1. INTRODUCTION

ABB Stressometer® is a system for on-line flatness measurement of ferrous and non-ferrous metal strips and foils during rolling process in cold rolling mills. The ABB Stressometer® was delivered in 1967 to ALCAN, Kingston, Canada for the first time and since then approximately 350 systems have been delivered, [3].

The measurement principle is based on the magneto-elastic phenomena which occur when permeability of a magnetic material is changing as a result of mechanical force exerted on the measuring roll. Latent mechanical forces (normally invisible to human eye) are present in a metal strip during and after cold rolling process and small differences of those along the strip length and width are manifested as unflatness (curves and waves) of the metal strip. By wrapping the strip at a known angle around measuring roll and measuring a radial force applied on it, these tension differences are detected, processed and presented to mill operators by the computerized processing equipment as on-line flatness curve of the rolled strip, [3].

The ABB Stressometer® system consists of the following main parts: measuring roll, signal transmission unit, computerized data processing part and human-machine interface, [3].

A measuring roll (Fig. 1) is mounted on the exit side of a cold rolling mill before coil mandrel. In reversing mills, two rolls may be installed, one on each side of the mill and used alternatively depending on the rolling direction. The measuring roll is manufactured from one solid piece of steel, thus being quite sturdy and therefore often installed instead of a deflector roll.

Fig. 1. Stressometer measuring roll

found normally in most of the cold rolling mills. Inside the roll, flatness measuring transducers are mounted in a 90° circular array in each measuring zone. Number of zones is determined by the maximum strip width rolled in the mill. This pattern enables four measurements per roll revolution. Zone widths are standardized to two sizes, 26 mm and 52 mm. Transducers are protected by hardened steel rings with an extremely wear-resistant surface. Measured values in form of electrical signals are transmitted through a signal transmission unit instantaneously and in parallel from all roll zones to the computerized data processing system. A variety of information and operative modes are available to mill operators through the user friendly human-machine interface, [3].

Stressometer® system measures radial force applied to each roll zone continuously. Radial force is caused by distribution of tension
through the metal strip. Metal strip is wrapped around the roll at a specified angle (α) while tension (T) resulting from the mill drives is applied to it (Fig. 2) to enable rolling, [2].

\[ M_{\text{max}} = T \times r \times e^{\mu \alpha} - 1 \]

where:

- \( T \) = metal strip tension
- \( r \) = roll radius
- \( \mu \) = friction coefficient
- \( \alpha \) = wrap angle (in radians)

In certain situations (small wrap angle or low friction), the metal strip may slip over the surface of the measuring roll.

2. DRIVE SYSTEM FOR STRESSOMETER APPLICATION

There are two methods to avoid slippage of the metal strip over the measuring roll. Either a substantial metal strip wrap angle over the roll or an auxiliary drive system, should be used. Both solutions add torque of such magnitude and direction that the minimum drag torque is never exceeded. Slippage of the metal strip over the measuring roll may result in marks over the strip surface, which of course should be avoided, [2].

To avoid slippage, the sum of the roll friction and acceleration torques should not be greater than the lowest drag torque present in the plant, [2].

Roll friction torque derives from the bearings, seals, air drag, etc. Acceleration torque arises from the roll's inertia multiplied by angular rate of acceleration. In applications where there is a risk of slippage, a drive system should be used. At first sight, it would appear that an inflexible speed regulation could be sufficient to control the speed of the measuring roll, so that slippage does not occur. However, an "absolute synchronism" would be necessary to prevent the slippage, which cannot be achieved in practice. Normally, the metal strip speed can only be estimated to an accuracy of approximately 2 - 10%. Therefore, the drive strategy should be to model the friction and acceleration torques and use an electromotor directly coupled to the measuring roll in order to create a compensating torque being the instantaneous sum of these torques, [2].

