop optimization, judgement is also done in Box 8, and if \(PC\) is larger than the previously calculated one, the optimization goes to 'end'.

The raising of \(V_{th}\) and \(H_b\) and the reduction of \(H_1\) are subordinated to the main object that is the lowering of \(T_{sl}.\) Lowering of \(T_{sl}\) is the most effective for energy saving in HSM and reduction of \(PC.\)

If it becomes impossible to change \(T_{sl}\) more and
a discharge temperature for each slab in a group due to \( T_{sl} \) changing limitation (Box 9), it is useful to research for another versions. The search continues to find \( T_{sl} \) in both "i" "j” loops. There are two ways (Box 13). If the reheating furnace capacity (RFP) is lower than the finishing group productivity (FGP), we may realize a calculation of a local optimum by \( H_s \) changing (Box 14). This will optimize the local sum (F\( G_a \)) of electric energy cost (EC), roll wear cost (RC) and crop-loss cost (CL) in the upstream of finishing train.

When the RFP>FGP (Box 13), the search yet aims the increase of \( V_{th} \) and then FGP. By employing thinner bar (Box 15) there are more heat loss during rolling that permits or demands higher \( V_{th} \) (Box 16) for ensuring the required \( T_{Fel} \) or \( T_{Fel} \).

III. HSM Economometric Model

1. Formulation of the Solving Scheme

In order to realise the problem, “HSM process optimization” in the first place, the optimization criterion functional must be established. This criterion, must unite heterogeneous technological processes i.e., casting or rolling of slab, reheating of slab, roughing and finishing rolling in HSM. In the situation, a pure technological criterion may not unite all these processes because of discrepancy and difference among the technological purposes of each component-like technologies. Then we introduce nontechnological criterion. Therefore the object of minimizing the production cost or PC (\( Y/t \) or specific representation) is taken up as such a criterion,

\[
PC = VC + CC \quad \text{(1)}
\]

where, \( VC \): variable cost component depending on rolling conditions

\( CC \): constant cost such as depreciation cost.

2. The Functional

HSM economometric model is mainly characterized by the connection of technological parameters with economical cost parameters. The model includes the calculation formula of change in PC components as follows; scale loss in reheating furnace (SL), fuel consumption cost (FC), roll wear cost (RC), electric energy cost (EC), crop loss at the entry of finishing train (CL), fixed cost in the preceding slabbing or continuous casting machine (CCP), and fixed cost of HSM (CC). CC includes equipment and labor cost, a part of maintenance cost (approximately 80% of the total maintenance cost) and a part of fuel consumption cost (approximately 40% of the total fuel cost). CCP and CC do not depend on mill productivity.

The measure of all components is expressed in \( Y/t \) of steel or specific cost. The total objective function is

\[
PC = F(F_1(SL), F_2(FC), F_3(RC), F_4(EC), F_5(CL), F_6(CCP), F_7(CC)) \quad \text{(2)}
\]

3. HSM Mathematical Model

The mathematical model describes the change of the average metal temperature from the exit of reheating furnace to the exit of finishing train. The metal temperature depends on heat loss and energy supply during rolling. The net heat loss is calculated in the model considering radiation, convection, contact with rolls and water cooling.

The roll separating force function, torque and power function, thickness changing formula, etc. are described in the model. The model includes also a procedure for a calculation of the change of metal grain size in HSM line. The details of these metallurgical and mechanical models can not be explained and dicussed here because of the lengthiness of the description. As for the reliability of this optimization procedure, the authors think that the methodology or the concept may be proper one, but the result can be improved better or more accurate if the data and the informations based on the source technologies are improved.

4. Description of the Object Functionals

In order to make the problem solvable and to raise the accuracy of solution, the basic technology method have been applied. The calculation is realised in comparison with the known technological version of a concrete mill. Then the equations give us only a derivative of PC components. Now the index 1 represents the parameters corresponding to the basic technological version and index 2 denotes those for a revised technological version.

