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INFLUENCE PARAMETERS ON TOOL DEFLECTIONS IN ROLL FORMING

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Abstract

In this paper, the compliant behaviour of a conventional setup of a roll forming mill is examined. On such a mill, few parts significantly contribute to the deflection of the tools when a strip of metal is transported and deformed. Namely the shafts with strung rolls. These components are characterised by the lowest stiffness. The tools are changed in case a changed profile geometry is produced. This leads to changing properties of the setup through changing rolls and changing assembly parameters. The identification and understanding of the main impact factors on the stiffness of this assembly is crucial to ensure constant properties when disassembled and assembled again. The roll set, the axial preload and the feather key position are assumed to have the biggest impacts. The roll set is the set of tools used in the considered forming pass. The axial preload is induced to clamp the rolls axially to keep them in position. The rotational position of the feather key is changed as the shaft turns and is considered as an impact factor on the deflections, as the groove weakens the shaft. These parameters are varied in a set of experiments to gather data to evaluate the significance of these impact factors. In the experiments the setup is burdened with a process-like load. Deflections and loads are measured and recorded simultaneously. The collected data sheds light on the main impact factors on the deflections, which are the roll set and the axial preload. These factors should deviate as little as possible from the first assembling to following assembling procedures of the identical rolls to ensure the same force-deflection behaviour of the whole setup. The data is then used to generate a nonlinear regression model to show that the used parameters are sufficient to describe the deflection behaviour of such a mill.

Keywords: roll forming; stiffness; deflection behaviour of machinery; shaft with rolls; tool deflection under load

1. Introduction

Roll forming is a continuous bending process, where an infeeding metal sheet is formed incrementally through contoured forming rolls at room temperature without changing the thickness of the material [1]. These rolls occur in pairs of horizontally arranged assemblies - the forming passes. These consecutively arranged forming passes gradually form the final profile shape. The process is highly productive for manufacturing profile shaped mass products. The range of applications of roll formed profiles is nearly endless. From automotive and construction industry over agriculture and environmental technology to the transportation and industrial engineering sector. As mentioned, the process is effective in mass production, but when it comes to increased demanded flexibility and lower quantities, roll forming has some disadvantages and other manufacturing methods are preferred. One of the big disadvantages is the high setup time for a changed profile geometry at the production line.

Roll sets, for producing the desired profile, are aligned on shafts. The rolls need to be set up in the right position, relative to each other and relative to the next as well as the prior forming pass, to ensure exact profile dimensions and to prevent forming defects in the process [2]. In order to compensate in-process deflections during production already in the setup process, offside the production plant, it is of high interest to predict the deflection of the shafts with equipped rolls under realistic loads. The shafts, equipped with rolls, are the most compliant components of conventional forming mills [3]. In consequence, time intense and worker’s experience depending fine adjustments at the production line can be reduced, which leads to less machine downtime [4]. In [3] and [5] the tool stiffness in the finite element simulation is considered by simple linear springs. This implementation lacks in accuracy when it comes to asymmetric profiles geometries and therefore an asymmetric force distribution between the operator- and drive-sided forming stand. To predict the deflections, a more detailed understanding of the behaviour is required. The generated knowledge can be used to build up a model of the machinery for simulations and improvements of the setup. Gotlih [6] investigated the stiffness behaviour of an industrial robot to build a simulation model. This model then was used to improve its mechanical characteristics. In roll forming, the deflection of the setup is also of high interest when it comes to changing material. An increase in strength or thickness of the material changes the arising forces in the roll forming process, which leads to increased deflections of the shafts. These variations may cause geometric changes of the produced profile. In the worst case the profile does not meet the set geometric tolerances anymore. In order to simulate such geometric deviations due to varying material properties, the tool stiffness has to be represented in an accurate way. This paper concentrates on the identification of the significant parameters that may vary the mechanical characteristics of the setup.

Although similar mechanical designs are common in different fields of engineering (e.g. gears, drive shafts), they mostly differ substantially from the current problem. In [7] the deflection of stepped shafts is investigated and a simple model approach is established to calculate their deflection. The setup used in this paper is similar to a stepped shaft, but differs in the presence of more than one loaded part. E. Radi [8] presents a mathematic modelling of a shaft-hub press fit. Such a fit behaves significantly different than a loose fit, which is present between the rolls and the shaft of a roll forming mill. An investigation of a shaft supported on both ends with strung rolls that are not press fitted, axially burdened with a preload and forced to bend as in the current focus, has not been found in literature.

