A New Cross Wedge Rolling Process for Producing Rail Axles

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Abstract. Rail axles are large-size parts produced in large batches. Currently, these parts are produced by metal forming techniques such as rotary forging, open die forging with hydraulic presses and open die hammer forging (minimum ram weight: 3 Mg). Nevertheless, not only are the above methods far from being efficient, they also lack accuracy (open die forging). As a result, new techniques for producing rail axles are constantly developed. One of such alternative techniques is based on the use of cross wedge rolling (CWR), which is the subject of the present study. An innovative roll design for producing rail axles by CWR is proposed. The rolls are provided with three pairs of wedge tools that act simultaneously on the workpiece and form the part in one revolution of the rolls, i.e., during 20 s. The numerical modelling of a CWR process with the proposed roll design reveals that the solution can be used to produce railway axles with the desired geometry. This technique, however, requires relatively high loads and torques. To decrease the force parameters, the forming process was modified and ran in two operations. The first operation consists in forming the central step of the workpiece while the other one involves the formation of steps on the ends of the workpiece. The results of the new simulation show a significant decrease in the loads and torques, which is caused, among others, by reducing the nominal diameter of the rolls from 1600 mm to 1200 mm. The numerical findings can be used to design a rolling mill for producing rail axles.

Keywords: Rolling, Finite element method (FEM), Tool geometry

1 Introduction

Rail axles, which come as solid or hollow pieces, are large-size parts manufactured in large batches. For instance, the annual production of rail axles in China alone amounts to approx. 300,000 pieces [1], which – taking into account their weight (approx. 400 kg) – gives an annual production of 120,000 tons.

Currently, rail axles are produced by open die forging on hammers or hydraulic presses or by rotary forging. Nonetheless, not only are these methods far from being efficient, they can lack accuracy (open die forging processes). For this reason, new methods for producing rail axles are sought, with emphasis on techniques based on skew rolling [2] and cross wedge rolling (CWR) processes [1, 3-5].

In this paper, the authors propose novel methods for producing rail axles described by the parameters shown in Fig. 1. The proposed solutions are based on the CWR process and allow for practically waste-free manufacturing of these parts. The proposed solutions are verified by FEM analysis.

2 New trends in the CWR technique

Cross wedge rolling (CWR) is widely used for producing parts such as stepped axles and shafts and for manufacturing preforms [6]. In recent years, however, numerous studies have been performed to develop the technological potential of this effective manufacturing technique. New trends in cross wedge rolling include:

- CWR for parts with steps with cross sections different than circular (e.g. square, oval, hexagonal), formed by tools with specially profiled forming surfaces [7-9]. The rolling of such parts is characterized by oscillatory variations in the forces resulting from cyclic changes in reduction ratio;
- CWR for toothed or worm shafts using tailor-made inserts fixed behind the sizing zone of the tools [10-14];
- CWR for hollow parts performed with an elongated sizing zone of the tools [3, 15-21];
- CWR for products made of non-ferrous materials such as titanium alloys [22-24], aluminum alloys [12], magnesium alloys [25], superalloys based on nickel [26] and copper [27];
- multi-wedge rolling in which the workpiece is

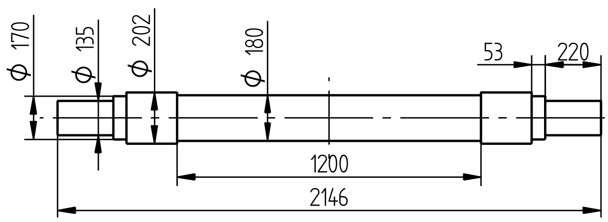

Fig. 1. Rail axle analyzed in the study

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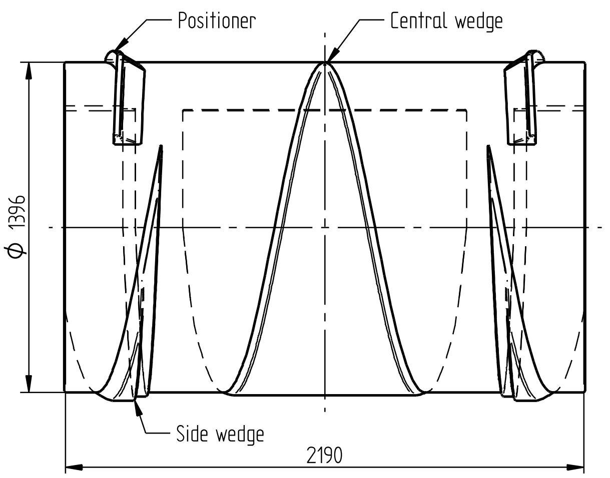

Fig. 2. Roll with 1600 mm nominal diameter used in one-stage CWR for rail axles

formed simultaneously by more than one pair of tools. This rolling technique is used in the production of very long axles and shafts (e.g. for the automotive or railway industry) [1, 3-5, 28] and in the processes wherein several short parts are formed simultaneously (e.g. balls for ball mills) [29-31].

