Roll load measurements on thin slab caster for liquid core detection

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Measurements of roll loads with strain gauges implemented on roll girders were carried out on a thin slab caster. Numerical calculations and shop tests indicated the applicability of this measurement arrangement. It has to be considered under the specific aspect that, owing to the low design height of thin slab casters, the occurring loads are considerably smaller than in standard slab casters. The evaluation of the measurement data obtained during operation of the thin slab caster was done from two main viewpoints. First, it was of interest whether it is possible to measure the presence of a liquid core at a given distance from the meniscus. Second, the measurements were supposed to be used for verification of the liquid core position calculated on line by Dynacats® VAI’s dynamic cooling model. Essential difficulties in evaluating the data originated from the changing thermal and mechanical loads. The slowly changing thermal loads that are superimposed on the mechanical loads make it impossible to determine the presence of a liquid pool simply by checking the strain gauge signal and comparing it with results collected during the shop tests. Mechanical load changes at relatively high frequencies occurred owing to varying roll forces even with minor eccentricities of the rolls. Thus, checking for critical values of the load changes also seems impractical. For on line prediction of the liquid core position, a combination of numerical estimation of the liquid core position with on line thermal tracking as an approximate approach and measurements for exact prediction seems to be the most promising strategy. An interesting alternative to this strategy could be the on line evaluation of fast Fourier transformed (FFT) strain gauge signals.

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INTRODUCTION

The aim of roll load measurements is to gather information of metallurgical and mechanical use. The most significant metallurgical factor examined in this paper is knowledge of the point of final solidification. Thus, the adjustment of the maximum casting speed on machines of short metallurgical length and the optimum casting speed on machines operating with soft reduction can be optimised. The mechanical task is to protect the rolls and segment frames from mechanical destruction owing to excessive roll loads. In this case, clamping of the segments can be interrupted for a certain time period. Various strategies are known for measuring roll loads under slab caster operating conditions. Angerer et al.¹ installed load cells between the bearing blocks and roll girders. These load cells needed good cooling and excessive maintenance to prevent short life cycles and thus were not considered to be applicable for on line liquid core detection. Measurements with strain gauges implemented on the distance blocks between the inner and outer segment frame have been reported.² Of course, this strategy can give


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exact results only if two or three rolls at most are integrated in one segment frame, which is not typical of standard segments in modern slab casters.

Schade et al. performed measurements with strain gauges implemented on the upper frames of segments with throughgoing rolls. This arrangement allows easy maintenance and ensures good accessibility of the measurement system. Nevertheless, it seems to be difficult to interpret the measurements with respect to liquid core position because of the thermal load cycles, e.g. at the beginning of each cast and disturbances caused by bent rolls.

The present work focuses on measurements for on line determination of the load conditions on segments of specific VAI design (Fig. 1). Strain gauges were implemented on the top of the girders carrying the intermittently supported rolls. This position ensured both protection from high temperatures and moisture and simplicity of maintenance.

LOAD SIMULATIONS

Finite element calculations were carried out to evaluate the strains occurring at the crossgirders under mechanical load conditions (presence of liquid core, ferrostatic pressure). A fully three-dimensional finite element model of a segment was built (Fig. 2). The segment frames were modelled as eight-node shell elements. Two node beam elements were used to model the tie rods connecting the inner and the outer segment frame and the rolls.

Three individual loads at the quarterpoints and the middle of the strand width represented the ferrostatic pressure at each individual roll. The loads were calculated according to the local ferrostatic pressure, the casting width, and the roll pitch.

The results of the finite element calculations indicated that the maximum strains occurring in the girders, which are designed for minimum displacement, are of the order of 100 μm m⁻¹, with exact values depending on the actual boundary conditions. Strains of this order of magnitude can reliably be measured by means of strain gauges.

To verify the numerical results, additional load tests were performed in the machinery shop. To simulate the roll load due to ferrostatic pressure, jacks were placed between the rolls and hydraulically loaded (Fig. 3). The hydraulic pressure was adjusted so that the load of three cylinders was equal to the roll load due to ferrostatic pressure.

Various load conditions were simulated by changing the hydraulic pressure. The measurements in general showed the linear dependence of the strains at the measurement position on the hydraulic pressure, which is typical of elastic deformations (Fig. 4). Only a slight hysteresis occurred owing to friction forces in the load cylinders. Moreover, the predicted strains were confirmed by the measurements.