The expressions of SL and FC are deduced from the reheating furnace mathematical model as follows.

\[
SL = 1.82 \times 10^{-4} T_{sl}^2 - 0.352 \times T_{sl} + 173.6 \quad \text{(3)}
\]

Equation (3) is valid at the temperature ranging from 1 000 to 1 300 °C. Then

\[
\Delta SL = 10^{-8}(SL_1 - SL_2)C_1 \quad \text{(4)}
\]

where, \( C_1 \): price of heated slab and

\[
C_1 = A_3 + A_4 - A_5 \quad \text{(5)}
\]

where, \( A_3 \): cost of cold slab

\( A_4 \): cost of reheating

\( A_5 \): scale price.

The fuel consumption is proportional to \( F \), and

\[
F = 504.6(2.5 \times 10^{-4} H_{sl} + 0.525) \times (7.05 \times 10^{-4} T_{sl} - 0.32) \quad \text{(6)}
\]

where \( H_{sl} \) is represented by mm. Then

\[
\Delta FC = (F_2 - F_3)C_1 \quad \text{(7)}
\]

where, \( FC_1 \): fuel consumption for the basic (starting version of) technology in price.

In determining of RC, we may assume that the roll wear is proportional to \( B \) which is the product of the rolling length of unit amount of steel and the mean value of rolling force in each stand. Then,
\[ \Delta RC = \{(B_2-B_1)/B_1\}\cdot RC_1 \] ..........(8)

where, \( RC_1 \): roll wear cost for the starting version of technology.

Change of electric power consumption in terms of price is given by the expression,

\[ \Delta EC = \{(P_2-P_1)/P_1\}\cdot P_{pl} \] ..........(9)

where, \( P_{pl} \): mill power consumption (kWh) calculated for each rolling stand and each size specification by means of HSM mathematical model

\[ P_{pl} \]: cost of electric power consumption in price for the starting technological version.

The value of \( CL \) can be found by

\[ CL = 7.85\Delta L\cdot B_b\cdot H_h/W_{s1} (t) \] ..........(10)

where, \( H_b, B_b \) are expressed in m.

\( \Delta L \): mean length of the cropped bar end \( (m) \)

\( W_{s1} \): slab weight \( (t) \).

Then

\[ \Delta CL = (CL_2-CL_1)\cdot CBL. \]

The cost of loss in bar CBL can be found approximately as

\[ CBL = A_6-A_7, \]

where, \( A_6 \): the price of hot strip coil

\( A_7 \): the price of crop.

\( \Delta CCP \) for slabbing mill was determined by the next equation and the concrete figures in the equation is valid for Bulgarian mill and must be changed when the optimization may be executed in other country,

\[ \Delta CCP = -\left[ CCP - CCP \right]/\left[ 2.3 \times 10^{-3}(H_{s2} - H_{s1}) + 0.5(W_{s2}/W_{s1} - 1) + 1 \right] \] (price)

.........(11)

where, \( CCP \): fixed cost for the slabbing mill.

\( \Delta CC \) for HSM can be found as

\[ \Delta CC = -\left[ CC - CC \right]/\left[ 1 + \Delta P \right] \] (price).........(12)

where, \( CC \): mill fixed cost

\( \Delta P \): change in mill productivity.

\( \Delta P \) for HSM is expressed as

\[ \Delta P_s = \{(1+RGT)/(1+RGT\cdot B_2/B_1)\}\cdot(1+\Delta P_s) - 1 \] ............(13)

where, \( RGT \): the ratio of rolling time between roll change to roll changing time

\( \Delta P_s \): change in mill productivity due to change in rolling speed and weight of slab \( W_{s1} \).

\[ \Delta P_s = \left\{ W_{s1}\cdot(T_{m1}+T_p)\right\}/\left\{ W_{s1}\cdot(T_{m2}+T_p)\right\} - 1 \] ............(14)

where, \( T_{m1}, T_p \): time of actual rolling and pause between passes, respectively \( (s) \).

Therefore, Eq. (13) takes into account of influence of rolling speed by \( T_{m} \), slab weight and roll wear through \( B \) on the mill productivity.