2. Materials and methodology

This paper presents an empirical approach to study the mentioned load-deflection behaviour. The loads are being induced by manual infeed of the upper against the lower roll set. Vertically arranged probes (TESA GT62 DC) in discrete positions acquire the deflections of the forming rolls (see Fig. 1 ①). Force sensors (Kistler 9333A), which are installed in the forming stands, measure the generated load ②. The axial preload on the rolls and shaft is detected by a strain gauge-based sensor system ③.The data is acquired by a DAQ-system (National Instruments 9205). The sampling frequency for all experiments is set to 50Hz. The roll sets are held in position by an axial preload, which is induced by a nut at the end of the shaft (see Fig. 1). This creates axial compression force between the rolls and causes tensile stress in the shaft. To reveal the influence of the preload, six different preload levels are investigated: 20kN/40kN/60kN/80kN/100kN/120kN. Previous studies showed that these are realistic values for the occurring preloads in the process, as the nuts are tightened by pneumatic impact wrenches, which are dependent on the handling, type of the wrench and the actual pressure in the pneumatic system.

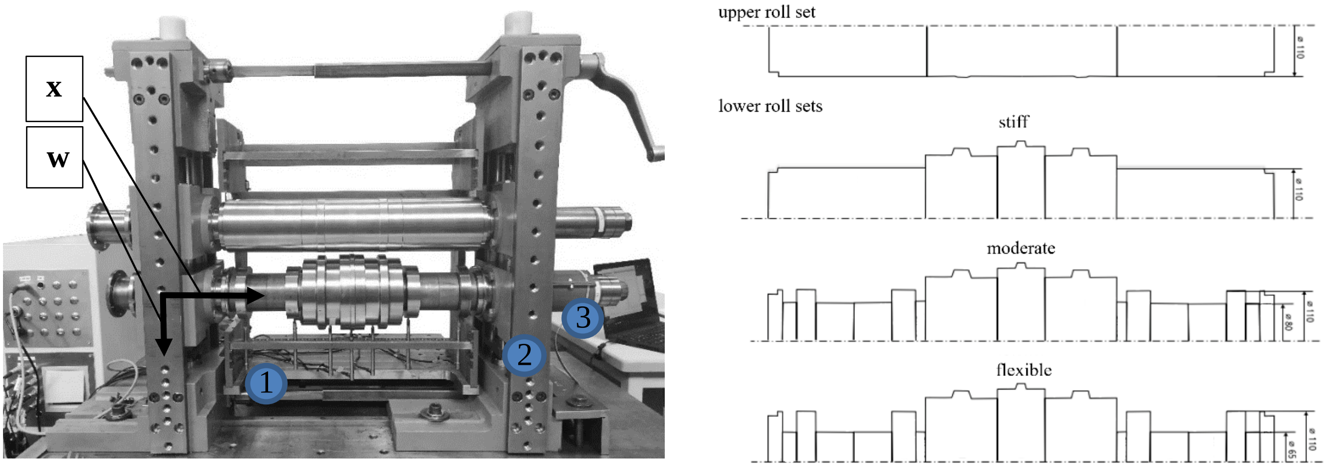

Fig. 1. Experimental setup and contour lines of the used roll sets

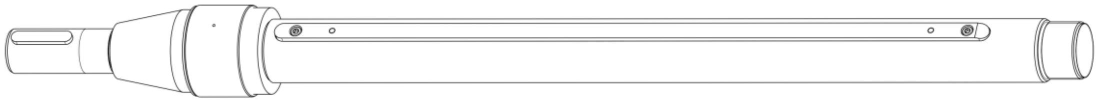

Fig. 2. Shaft with feather key

The rolls are connected to the shaft by a feather key (Fig. 2). The key itself, as well as the groove in the shaft, are also impact factors on the resilience of the system. Therefore, the angular key-position is also varied: horizontal, vertical in the compression zone and vertical in the tension zone. To represent the maximum variation of forming rolls, three different roll sets are studied (Fig. 1 right). One roll set being rather stiff (large diameters, wide rolls, small clearance between rolls and shaft) and one being relatively flexible (small diameters, many individual short rolls, small clearance between rolls and shaft). The third roll sets' geometric characteristics are somewhere in between the others. To generate reliable data, every experiment is repeated five times. The upper roll set is identical in all experiments (Fig. 1 right). All individual parameters which were varied and the chosen stepping is represented in Table 1.