3 CWR for rail axles

3.1 One-stage CWR process

First of all, the study investigated whether it was possible to produce a rail axle in one CWR operation, i.e., using a pair of identical tools, one of them being

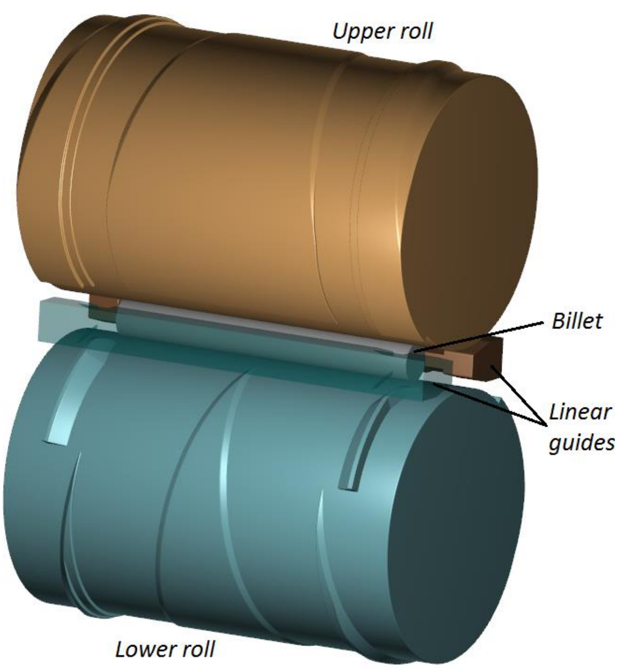

Fig. 3. Geometric model of CWR for rail axles formed with 1600 mm diameter rolls

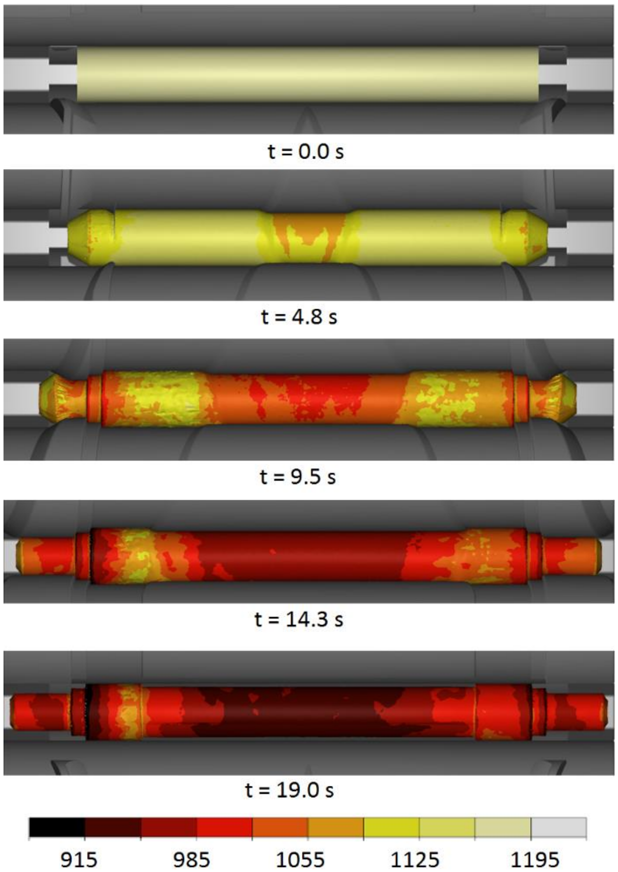

Fig. 4. Workpiece shape changes and temperature distribution (in °C) in CWR for producing rail axles

shown in Fig. 2. Given the overall dimensions of the product, a multi-wedge rolling technique was employed in which the axle is deformed simultaneously by three pairs of tools that form the central step and end steps at the same time. In addition, due to product elongation caused by the action of the central wedge tool, the side wedge tools are deflected from the tool motion direction.

