Fatigue of backup rolls, length of campaign and dressing amount

Daniel Hajduk, Pavel Simecek, Marcelo Arantes Rebellato, Gilson Teixeira Cornelio

ITA Ltd., Martinska 6, 709 00 Ostrava, Czech Republic, e-mail: pavel.simecek@ita-tech.cz, daniel.hajduk@ita-tech.cz

Aços Villares, Villares Rolls, Pindamonhangaba Plant, State of São Paulo, Brazil e-mail: marcelo.rebellato@villaresrolls.com, gilson.cornelio@villaresrolls.com

Abstract

The paper deals with a fatigue of backup rolls and with prediction of length of roll campaign. Loads acting on backup rolls degrade their surface layer, which can lead to spalling or even severe cracks of the rolls. To prevent this method of estimation and accumulated damage has been developed and tested. This method in form of computer program enables to identify the most stressed parts of backup roll surface, calculates the accumulated damage caused by every strip (characterized by measured separating force, bending force, strip width and other parameters), predicts a suitable length of the backup roll campaign and calculates an economical dressing amount. By this way it is possible to increase the performance of backup roll and reduce the danger of spalling.

Key words: Hot rolling, Backup roll, Fatigue, Spalling, Length of BuR campaign, Dressing amount.

1. Introduction

The backup rolls are very loaded machine parts. The most frequent damages are spalling of the surface and cracking especially in edge region of the barrel and transverse cracks of the neck. The spalling (e.g. Fig. 1) is caused mainly by contact stress between work roll and backup roll but other loading may play an important role as well.

Fig. 1: Examples of damaged backup roll

Cracking of the roll surface in edge region is caused by the same mechanisms. Transverse cracks of the neck are comparatively rare and there will be not discussed in this paper. Presented computer model can detect the stress level of the most important loads, calculate when the roll is damaged critically an estimate the length of roll campaign.

2. Backup rolls surface degradation

The most important loading phenomena in backup rolls are as follows:

- Hertzian contact load between backup roll and work roll,
- Residual stress in roll (due to thermal treatment and other production influence),
- Bending stress.
The spalling is caused by stresses generated mainly by contact between work roll and backup roll. Other loading have much smaller influence, but they should be taken into account when fatigue of surface layer is analysed. Bending stresses are much lower than Herzian stress. But as it is cyclic loading it can influence the damaged layer of the backup rolls. Residual stresses are static, but they might reach very high values. They change with reduction of roll radius and are redistributed after each grinding.

2.1 Contact (Hertzian) stress
According to Hertz theory maximum HMH stress can be found under the surface. The depth of stress peak depends on diameter of the rolls, specific contact force and mechanical properties of roll materials. In common backup rolls for hot strip mills it varies from 3 to 9 mm. In this depth the first microcracks originate and they can grow up to the surface and form spalls.

![Fig. 2: Hertzian stress in rolls](image)

2.2 Estimation of residual stresses
Residual stresses can reach enormous values. They can be measured in thin layer under the surface by drilling method. An example of residual stresses measured on sleeved backup rolls is demonstrated in Fig. 3.

![Fig 3: Measured residual stresses (in 2 points) under the surface of the sleeved backup roll](image)
Under certain simplified assumptions it is possible to calculate residual stresses due to thermal treatment of rolls [1]. A computer analysis showed regions under the roll surface with high negative stresses. Obtained stresses were slightly lower (25\%) than the measured ones.

![Computed distribution of residual stresses in the sleeved roll](image)

**Fig. 4: Computed distribution of residual stresses in the sleeved roll**

### 3. Grinding of backup rolls

Grinding of backup rolls removes a part of damaged layer. After grinding residual stresses are partly redistributed but the accumulated damage of material remains. New rolling increases the damage of the surface layer (see Fig. 5). The deeper the grinding, the more of the damaged layer have been removed and the longer new backup roll campaign can be.

