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ANALYSIS OF HOT ROLLING OF A CHANNEL SECTION USING NUMERICAL SIMULATION

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Abstract— **Numerical techniques offer the convenience of investigation of the rolling process closely to analyze pass filling during rolling of structural steel sections, while obtaining a range of information pertaining to the response of rolls including force, torque and stresses. The paper deals with some issues encountered in and applications of the finite element method (F.E.M.) based simulation of rolling of a typical structural steel section (200 x 75 channel). The study has been made in the context of rolling of this section in the intermediate stands of a typical Section Mill. The paper attempts at investigating the role of coupling of rolls and the effect of modification in the penultimate intermediate stand pass on overall response during rolling.**

Keywords—**Hot Rolling, Simulation, Finite Element Method, Computation Time, Structural Section**

I. INTRODUCTION

The application of numerical techniques like the finite element method (F.E.M.) for obtaining information on process parameters during rolling and analyzing possible process or design alternatives without incurring the cost of actual field trials is being increasingly recognized as a viable proposition in the interest of cost-effectiveness. Also, the fact that a substantial corpus of the literature dealing with analytical formulations on rolling theory are limited to flat rolling, simulation as a tool becomes all the more significant in the context of analyses of rolling of non-flat products. However, such a pursuit is often fraught with intricacies typical of numerical simulation, including those related to computation time, mesh distortion, solution convergence and accuracy. The paper presents an overview of a rolling simulation study undertaken in the context of a typical structural steel section (200 x 75 channel) and some computational considerations involved therein, while also trying to assess how such information can potentially be applied for analyzing pass-design alternatives.

II. SIMULATION APPROACH

The analysis models were set up in the pre-processor (CAE) of the F.E.A software Abaqus. A CAD software (Auto CAD) was used for the creation of two-dimensional sketches for roll passes that were imported into Abaqus/CAE and converted into three-dimensional entities. The rolls in the present context were idealized as rigid bodies, their kinematic and thermal state being specified at the reference points associated with them. The analyses runs were carried out in Abaqus/Explicit. The rolled stock was modelled as a deformable body and discretized using a continuum hexahedral element C3D8RT, which employs reduced integration. Appropriate stiffness control was invoked for alleviating element hourglassing, while mesh smoothing was effected through an ALE strategy. For the chosen element, Abaqus/Explicit offers the capability of steady state detection [1] which facilitates termination of computation once a constant shape of the rolled section is attained. This determination was done in the present study through the equivalent plasticity, spread, force and torque norms. Planes of elements in a Lagrangian analysis are typically sampled at the exit plane for these norms and when their values are found to fall within a specified tolerance for three consecutive planes, steady state is determined to have been achieved. The termination of computation generally occurs when the steady state plane so determined moves a defined distance downstream of the exit plane.

The intermediate stands of the mill under study employ a total of seven passes for rolling 200 x 75 channels, four of which are in the first of these stands while the rest are in the second. The rolling simulation was done pass-wise, with the steady state output of one pass forming the basis for the input of the subsequent pass. The following material properties were considered for the rolled steel: thermal conductivity k was taken as 60 $Wm^{-1}K^{-1}$; specific heat capacity c as 460 $Jkg^{-1}{}^{\circ}C^{-1}$, modulus of elasticity E as 2.1×10^{11} Nm^{-2} and density ρ as 7800 kgm^{-3}; the coefficient of friction was considered as 0.3. The stress-strain data of the typical steel composition (C: 0.22; Mn: 0.87; S: 0.032; P: 0.018; Si: 0.27) of the rolled section were determined through hot upsetting tests in a Gleeble thermo mechanical simulator at appropriate combinations of temperature and strain rate [2].

In order to further economize computation, use was made of the automatic mass scaling technique. The impact of the use of this on computation time and von Mises stress values has been discussed elsewhere [3]. Mass scaling in Abaqus for bulk rolling processes can be executed automatically through initial specification of certain parameters like the average element

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length, L, in the rolling direction, the feed rate, V_f, at steady state conditions and the number of nodes, n, in the cross-section of the rolled stock. Based on these specified values, an initial estimate of the stable time increment Δt is made thus:

$$\Delta t = \frac{L}{V_f n} \qquad (1)$$

In practicality, Abaqus reduces the stable time increment so determined by a factor, so that the actual value used for computation is more conservative than that given by equation (1). Also, this value is dynamically computed throughout the analysis to take into consideration the evolving parameters.