Key position	**Roll set**	**Axial preload [kN]**
Horizontal (H)	Flexible	20
Vertical compression (VC)	Moderate	40
Vertical tension (VT)	Stiff	60
		80
		100
		120

Table 1. Table of Variations

The collected data is used to generate a regression model. Based on this model, it is presented that the used parameters are sufficient to describe the deflection behaviour of a roll forming mill.

3. Results

The measured data is presented in Fig. 4 to Fig. 6. The ordinate represents x-position (see Fig. 1). The abscissa plots the deflections measured on the rolls during the experiment with a certain load level. The deflection of the forming stands is compensated in all data shown in the following figures. This leads to "pure data" of the deflections of the shafts equipped with forming rolls. An exemplary maximum external load of 20kN is used, because it represents often occurring forming forces.

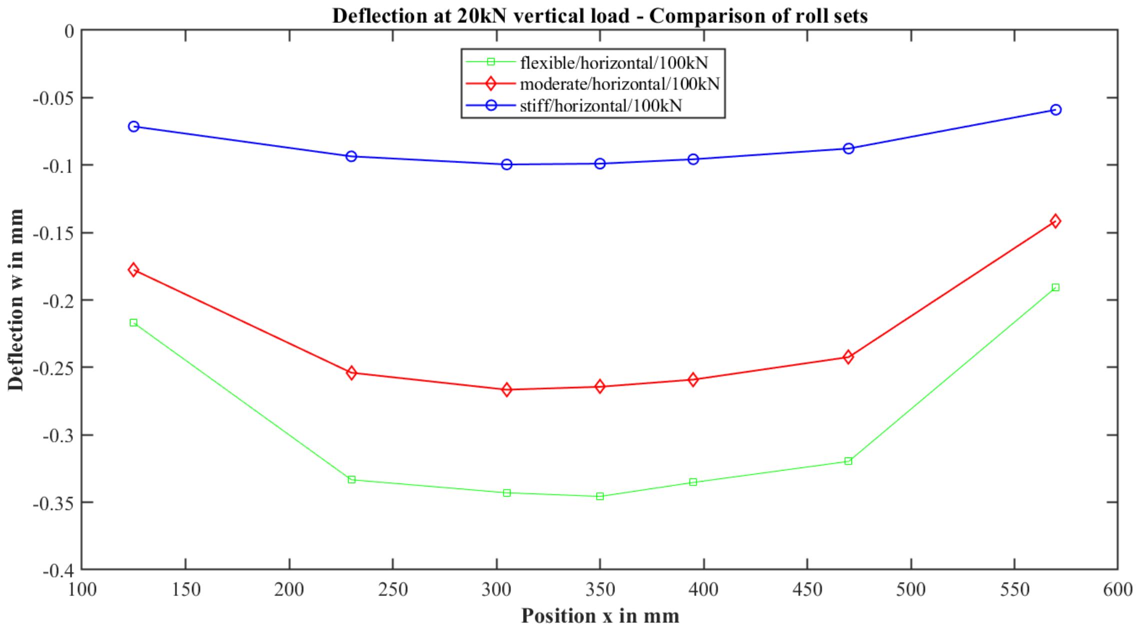

Fig. 4. Measured deflections at 20kN load – Variation of roll sets

Figure 4 shows the differences in the deflections caused by variation of the roll sets. The flexible roll set shows a more substantial deflection than the stiff roll set, at the same load and a preload level of 100kN. This behavior can also be observed for all other preload and load levels. This indicates a significant influence of the used roll set on the occurring deflections of the rolls when a load is induced.

The next varied parameter is the axial preload. Fig. 5 shows that increased axial preloads result in a decrease of the deflections of the tools. Additionally, at high preload levels, a small change in preload results in a small absolute change of the observed deflections.