![Accumulated fatigue damage considering removal of dressing amount](image)

**Fig. 5: Accumulated fatigue damage considering removal of dressing amount**
4. Monitoring of backup roll damaged layer

Special software implemented into existing Level 2 or working separately enables on-line or off-line monitoring of accumulated damage of backup rolls. It consists of the following submodels (see Fig. 6).

![Backup roll monitor submodels](image)

4.1 Calculation of contact pressure

The pressure between work roll and backup roll is influenced by actual parameters and is changing in the strip length (thermal camber, dynamic bending forces, separating force etc.). Calculation of contact pressure for changing conditions on one strip would be rather time consuming. That’s why a simplified way is performed, considering constant rolling conditions for the whole length of the strip (separating force, bending force). Thermal camber and wear are updated ones on each strip.

![Specific contact force between rolls](image)

The contact pressure distribution is calculated for the contact line between backup roll and work roll using simplified spring beam model Rollflex [2]. Rolls are modelled by beams connected by nonlinear springs. Contact pressure (linear specific force N/m) obtained by simplified model is very close to those obtained by 3D FEM analysis except for the places where roll profile changes abruptly (region of chamfer on backup roll) [2]. Knowing this disadvantage a system of corrections is used to have more realistic distribution of contact pressure (Fig. 8).
4.2 Calculation of accumulated damaged layer

The calculation of damaged layer is done according the following scheme (Fig. 9):

- Calculate hertzian stresses
- Calculate bending stresses
- Calculate residual stresses
- Calculate resultant cyclic loading
- Construct fatigue strength
- Calculate accumulated damage using Miner’s rule

From all stress components HMH maximum and minimum stress for each revolution of the roll is calculated. Resultant cyclic loading is transformed to symmetrical one and fatigue strength curve is constructed using Smiths diagram and material parameters of the roll. Miner’s rule enables to evaluate various loadings and calculate accumulated fatigue damage [4]:

Fig. 8: Comparison of specific force between backup and work roll from simplified and FEM model

Fig. 9: Calculation algorithm of damaged layer
\[ F_a = \sum_{i=1}^{k} \frac{n_i}{N_i} \]

\( F_a \) ... accumulated fatigue damage  
\( N_i \) ... maximum number of loading cycles for stress  
Level 1 \( (N_i = \text{crack}) \)  
n\(_i\) ... number of loading cycles for stress Level 1  
i ... index of the stress level  
\( k \) ... number of stress levels  
stress 1,2 ... value of equivalent cyclic stress

Calculated accumulated damage in surface layer after rolling of several strips can be seen in Fig. 11. Maximum values can be observed in the beginning of taper on backup roll.

**Fig. 10: Calculation by Miner's rule**  
**Fig. 11: An example of accumulated damage**

### 4.3 Estimation of grinding amount

As described before, grinding amount and the length of backup roll campaign are in relation. In most mills the period of backup roll change (backup roll campaign) is constant (number of days). If the load of the mill is lower for various reasons (lower mill performance, unexpected shutdown etc.) grinding amount can be smaller. In opposite case of excessive performance of the mill the grinding amount should be higher or even the length of campaign should be shortened.

In monitoring mode the software checks the level of accumulated damage and when the preset level is reached, an alarm occurs on HMI monitor. After finished backup roll campaign dressing amount is calculated considering the same length of the next backup roll campaign and the same loading.

**Fig. 12: Accumulated fatigue damage considering removal of dressing amount**
5. Conclusion

Described system of backup roll monitoring can be used for optimization of backup roll performance. Critical spots on backup roll surface can be simply identified and relevant measures can be taken to prolong the service life of backup rolls [5]. Each campaign of backup roll can be evaluated from the point of view of backup roll service life. All this together with feedback in terms of non-destructive testing of roll surface can increase the performance of backup rolls.

References


This paper was supported from budget chapter of Ministry of Industry and Trade, Czech Republic within the program TIP - project FR-TI 3/053.