When the rolling mill productivity for any product size may be limited by reheating furnace capacity, \( \Delta P \) in Eq. (12) must correspond to the change in reheating furnace productivity. Thus \( \Delta P \) will be determined by next equation as

\[ \Delta P = P_{pl}/P_{pl} - 1 \] ............(15)

where, \( P_{pl} = (0.67-5.0\times10^{-4}H_{s1})(1.73-1.07\times10^{-3}T_{s1}) \) and \( H_{s1} \) is represented in mm.

**IV. Results and Discussion on the Application for Usual Schedule**

1. **Results and Discussion in the Case of Bulgarian Mill**

   An example of optimization in Bulgarian 1 700 mm HSM for product size 10 mm x 1 250 mm is illustrated in Figs. 2 and 3. Three technological versions of rolling are shown there. The basic technological version is as follows:

   \( T_{s1} \): 1 260 °C, \( H_b \): 24 mm and \( V_{th} \): 3.5 m/s.

   The optimization condition from technological requirements are as follows:

   \( T_{s1} \): 890 °C

   Rolling load: admissible lowest in each stand

   Slab weight: 14 t.

   Fig. 2. Production cost change for different technological schedule of rolling 10 mm x 1 250 mm strip in a Bulgarian mill.

   Fig. 3. Temperature change along the line.
One optimized version through "i" loop in Fig. 1 is as follows and shown in Figs. 2 and 3 as case 1: 
\( T_{s1}: 1050 \, ^\circ C, \ H_b: 45 \, mm \) and \( V_{th}: 5 \, m/s \).
The other optimized version established through "k" loop in Fig. 1 is as follows:
\( T_{s1}: 1260 \, ^\circ C, \ H_b: 20 \, mm \) and \( V_{th}: 6 \, m/s \).
This version is shown in Figs. 2 and 3 as case 2.

Changes in each cost component of PC for cases 1 and 2 are shown in Figs. 2 and 3 in comparison with the initial technological version. All cost components are explained already in Chap. III.

Figure 3 illustrates the temperature transition along the stream of HSM and at the same time schematically the mill layout. The mill has a vertical scale braker, a horizontal scale braker shown as \( R_1 \), a roughing stand and 6-stand finishing train.

The results are as follows:
1. It is possible to reduce slab temperature by more than 200 °C due to increase of \( H_b \) and also \( V_{th} \) (case 1). According to this, decrease of SL is 60 %, that of FC 26 %, that of CC 15.3 % and PC can be reduced by 17.9 % notwithstanding to increase of RC by 8.3 %, EC by 16.7 % and CL by 8.2 %.
2. When RFP > FGP, the optimization can be proceeded on loop "k", and the optimized schedule must be case 2. This permits to reduce PC by 11.7 % through decrease of CC by 24.4 %.
3. The optimum \( T_{s1} \) is a function of \( H_b \) and \( B_s \), and the calculation result is illustrated in Fig. 4. \( H_b \) as a function of \( H_b \), \( B_s \) and the optimized \( T_{s1} \) is illustrated in Fig. 5. The optimum results illustrated in Figs. 4 and 5 are much useful to reduce FC, to increase RFP and FGP and consequently to reduce PC as shown in Fig. 6.

2. Results and Discussion on an Example for a Japanese HSM under Japanese Financial Situation

In order to test validity of the optimization concept, the application was tried to a Japanese HSM under Japanese financial situation. The HSM is much different from the Bulgarian and also the financial situation differs much from that of Bulgaria. The financial model is shown in Table 1 as specified representation of cost. In this work, only such cost share ratio is necessary. In Fig. 7, a schematical layout of a Japanese HSM is illustrated.

Some calculations are made for product size of 4 mm x 1000 mm. The results are illustrated in Figs. 7 and 8. The initial technological schedule is as follows:

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The optimized version on loop "i" is as follows: $T_i: 1200 \, ^\circ C, J_{ib}: 30 \, mm$ and $V_{th}: 7.7 \, m/s$ shown in the figures as case 1, and then if continuing the optimization on loop "k", we may obtain another version named as case 2 as follows: $T_i: 1200 \, ^\circ C, J_{ib}: 30 \, mm$ and $V_{th}: 7.7 \, m/s$. In order to keep $T_f: 890 \, ^\circ C$, in case 1 the zooming rate is set at 0.03 m/s$^2$ and in case 2 at 0.05 m/s$^2$.