The proposed solution was verified by a numerical simulation in Forge NxT 1.1. This software had previously been used for the modeling of skew and cross rolling processes [32-34].

Fig. 3 shows a geometric model of the analyzed rolling process. The model consists of two rolls (shown in Fig. 2), two guides (for maintaining the billet in the working space between the rolls) and a billet with a diameter of 202 mm and a length of 1660 mm. The billet was assigned the properties of 42CrMo4 steel, the model of which was obtained from the material database of the employed software. The billet was preheated to a temperature of 1180 °C, and the temperature of the tools during the rolling process was maintained constant at 250 °C. The rotational speed of the rolls was fixed at 3 revolutions per minute, the heat transfer coefficient between the workpiece and the tools was set to 10 kW/m^2K, and the friction factor on contact surface was set equal to 0.99.

The numerical simulation allowed for close examination of the proposed rolling process for producing a rail axle shown in Fig. 4. Examining the

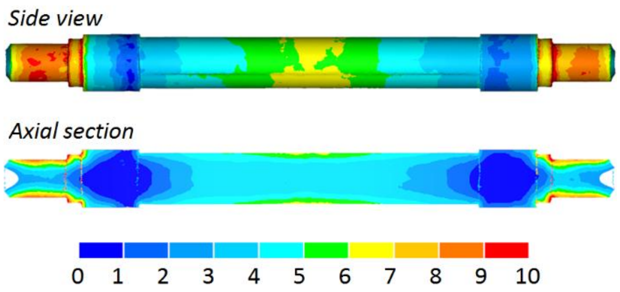

Fig. 5. Distribution of effective strains in a rail axle produced by CWR

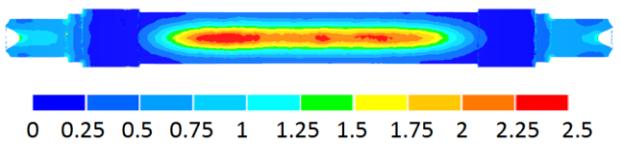

Fig. 6. Damage function distribution, as calculated in accordance with the Cockcroft-Latham criterion

data in the figure the following can be observed: first of all, tapered ends are formed on the billet to reduce the size of cavities on the ends of the workpiece. Next, all steps are formed at the same time, and, finally, the workpiece is formed into the desired shape. It is worth stressing that the temperature of the workpiece during the rolling process remains in the hot working range. Significant temperature drops only occur in the surface layers of the workpiece.

Fig. 5 shows the distribution of strains in the produced rail axle. It can be observed that the highest strains are located in the surface layers of the steps on the workpiece ends and at the center of the central step, hence where the tools cut into the billet. This distribution of strains results from rapid metal flow in a circumferential direction and is typical of CWR processes [6].

The employed software allowed for investigating the probability of crack occurrence at the center of the workpiece. To this end, we examined the distribution of the damage function calculated in accordance with the Cockcroft-Latham criterion, as shown in Fig. 6. It can be observed that the function reaches very high values in the axial zone, which indicates the probability of

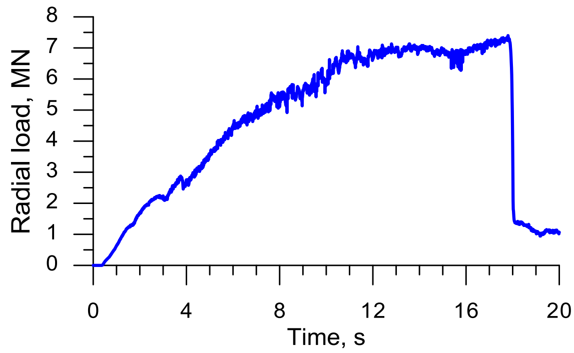

Fig. 7. Radial load distribution on the roll

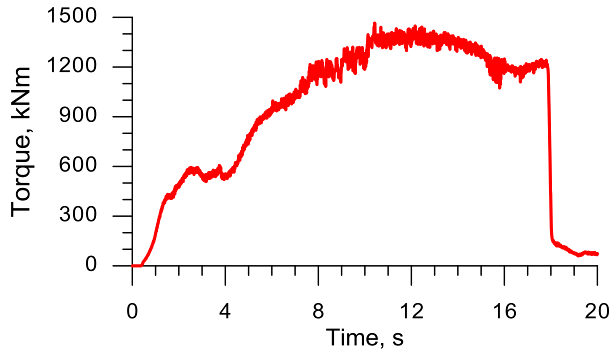

Fig. 8. Torque distribution on the roll in one-stage CWR

material cracking in this region. This stems from the difficulty with removing ovalization of the cross section of the central step, which leads to cyclic compression as is the case in the Mannesmann process.