PLANT EXPERIMENTS

The continuous casting machine at Armco Mansfield Inc. (Fig. 5) has a straight mould, a bow radius of 5 m, and a maximum metallurgical length of 16.5 m. The design allows for a casting thickness in the range of 70-150 mm and a maximum width of 1350 mm. The roller gap during the trials was adjusted to 130 mm.

Strain gauges were fitted on the roll girders in six different positions. The distance of strain gauges SG1-SG6 from the meniscus was 66, 70, 79, 83, 94, and 108 m, respectively. During casting, the strain gauge signals, the casting speed, and the calculated liquid core length were stored every 10 s.
Signal changes at the strain gauges during the start of casting occur over a period of 30 min (Fig. 6). They clearly correlate with changes in the temperature fields of the roll girders.

The casting speed and the corresponding signals for three different strain gauges during standard operation of the caster are shown in Fig. 7.

The signal at SG1 is the one with the largest variations. Nevertheless there is no obvious direct correlation between changes in the casting speed and changes in the roll load.

At SG3, changes in the casting speed cause significant changes in the roll load. They are considered to be directly related to the passing of the point of final solidification at the measurement position. It is important to note that there is always a time lag between acceleration or deceleration and the ‘characteristic’ change in the strain gauge signal.

More frequent load changes occur at SG5 after changes in the casting speed. Moreover, the time lag between speed and signal changes after decelerations is shorter at strain gauge SG5 than at strain gauge SG3, but longer after accelerations. This is due to the fact that SG5 is positioned further away from the meniscus and this is passed by the point of final solidification at a higher average casting speed than SG3.

A ‘manual estimation’ of the range of the point of final solidification on the basis of checking for ‘characteristic’ load changes is shown in Fig. 8. It is compared with on line calculated points of final solidification from Dynacs®, VAF’s dynamic cooling model, which carries out on line calculation of the thermal field of the strand, with the actual casting and cooling conditions as initial and boundary conditions. Though the resolution of the measurement is not very high, the numerical results are well confirmed by the measurements.

For ‘manual estimation’ of the passing of the point of final solidification at a certain strain gauge position, correlations between changes in the casting speed and ‘characteristic’ changes in the roll loads were sought. This search strategy implies that a roll load increase at a certain strain gauge position is followed by a roll load decrease, and vice versa. This is due to the fact that the point of final solidification can not arrive twice from the same direction at a certain roll.

Most interestingly, this strategy for the evaluation of the liquid core position fails for SG6. Following the trend in Fig. 8 from 3:30 to 6:00 am, which is shown in more detail in Fig. 9, two successive ‘characteristic’ decreases in the roll load were recorded. In both cases the roll load decrease can be correlated with a preceding decrease in the casting speed.
To understand this phenomenon, a more detailed analysis of the strain gauge signals was performed applying discrete Fourier analysis (Fig. 9). At the highest load level, small amplitudes are found over a wide range of frequencies except for the very low ones. FFT analysis of the strain gauge signal at the medium load level shows one distinct peak at frequency \( f \), which is dependent on the casting speed \( v_c \), and the roll diameter \( d_r \): \( f = \frac{v_c}{d_r \pi} \). In contrast to the results described above, no disturbances at higher frequencies were found in the frequency domain of the strain gauge signal at the low load level.

Consequently, the results of the FFT analysis were interpreted as follows.

At the highest load level the roll is in contact with a strand with a liquid core, and thus exciting forces can occur at many different frequencies, but all of them are strongly damped.

If the strand is fully solidified, its resistance to deformations is increased drastically. Therefore, the roll load varies with one cycle per roll rotation, even if the eccentricity of the roll is minor. This behaviour can be found in the strain gauge signals at the medium load level.

After shrinkage of the fully solidified strand away from the strand containment, no further perturbances were found in the frequency domain. This is evident in the frequency domain of the strain gauge signals at the low load level.

**CONCLUSIONS**

Experiments with strain gauges implemented on the roll girders on segments of a thin slab caster have shown interesting starting points for on line liquid core detection. One approach could be the combination of on line calculation of the thermal field in the strand and strain gauge measurements. Another possibility seems to be the on line application of FFT analysis of the strain gauge signals and checking for typical results in the frequency domain. Examples of both strategies have been given in the present paper.

**REFERENCES**