2.1. Drive controller

The functional module with speed controller including dead band option is based on a PID algorithm with set point weighting (Fig. 3), [1].

\[ u(s) = K_p \left[ bY_r(s) - Y(s) \right] + \frac{1}{T_s + T_{fb} + 1} e(s) \]

where:

- \( K_p \) = controller gain
- \( b \) = set point weighting factor
- \( T_s \) = integral time constant
- \( T_{fb} \) = derivative time constant
e = speed error (difference between reference and actual speed value),

\[ K_p = \text{relative gain of speed controller}, \]

\[ Y_r = \text{speed set point reference}, \]

\[ Y = \text{speed feedback}, \]

\[ T_i = \text{integr. time constant (defined as parameter)}, \]

\[ T_d = \text{deriv. time constant (defined as parameter)}, \]

\[ T_f = \text{filter time constant in derivation part (defined as parameter)}. \]

When in certain circumstances the measuring roll is not in contact with the rolled metal strip (drag torque = zero), it is not possible to apply only a torque regulation because it would result in a large speed errors. By adding a dead band to the speed regulation, a small speed error will result in a limited torque increment within the dead band (lower than the smallest drag torque) while a large speed error will result in a large torque. To achieve a dead band, the existing standard circuits in a drive system are supplemented with the dead band module (Fig. 4), [2].

A dead band evaluator chooses the nominal value for the torque limiter (current limiter) too, so that a "soft" torque control limit is engaged inside the dead band. Maximum torque limit is chosen outside the limits of the dead band, [2].

To compensate for the roll friction, a compensating counter-torque is applied against it. Since friction is non-linear with respect to speed, it is necessary to define friction function by means of function generator element with 5 speed set points (1%, 5%, 15%, 45% and 100% of max. speed). To be able to define the friction function, installation site conditions and experience of the commissioning people play predominant roles. After installation to the site, the friction compensating parameters are recorded in the drive system memory by running the motor coupled to the measuring roll at the 5 speed values mentioned above without applying any other load, [2].

The friction compensation signal is added to the nominal torque signal at the input of the torque regulator (Fig. 5), [2].

\[
M_f = J \times w
\]

where:

\[ J = \text{inertia of the measuring roll}, \]

\[ w = \text{angular rate of acceleration}. \]

In Stressometer® application, the nominal speed reference must be filtered to avoid overriding the derivative part. Filter module is composed of two filter units, a low pass filter with adjustable time constant and a slope limit filter with adjustable maximum slope, (Fig. 6). This acceleration compensation signal is added to the nominal torque reference, [2].

![Fig. 4. Dead band module](image)

![Fig. 5. Friction compensation module](image)
3. CONCLUSION

Every serious producer of cold rolled strips in the world tries to acquire a thorough knowledge of the products it delivers to customers. Metal strips and foils are during cold rolling process susceptible to a lot of different factors influencing the final product characteristics and quality. Among these factors, flatness of the final product is quite important one and therefore requirements for as accurate as possible measurement method are of the paramount interest.

ABB Stressometer® method with its online measuring roll is one of the most known and accepted around the world for more than 30 years. As a part of the measurement process, even the auxiliary drive system coupled directly to the measuring roll plays an important role. It enables flatness measurements from very low speeds through acceleration part to the nominal rolling speed and vice-versa by automatic control of the measuring roll speed and synchronism between rolled strip and measuring roll in all working conditions. Thus slippage of the metal strip over the roll is avoided.

From the above description it is quite easy to deduct that for Stressometer® applications both speed and torque regulations are required. Since ABB ACS 600 motor controller (manufactured by ABB Industry OY, Drive Products & Systems, Helsinki, Finland) in its software contains both regulators with possibility to program application functions, all the necessary work is consisted in the enhancement of its existing functions to solve this particular regulation situation.

This application adaptation work was made by a group of people in Force Measurement Division of ABB Industrial Systems AB in Västerås, Sweden, which have a good knowledge of the requirements imposed on the flatness measurement system installations as well as the factors influencing the flatness of the cold rolled metal strips and foils.

4. REFERENCES