Figs. 7 and 8 show the distributions of the force parameters, i.e., the radial load (acting on the rolls) and the torque. Analysis of these figures reveals that the realization of the proposed rolling process for rail axles will require the application of high loads and torques. What may be particularly difficult to obtain in practice is a torque amounting to 1.4 MNm, as this requires a power of 900 kW.

3.2 Two-stage CWR process

To decrease force parameters in the rolling of rail axles, we also investigated a CWR process performed in two

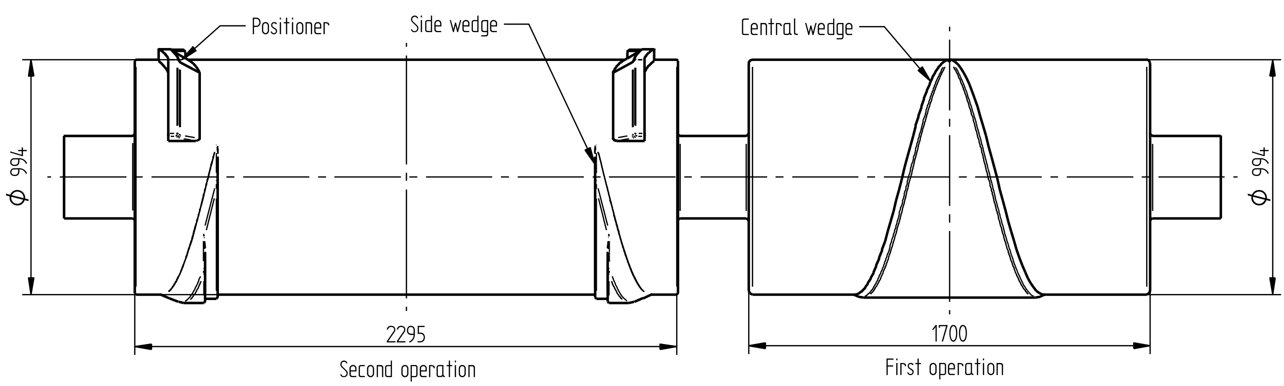

Fig. 9. Roll with a 1200 mm nominal diameter, used for forming rail axles by two-stage CWR