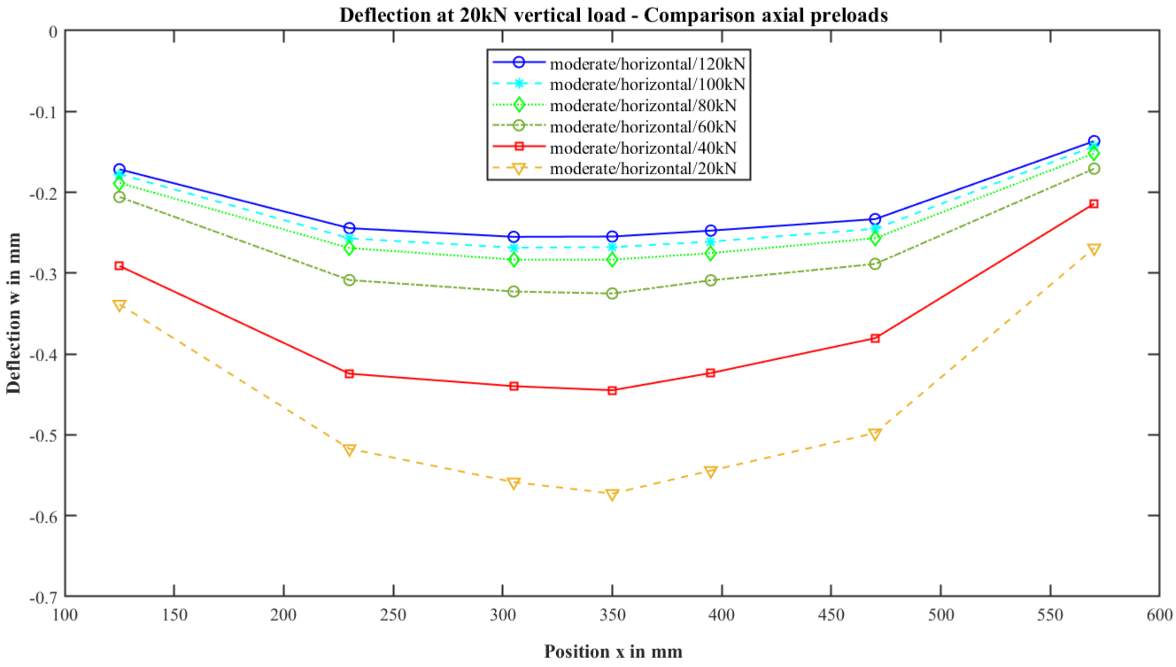

Fig. 5. Measured deflections and forces - Variation of axial preloads

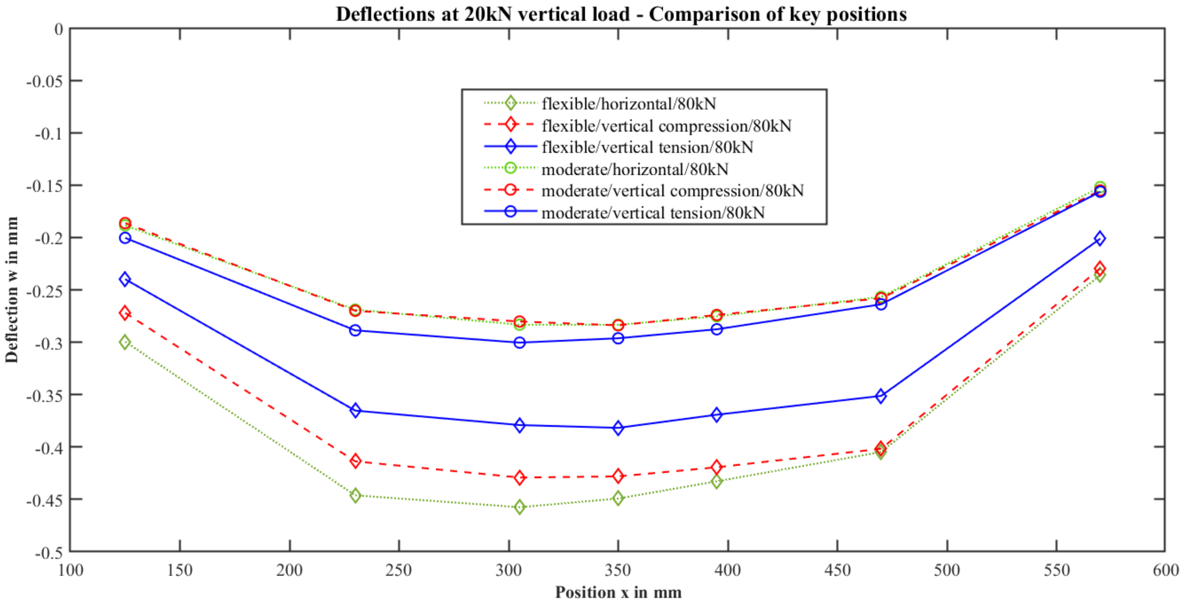

Fig. 6. Measured deflections at 20kN load – Variation of key positions

The third variation parameter -the key position- shows blurred behaviour. A difference can be observed in the deflections of the different key positions when all other parameters are held constant (Fig. 6). According to Figure 6, a definite impact of the feather key position, independent of the roll set, can not be derived. For the flexible roll set, the horizontal key positions show the highest deflections. On the other hand, for the moderate roll set the vertical tension position of the feather key is dominant in deflections. This inconclusive behaviour can be observed in all data sets.