In the financial situation of Japan, often mill productivity never affects on cost calculation anyway, and then the calculation result for such case ($CC=0$) is also given in Fig. 7.

The results established for the HSM with the same technological requirement are as follows:

1. It is possible to reduce slab temperature by 160 $^\circ C$ by increasing the bar thickness from 40 to 55 mm and $V_{th}$ from 6.3 to 7.6 m/s (case 1). This change decreased $SL$, $PC$, $CC$ and $PC$ considerably as shown in Fig. 7. In this calculation, the fact that slabs were charged in the reheating furnace at 400 $^\circ C$ was taken into account. The FGP increased in this case by 12%, notwithstanding to some decrease in acceleration rate from 0.03 to 0.02 m/s$^2$. In changing the rate, the interstand cooling was not taken into account.

2. If loop “k” optimization shown in Fig. 1 is employed because $RFP < FGP$, the better schedule will be recommended as case 2. In this case, $V_{th}$ must be high in order to avoid interstand cooling of strip because of decrease in $H_b$ and a higher FGP results. This permits to reduce $PC$ by 11% due to decrease in $CC$ by 20%.

V. Results and Discussion on the Application for the Rolling Where $H_b$ Changes along the Transfer Bar in a Japanese Mill

1. Essence of the New Method

The new method is marked by changing $H_b$ along the length of transfer bar. In hot rolling, deformation resistance depends more on strain rate and temperature than on reduction of thickness. Therefore, in the new method transfer bar thickness can be largest at top end and decrease gradually to tail end. Of course, the strip thickness must be constant through the whole length at the exit of finishing train.

2. Strip Thickness Changing along the Strip Length in Finishing Train

The change of strip thickness $\Delta H \Sigma$ is the sum of the next components. The first is that due to rolling force (RF) change. The second is historical component which is affected by the prior stand thickness change. In this calculation, change of crown is neglected.

The result of the calculated thickness change in finishing train of the Japanese HSM where 2.4 mm x 1000 mm strip is rolled is shown in Fig. 9. The thread speed is 10.8 m/s at first, and the acceleration rate is 0.045 m/s$^2$. $H_b$ is 33 mm and the weight of slab is 15.5 t. The temperature drop in the first stand through the length of transfer bar is about 70 $^\circ C$, and the rolling speed increases from 0.79 to 1.01 m/s, as shown in Fig. 10. In this condition, change in strip thickness $\Delta H_f$ in $F_1$ is 0.58 mm. And then $\Delta H$ (historical component of $\Delta H \Sigma$) in $F_2$ is 0.08 mm. Figure 9 illustrates $\Delta H_f$'s, $\Delta H$'s and $\Delta H \Sigma$'s in the all finishing stands.

There are given in Table 2 reduction schedules,
rolling force data and rolling torque data for these two rolling technologies one of which is constant \( H_b \) case, i.e., usual technology, and the other of which is changing \( H_b \) case, i.e., new technology.

\( \Delta H \) is 0.11 mm after the final stand even when the \( T_f \) is kept constant. This is because of the increase of loading load in each stand due to the increase of deformation resistance depending on temperature and strain rate as a result of zooming.

Figure 10 shows the conditions and results in the case of new technology where \( H_b \) is thicker at the top end and thinner at the tail end than usual \( H_b \). Table 2 shows reduction schedules, values of rolling force and rolling torque for the both ends.

The possibility to increase load for the top end enables us to settle larger \( H_b \), lower \( T_1 \) (1 080°C) and constant \( V_{th} \) (10.8 m/s) through the length of strip. \( H_b \) is 27 mm for the tail end, and rolling reduction at every stand is larger for top end than for tail end. This results to lower rolling force for tail end.

In order to produce thickness varying transfer bar, rolling reduction might be smaller for top end and gradually increase to tail end in rougher. The temperature drop is larger at top end in rougher as shown in Fig. 10. But notwithstanding to this and also thinner thickness at tail end, the temperature drop at the entrance of finisher is about the same (65°C) as in the case of the usual rolling. For this new schedule, Table 2 shows that \( RF, \Delta H, \Delta HH \) and \( \Delta H \Sigma \) are approximately zero through the whole length of the strip.