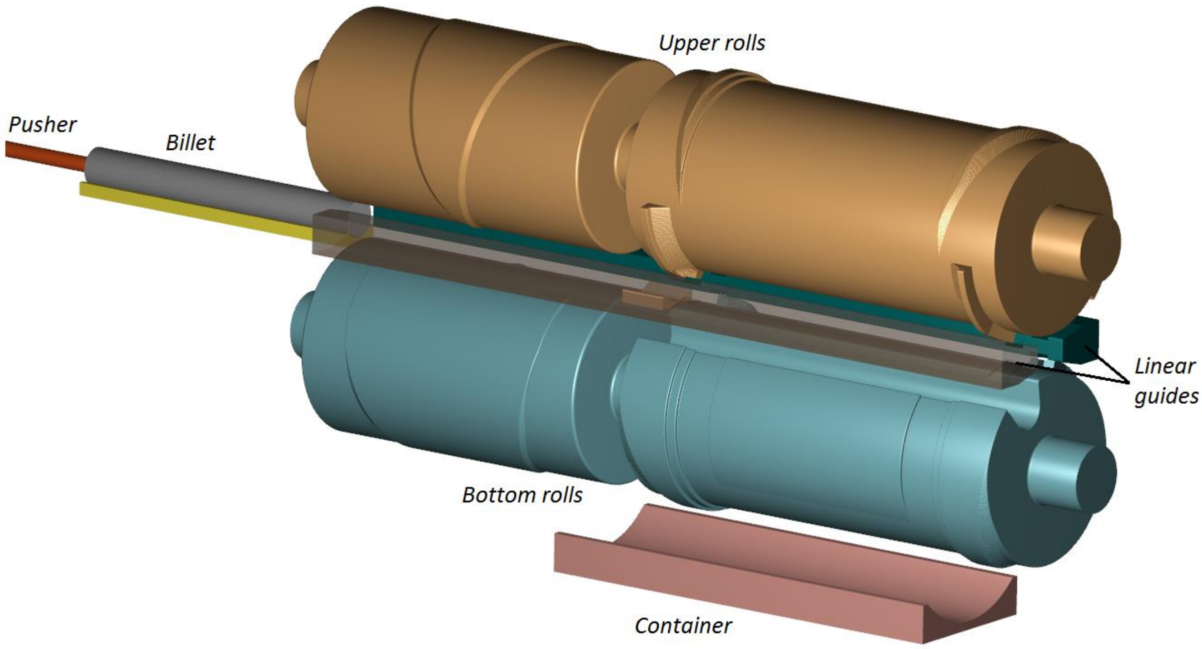

Fig. 10. Model of two-stage CWR for producing rail axles by rolls with 1200 mm nominal diameter

operations with two pairs of rolls shown in Fig. 9. The first stage involves forming the central step of the part. Second, following the positioning of the billet between the guides, steps are formed on the ends of the workpiece. A side effect of dividing the forming process into two operations is that the nominal diameter of the rolls (equal to the axial spacing between the rolls) must be decreased from 1600 to 1200 mm.

Similarly to the one-stage rolling process, the proposed design solution was first verified by a numerical simulation. The geometric model of the two-stage CWR process is shown in Fig. 10. This time, the entire production cycle was modelled, from the feeding of the billet and passing the workpiece to the other pair of the rolls, to the removal of the finished part from the working space of the tools. The parameters of the forming process were identical to those applied in one-

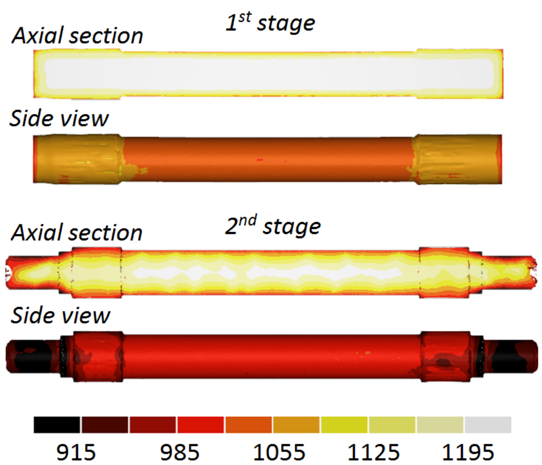

Fig. 11. Temperature distribution (in °C) in a rail axle produced by two-stage CWR

stage CWR. The speed of the pusher for billet displacement was set to 100 mm/s.

Analysis of the numerical results of the proposed two-stage CWR process for producing a rail axle demonstrates that despite extending the forming time to 90 s, the temperature of the billet is in the hot working range (Fig. 11). This may results from a large accumulation of heat. The highest drops in temperature can be observed in the end steps of the product, however the drops only occur in the surface layers of the material.

The proposed change to the CWR technique also led to reducing strains in the product (Fig. 12). This results from decreased shear stresses (considered to be redundant) due to reduced diameter of the roll, as a result of which individual steps on the rail axle are formed by shorter wedge tools. In addition to this, one must also take account of the fact that cross-sectional ovalization in individual steps of the axle is reduced.

As a result of dividing the rolling process into two operations, the probability of crack occurrence in the central step of the product is greatly reduced (Fig. 13). This is reflected in a two-and-a-half decrease in the damage function calculated according to the Cockcroft-

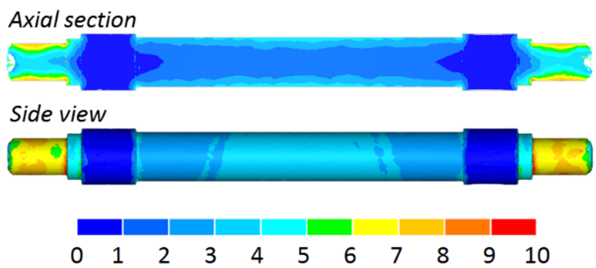

Fig. 12. Distribution of effective strains in a rail axle produced by two-stage CWR

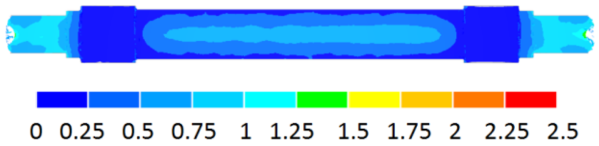

Fig. 13. Damage function distribution in a rail axle produced by two-stage CWR, as calculated in accordance with the Cockcroft-Latham criterion

Latham criterion. Therefore, it can be assumed that the two-stage CWR helps prevent material cracking.

