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Improving the thickness accuracy of cold rolled narrow strip by piezoelectric roll gap control at high rolling speed

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ABSTRACT

Particularly in fast rolling mills, conventional actuators reach their dynamic limits, when longitudinal thickness variations of the incoming strip shall be reduced with high accuracy by model-predictive roll gap control. Accordingly, the applicability of highly dynamic piezoelectric actuators in combination with electromechanical spindles and a high frequency precision measurement of the thickness in front of the roll gap was examined. Rolling tests in a cold rolling mill for narrow slit strips show that this novel concept is suitable to provide the required dynamic actuation especially at high rolling speed.

1. Introduction

There is a high economic demand for enhanced thickness tolerances for rolled material. During the rolling process, a controller sets the actuators for the roll gap adjustment to minimize the strip thickness tolerances. Due to rising rolling speed, the dynamic requirements imposed on such actuators increase. Conducted investigations regarding actuators' characteristics show that from a certain rolling speed, the dynamic potential of conventional actuators is exploited [1]. Therefore a further speed increase is at the expense of worse tolerances. In comparison to traditional actuators, piezoelectric actuators can reach an acceleration up to 10,000 times the acceleration of gravity [2]. Therefore, this work deals with the suitability of highly dynamic piezoelectric actuators for roll gap adjustment in rolling mills of industry scale.

Due to the elastic behavior of all parts of the mill stand, rolling force variations lead to variations of the roll gap. As most fluctuations (like incoming thickness, strength, temperature, friction etc.) influence the roll force in consequence undesired fluctuations in the thickness of the rolled material can occur.

Depending on which precision should be reached and which fluctuations shall be compensated, different types of strip thickness controllers are used in industry. These include conventional controllers like feedback control, mass flow control, feedforward control and gauge-meter control [3] or advanced control systems like a model-predictive roll gap control [4]. In addition also other product quality measures like flatness or even material properties are controlled to some extent [5].

Nowadays, mostly hydraulic or electromechanical actuators are used to control the roll gap during the rolling process. In comparison to electrical actuators, hydraulic actuators are up to three times faster [6]. However, particularly in cold rolling mills for narrow slit strips electromechanical actuators are frequently installed.

Based on European Standard EN 10140 [7] the narrowest thickness tolerance of cold rolled strips with a width smaller than 125 mm and a thickness of 1 mm is ±1.5%. As the strip gets thinner, the thickness tolerances increase up to 4.0% for a strip with a thickness below 0.1 mm.

Until now, using piezoelectric actuators in rolling mills has had relatively little attention. Ng et al. [8] describe piezoelectric roll gap adjustment for small laboratory mills in order to texture the surface in an electrical-assisted micro-rolling process. Zhou et al. [9] used a piezoelectric roll gap adjustment in a micro rolling process for surface texturing of a 15 μm deep microchannel array.

However, in other machine tools the highly dynamic potential of piezoelectric actuators is widely used. For instance, reviews on the use of highly dynamic piezoelectric actuators in the fields of grinding [10], drilling [11] and honing [12] have been published.

It is therefore the aim of the present study to investigate the application potential of piezoelectric roll gap adjustment to improve the thickness accuracy by model based compensation of thickness variations of the incoming strip. An industrial scale cold rolling mill for narrow slit strips is enhanced by high precision thickness measurement and piezoelectric roll gap actuators. Based on the theoretical evaluations given in Ref. [1], a tailored model based control was now realized and tested up to high rolling speed.

2. Suitability of piezoelectric roll gap adjustment

The elongation of the piezoelectric material depends on the applied voltage. Even though the physical destruction pressure may be up to 250 MPa, the permitted operating pressure is

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significantly lower because of depolarization [13]. Consequently, a large cross-sectional area is required for high rolling forces. However, the electrical capacity of a piezoelectric actuator rises with its cross-sectional area [13] which leads to a longer charging process for a given voltage amplifier. Therefore, the amplifier and the cross-sectional area have to be adapted to the required dynamics and rolling forces. As for narrow slit strips relatively low rolling forces are needed, two piezoelectric stack actuators of the type PSt 1000/25/150 VS35 and two voltage amplifiers with a maximum output voltage of 1000 V and a maximum output current of 3 A are used for this investigation. The piezoelectric actuators have a depolarization pressure of 70 MPa, an actor diameter of 25 mm and a height of 150 mm, respectively.

Accordingly the two selected piezoelectric actuators can only achieve a maximum force of approximately 70 kN. Fig. 1 shows on the base of a non alloyed steel (1.0330) with a thickness of 1 mm, that the range of application defined by the strip width and thickness reduction is restricted by the maximum force (red plane).

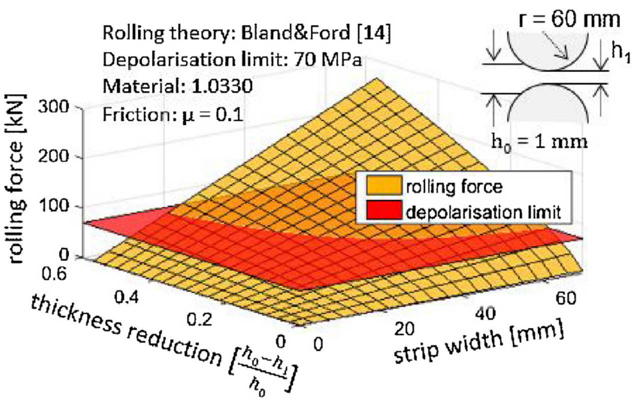

Fig. 1. Rolling forces for different thickness reductions and strip widths in comparison with the depolarisation limit of two PSt 1000/25/150 VS35.