Simulation for the different passes required adapting both the mesh definition as well as ALE strategies for controlling mesh distortion. Contact interactions were defined using the surface - to - surface contact algorithm, with mechanical constraint enforced through the penalty contact algorithm in Abaqus.

III. Influence of Coupled Rolls

In the present study, the context of simulation was rolling in the intermediate train of a Section Mill which comprises two 3-high stands, with the rolls of the first of these stands coupled to those of the second for power transmission. Coupling of rolls implies additional load for the common drive as inertias of rolls come into play, even if rolling were done in only one of these stands. Since mill load is often an issue that comes to fore in the event of catastrophic roll failures, it becomes pertinent to examine the relative contributions of the possible causative factors towards excessive mill load. In order to model the coupling of rolls in the F.E.A software Abaqus, use was made of connector elements. The actual replication of coupling between the rolls of the two stands would have called for additional contact interactions; however, this was simplified by way of connector elements, which resulted in activation of rotational degrees of freedom in the driven roll, while ensuring that there was no relative rotation between the coupled rolls. The results of analyses with the rolls coupled were compared with those in which the rolls were de-coupled. Fig. 1 shows the typical simulation result for rolling of the section (200 mm x 75 mm) in the second pass of the first intermediate stand, factoring in the influence of coupling of rolls of the second intermediate stand.

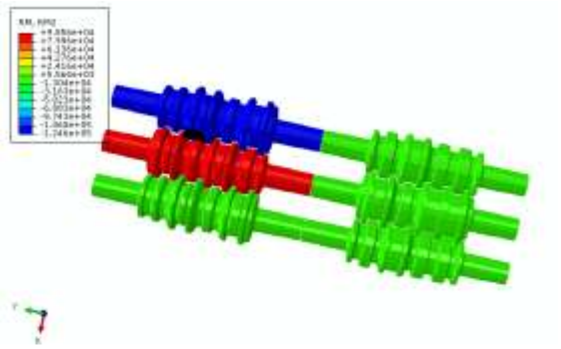

Fig. 1. Roll torque simulation – coupled rolls (200 x 75 channel : pass P2)

The values of the torque component RM2 are shown plotted in this figure as consolidated values at the first intermediate stand rolls: 98.56 x 10^3 Nm for the middle roll and 124.63 x 10^3 Nm for the top roll. The corresponding values when the rolls were decoupled were found to be: 98.08 x 10^3 Nm for the middle roll and 124.58 x 10^3 Nm for the top roll. The results seem to suggest that coupling of rolls leads to an increase in the total torque requirement by about 530 Nm which, taking the characteristics of the D.C. motor [4,5] used for the drive into consideration, implies an additional armature current of approximately 5 A. This estimate however excludes the inherent frictional resistance in the rolls as only rotary inertias were called into play in the simulation.

IV. Alternative Pass Design Considerations

One of the major advantages of simulation lies in its ability to examine "what-if" scenarios and carry out virtual rolling trials as opposed to actual field trials, which carry with them significant cost and logistic implications. A comparative study was done here of two alternative design considerations in the penultimate (sixth) pass of the intermediate train.

In the present study, the impact of altering the collar radius (rc) near the open flange of the top roll in the sixth pass was examined. In the first alternative (case A), the value of rc was considered as 20 mm while in the second (case B) it was reduced to 6 mm. The typical simulation result indicating the vertical roll force component (RF1) employing the larger rc value has been shown in Fig. 2.