In addition, the two-stage CWR technique for producing rail axles has a positive effect on the force parameters of the process. The maximum radial load (which ensures stiffness of the rolling mill) is reduced by 25% while the torque is decreased by as much as 60%. In this case, the estimated power of the rolling mill is only 350 kW. In connection with this, it should be noted that rolling mills currently used in industrial practice have similar parameters [35]. For example, the H1400 rolling mill manufactured in China is equipped with 1400 mm diameter rolls, and its driving power is 220 kW. Another Chinese rolling mill, D46-165x1200, is provided with the rolls described by a diameter of 1200 mm and the engine with a power of 315 kW. Given the above, the construction of a rolling mill for two-stage rolling of rail axles is feasible.

4 Conclusions

The results of the study lead to the following conclusions:

- rail axles can be produced by the CWR method performed in either one or two stages;
- the two-stage CWR technique is more effective for two reasons: (i) it prevents material cracking in the axial zone of the workpiece, and (ii) it requires lower loads and torques;
- among rolling mills available on the market, one can find machines with parameters similar to those of rolling mills for producing rail axles. Therefore, the construction of a tailor-made rolling mill for producing these parts is feasible;
- the research on the CWR method for producing rail axles should be extended to include experimental tests on real material.

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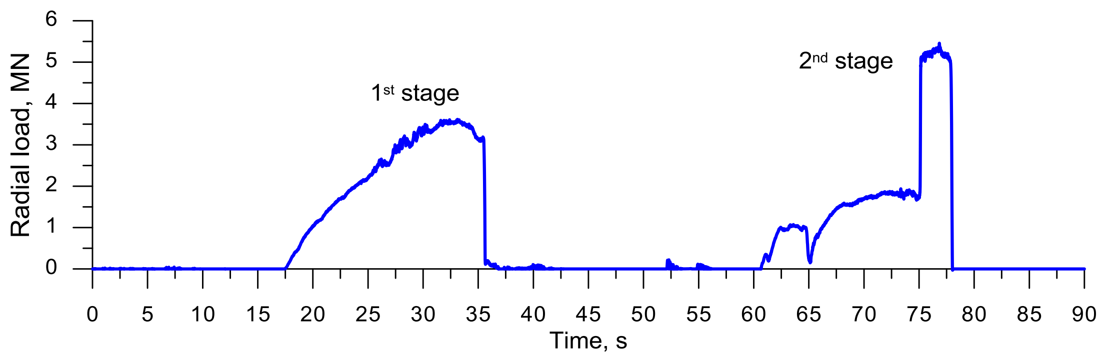

Fig. 14. Radial load distribution in two-stage CWR for rail axles

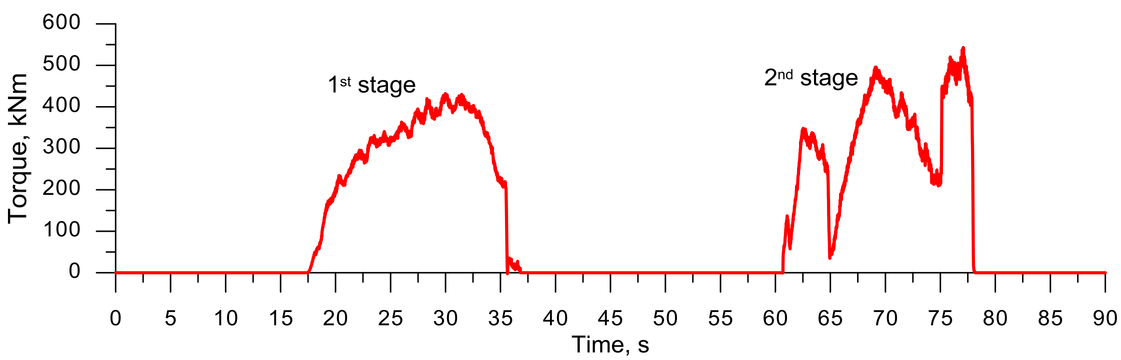

Fig. 15. Torque distribution on the roll in two-stage CWR for rail axles

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