Fig. 2 compares the step response of the piezoelectric actuator with the response of the installed spindle drive for roll gap adjustment. The elongation of the piezoelectric actuator is measured by resistive foil strain gauges and the stroke of the spindle is detected by rotation measurement.

Both actuators use a PI position control. However, the sampling rate of the piezo position piezo is 1 ms, Fig. 2 shows only this actuator position after each 3 ms for reasons of clarity. Based on a Profibus interface the sample rate of the spindle position is less. Nevertheless, it is obvious that the piezoelectric actuator in combination with the amplifier reaches the final position approximately ten times faster than the spindle drive.

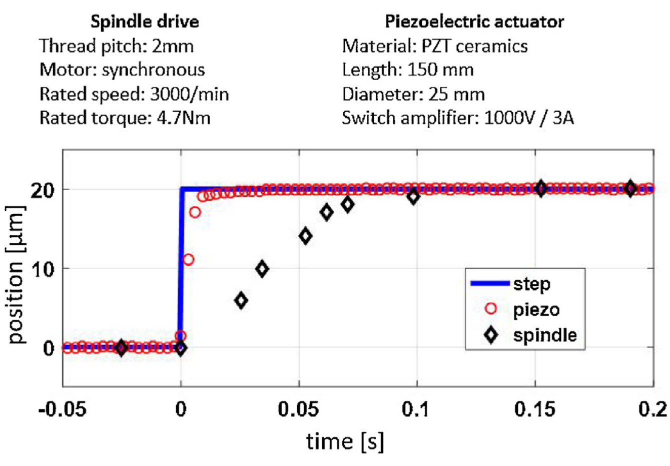

Fig. 2. Step response of the piezoelectric actuator PSt 1000/25/150 VS35 in comparison with a spindle drive for roll gap adjustment powered by a Siemens 1FK7060 synchronous motor.

Besides the depolarization a second limiting factor of piezoelectric actuators is their small stroke length with a maximum stroke of about 0.1% of the actuator's height. This is not sufficient to generate high enough rolling forces when integrated in an elastically reacting mill stand. Accordingly the piezoelectric actuators must be installed additionally in series to conventional actuators so that the piezoelectric actuators can provide their high dynamics while the conventional actuators can provide the required preloading to reach a suitable operating point.

3. Combined spindle drive and piezoelectric actuation

The operating points of a piezoelectric actuator show a hysteresis behavior and are located within a characteristic force/displacement-triangle (see Fig. 3). The gradient of the balance line of the operating points is equal to the system stiffness c_s, against which the piezoelectric actuator operates. Only against a rigid system ($c_s = \infty$) the actuator can provide the maximum generated force, while maximum displacement can only be reached with no system stiffness c_s. Preloading the actuator with a force f_{pre} shifts the triangle against the piezo stiffness c_p while the size of the triangle and its force range Δf stay constant. This force range adjustment by preloading is one advantage of a combined actuator concept.

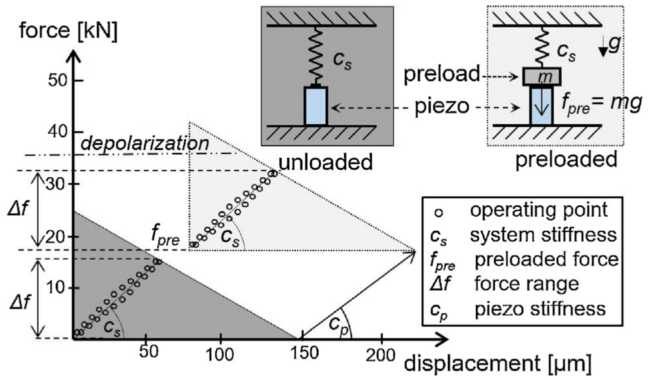

Fig. 3. Shift of the force/displacement-triangle and the force range Δf of piezoelectric stack actuator (PSt 1000/25/150 VS35) by a preload f_{pre}.

Two of the investigated piezoelectric actuators are installed in a two-high stand of a rolling mill for narrow strip and wire. The actuators are placed below the working rolls and ensure the adjustment of the lower rolls while the two existing spindle drives ensure the adjustment of the upper rolls (Fig. 4). Each spindle is connected with a worm gear and driven by a synchronous motor, described in Fig. 2.

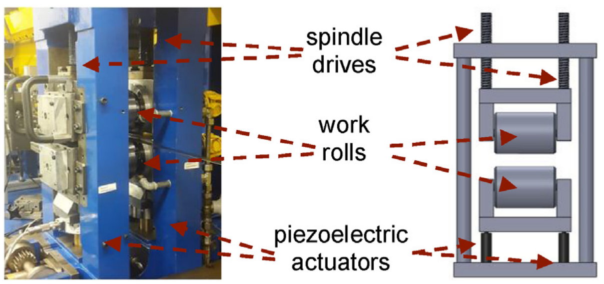

Fig. 4. Assembly situation of the piezoelectric actuators in a two-high stand of a rolling mill.

Before the high precision rolling process starts, the spindle drives preload the rolling stock as well as the piezoelectric actuators and shift the triangle into the appropriate force range. This allows a roll gap adjustment using only the highly dynamic piezoelectric actuators during the rolling process. Therefore just the piezoelectric actuators have to be controlled.

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