Figure 7 presents a comparison of the behaviour of the flexible and stiff roll set with different preloads. The ordinate represents the occurring deflection of a point on a roll at x=350mm. This point is exactly in the middle of the roll sets. The actual load on the rolls during the experiment is plotted on the abscissa. The lines represent the deflection of the middle of the roll sets when the force is gradually increased. The deflection at this point has been identified as a characteristic to clearly compare different measurements.

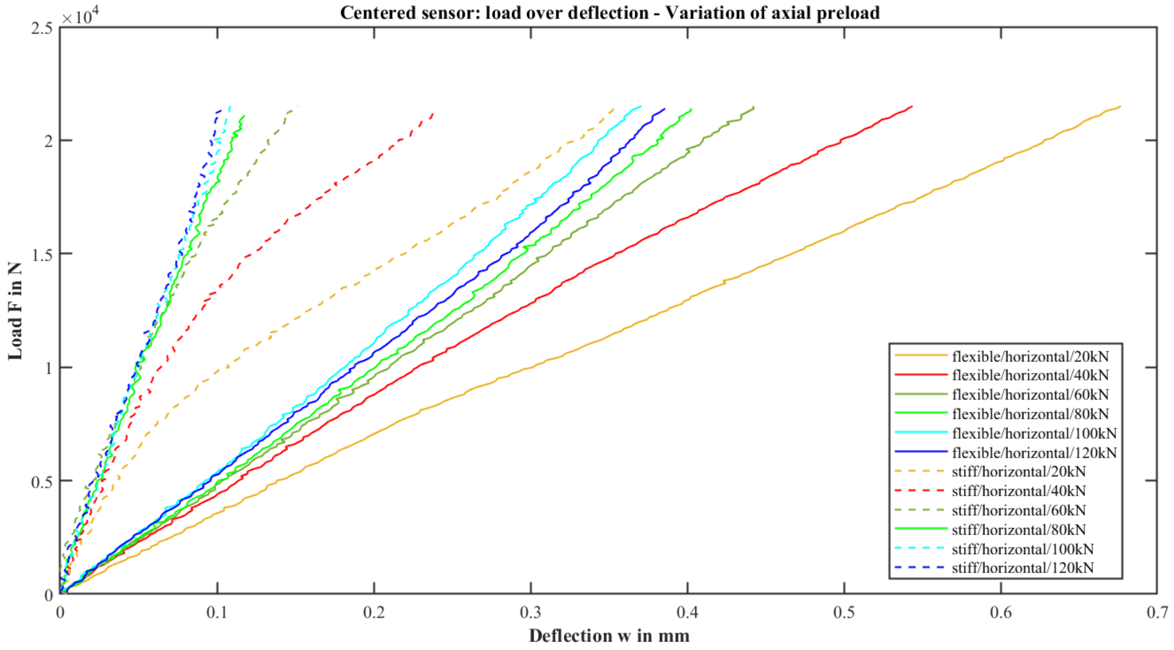

Fig. 7. Measured deflections with increasing load – Variation of axial preload

In the measured range of the load, curves with higher preload levels tend to show almost directly proportional relation between deflection and induced load. Curves of experiments with lower preload behave differently.

The stiff roll set shows a much more non-linear behaviour over all preload levels than the flexible roll set. This trend can also be observed for the moderate roll set (not shown here). The following thesis is established to explain this behaviour: The stiff roll set consists of little individual rolls with big lengths and diameters compared to the other roll sets. These circumstances force the rolls to tilt more relative to each other with rising induced loads. This tilting is suppressed by high preloads and therefore occurs at higher load levels when the preload is increased. This effect leads to nonlinear behaviour in the deflection-load plots.

The maximum deflection of a point on the rolls centred in the middle of the forming pass, loaded with 20kN, is used as the target value for the following regression model (see Fig. 4). This point seems to be a proper characteristic for the compliance of the setups.