The economic results for the new schedule are given in Table 3 in comparison with that for the usual schedule. The total production cost can be reduced by 763 ¥/t when the thinner strip is produced and FGP gives the limitation of the mill complex productivity.

**Table 2. Calculation results for the basic and new reduction schedule for 2.4 mm \times 1 000 mm and the weight of 15.5 t, \( V_{th} = 10.8 \) m/s and \( T_f = 900 \)°C**

<table>
<thead>
<tr>
<th>Version</th>
<th>Parameter</th>
<th>( R_1 )</th>
<th>( R_2 )</th>
<th>( R_3 )</th>
<th>( R_4 )</th>
<th>( R_5 )</th>
<th>( R_6 )</th>
<th>( F_1 )</th>
<th>( F_2 )</th>
<th>( F_3 )</th>
<th>( F_4 )</th>
<th>( F_5 )</th>
<th>( F_6 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Jpn-HSM</td>
<td>( H_{exit} ) (mm)</td>
<td>250</td>
<td>195</td>
<td>140</td>
<td>90</td>
<td>60</td>
<td>41</td>
<td>33</td>
<td>18</td>
<td>9.8</td>
<td>5.8</td>
<td>4.0</td>
<td>2.9</td>
</tr>
<tr>
<td>( T_f = 1 240 )°C</td>
<td>( H_b = 33 ) mm</td>
<td>( a = 0.045 ) m/s²</td>
<td>1 600</td>
<td>1 480</td>
<td>1 200</td>
<td>1 180</td>
<td>1 140</td>
<td>1 100</td>
<td>1 480</td>
<td>1 350</td>
<td>1 200</td>
<td>1 000</td>
<td>1 000</td>
</tr>
<tr>
<td>( RT ) (t/m)</td>
<td>( RF ) (t)</td>
<td>280</td>
<td>260</td>
<td>300</td>
<td>200</td>
<td>150</td>
<td>60</td>
<td>115</td>
<td>80</td>
<td>50</td>
<td>27</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>New schedule</td>
<td>( H_{exit} ) (mm)</td>
<td>250</td>
<td>195</td>
<td>150</td>
<td>110</td>
<td>80</td>
<td>60</td>
<td>51</td>
<td>26.9</td>
<td>13.1</td>
<td>6.8</td>
<td>4.4</td>
<td>2.85</td>
</tr>
<tr>
<td>( T_f = 1 080 )°C</td>
<td>( H_b = 51 ) mm</td>
<td>( a = 0.128 ) m/s²</td>
<td>2 000</td>
<td>1 900</td>
<td>1 920</td>
<td>1 830</td>
<td>1 600</td>
<td>1 600</td>
<td>1 900</td>
<td>1 770</td>
<td>1 600</td>
<td>1 240</td>
<td>1 300</td>
</tr>
<tr>
<td>( RT ) (t/m)</td>
<td>( RF ) (t)</td>
<td>325</td>
<td>320</td>
<td>290</td>
<td>240</td>
<td>170</td>
<td>70</td>
<td>180</td>
<td>130</td>
<td>80</td>
<td>38</td>
<td>32</td>
<td>10</td>
</tr>
</tbody>
</table>

\( H_{exit} \): thickness at the entrance of the stands

\( RF \): rolling force

\( RT \): rolling torque

**Fig. 9. Change of strip thickness components in the finishing train for rolling of 2.4 mm \times 1 000 mm strip.**

**Fig. 10. Change of temperature for the different rolling schedules in rolling of 2.4 mm \times 1 000 mm strip.**

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VI. Conclusion

The described approach permits an effective operation conditions for each part of HSM in order to reduce production cost and to process the high quality hot strip. The approach can be applied to HSM in wide range of economical situation and for different type of HSM. Furthermore, with this approach a new rolling schedule, in which the thickness of transfer bar decreases with the length of bar, gives us a possibility to reduce production cost, to keep the accuracy of strip gauge and to process high quality hot strip.

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