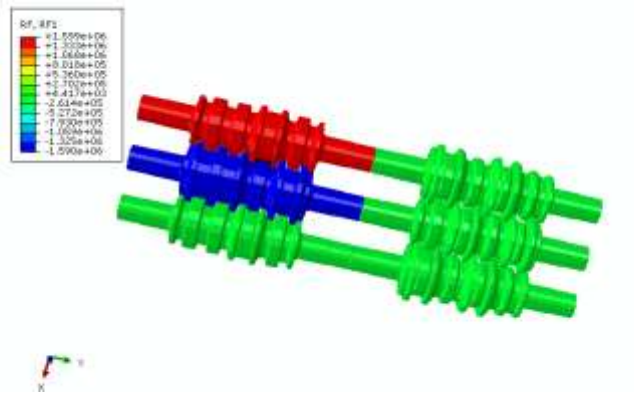

Fig. 2. Vertical roll force component (RF1) in penultimate pass (Case A: higher rc value)

The roll force and torque components for the two cases have been summarized in Tables 1 and 2. The total values work out as 86.55 x 10^3 Nm and 3.19 x 10^6 N for the torque and force components, respectively for case A. In case B, the reduced value of rc yielded 108.61 x 10^3 Nm as the total torque component and 3.27 x 10^6 N as the total force component, indicating an increase of 25% and 2.5%, respectively, over the corresponding values obtained in case A, which employed a higher value of rc.

Table -1 Roll response (rc = 20.0 mm) in penultimate intermediate pass – case A

Roll	Torque (RM2)	Roll	Force (RF1)
Middle Roll (Intm #1)	**7.56 x 10^3 Nm**	**Middle Roll (Intm #2)**	**1.59 x 10^6 N**
Top Roll (Intm #1)	**78.99 x 10^3 Nm**	**Top Roll (Intm #2)**	**1.60 x 10^6 N**

Table -2 Roll response (rc = 6.0 mm) in penultimate intermediate pass – case B

Roll	Torque (RM2)	Roll	Force (RF1)
Middle Roll (Intm #1)	**14.22 x 10^3 Nm**	**Middle Roll (Intm #2)**	**1.63 x 10^6 N**
Top Roll (Intm #1)	**94.39 x 10^3 Nm**	**Top Roll (Intm #2)**	**1.64 x 10^6 N**

The impact of rolling in the subsequent (seventh) pass of the individual sections resulting from the two alternative designs was also examined. Simulation results for pass 7, using stock from the smaller rc alternative (case B) in pass 6, seem to suggest a marked decrease in roll torque (around 47.8%) , but also a significant increase in roll force (around 19%) in comparison to the corresponding values obtained by rolling the stock resulting from case A (Tables 3 and 4).

Table -3 Roll response (stock from rc = 20.0 mm in previous pass) in final intermediate pass

Roll	Torque (RM2)	Roll	Force (RF1)
Middle Roll (Intm #1)	**85.44 x 10^3 Nm**	**Middle Roll (Intm #2)**	**890.78 x 10^3 N**
Bottom Roll (Intm #1)	**21.88 x 10^3 Nm**	**Bottom Roll (Intm #2)**	**883.15 x 10^3 N**

Table -4 Roll response (stock from rc = 6.0 mm in previous pass) in final intermediate pass

Roll	Torque (RM2)	Roll	Force (RF1)
Middle Roll (Intm #1)	**37.28 x 10^3 Nm**	**Middle Roll (Intm #2)**	**1.10 x 10^6 N**
Bottom Roll (Intm #1)	**18.73 x 10^3 Nm**	**Bottom Roll (Intm #2)**	**1.01 x 10^6 N**

This preliminarily suggests that decreasing rc in the penultimate pass has a deleterious impact on the vertical roll force component in the subsequent pass which can have potential implications on the product dimensions. The decrease in roll torque for case B, on the other hand, may not be of decisive significance in view of the decreased torsional loads in the last passes relative to those in the initial ones of the intermediate stand. The results seem to suggest, therefore, that between the two alternatives, a higher value of rc in the penultimate pass would be preferable.

V. CONCLUSION

The paper deals with some of the typical issues involved in and possible applications of three-dimensional rolling simulation of a typical structural steel section. The influence of coupling of rolls and that of pass design changes on response during rolling were studied. Some computational considerations for effecting economy in computation were also briefly referred to.

Although the results presented in the paper need more extensive validation study, they can serve as preliminary information to set the course for further investigation. As a tool to visualize the rolling process at close quarters and examine process alternatives and parameters so resulting, simulation offers a convenience that other investigative approaches may not. Several challenges need to be resolved, however, in the pursuit of pragmatic and accurate three-dimensional computer simulation of non-flat rolling. These may well be worth the effort, however, given the paucity of theoretical formulations for rolling of non-flat products and the unbounded potential of this cost-effective tool.

VI. REFERENCE

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