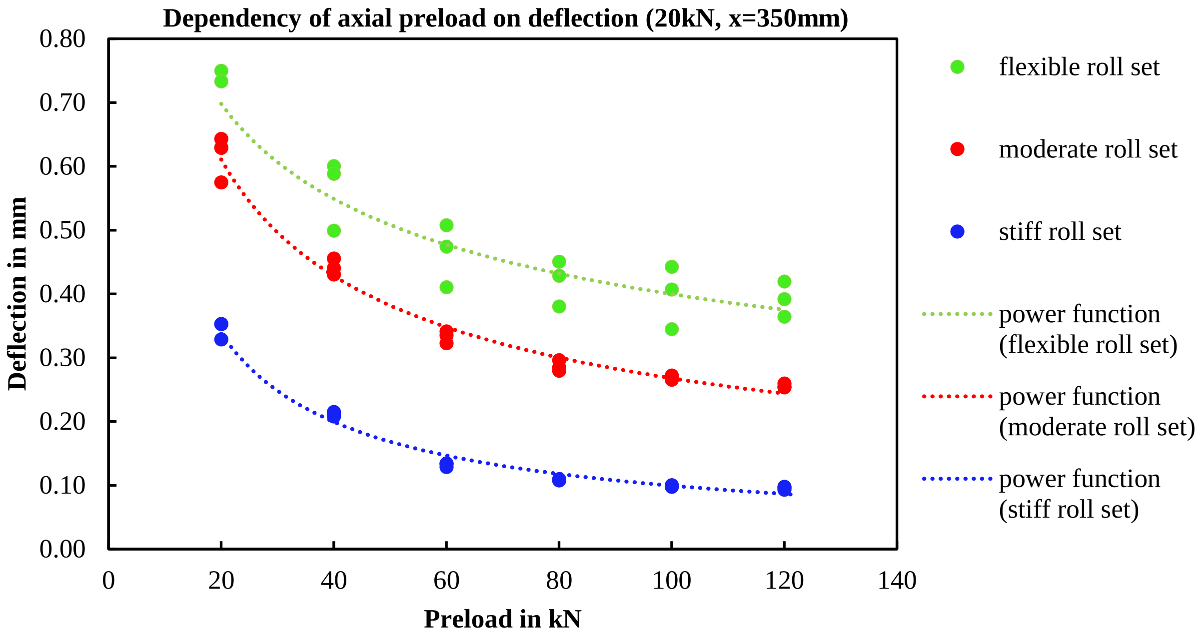

Fig. 8. Dependency of axial preload on deflections at 20kN load and at position x=350mm

Figure 8 shows an obviously nonlinear dependency of the axial preloads on the measured deflection at 20kN at x=350mm. Therefore, a linear regression cannot model the data properly. This nonlinearity is modelled by a power function for the individual roll sets.

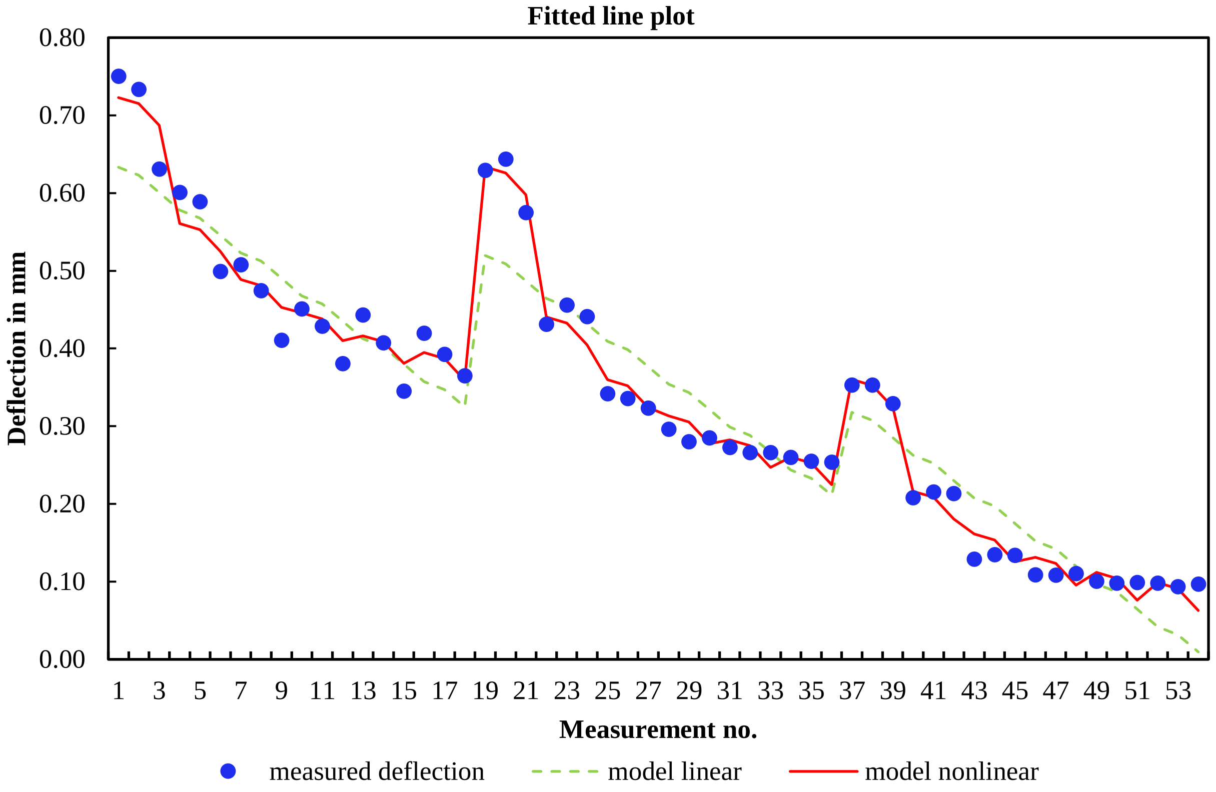

Fig. 9. Comparison of all Observations and the found models

Figure 9 presents the difference of the regression models compared to the measured data. For purposes of presentation the abscissa contains the numbers of the measurement ordered by roll set (1-18: flexible, 19-36: moderate, 37-54: stiff), axial preload in ascending order and by key positions (VT, VC, H). The found nonlinear model matches the measured data satisfactorily.

The found function is:

$$\begin{aligned} w = {} & flex \cdot 2.454 \cdot preload^{-0.494} + moderate \cdot 3.450 \cdot preload^{-0.604} + stiff \\ & \cdot 3.402 \cdot preload^{-0.757} + 0.156 \cdot flex + 0.062 \cdot moderate \\ & - 0.028 \cdot H + 0.008 \cdot VT \end{aligned} \tag{1}$$

The variables "flex", "moderate", "stiff", "H" and "VT" in equation (1) represents boolean values for the considered test setup. Where the first three variables represent the roll set and the others are used to consider the key position. The numbers were rounded to three decimal places.

The influence of the key position is rather blurred. Especially for the flexible roll set, the key positions seem to show a non-negligible influence on the deflections (see Fig.9). The other roll sets do not show this behaviour in the same intensity. Further measurements are necessary to determine the impact of the key position in a more detailed way. It is possible that the effect of the key position is superimposed by other unknown effects.

4. Conclusions

This study sheds light on the main impact factors on the observed deflections. Obviously, the roll set and the axial preload show a major impact. The key position turned out to be less significant or even inconclusive. The axial preload needs to be kept at defined levels to get reproducible behaviour of the setup under induced load. It can also be seen that the stiffness of the assembly increases with higher preload. In the investigated load level spectrum, the deformation and the loads show a nearly linear relationship at higher axial preloads. Limiting the preload to high levels therefore will facilitate the creation of a simple model for the behaviour of the whole setup. Additionally, it guarantees reduced scatter in the mechanical characteristics of the reassembled forming passes.

The influence of the key position or other yet unknown influence factors should be investigated in further studies. More data of different roll sets should be collected to expand knowledge of the behaviour of the setup. To clarify the thesis about the tilting of the rolls, a FE-model may be used for validation.

The collected data may also serve as a basis for validations of simulation models of the deflection of the rolls. With these simulation models, the goal of compensating in-process deflections in the setup process offside the production plant to decrease fine adjustment times and scrap production on the production plant.

The applied regression model shows that information about the roll set, the axial preload and the load level are containing enough information to build up models for the deflection behaviour of such a roll forming mill. The model may be expanded to additionally collected data for other roll sets and other load levels than 20kN. Further investigations need to be done on how the information of the roll set can be broken down to a few parameters derived from roll set geometry to reliably determine the load deflection behaviour even for roll sets of unknown mechanical characteristics.

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