First Control

IMPROVED AGC CONTROL IN COLD ROLLING USING LEARNING TECHNOLOGY.

Gunnar BENGTSSON
First Control Systems AB, Ängsgärdg. 4, S-72130 Västerås, Sweden

Summary.
In this paper we will describe some substantial improvements made in strip thickness control in cold rolling using the self-adaptive AGC 2000X control system, developed by First Control. Long-term production experience from two installations will be shown, a new 12-high Mitsubishi cold rolling mill and an old Sendzimir mill. The improvements with self-adaptive control methods compared to conventional AGC control can be judge to at least 1-3% more strip within tolerances and 50-75% smaller deviations in strip thickness.

1 Background

The efficiency of the AGC thickness control system is crucial for the strip quality. Even if the requirements on new mills today are very hard, most AGC control systems are still using old-fashioned control methods, despite the fact that more intelligent control techniques have been available for some time. The control methods described in this paper were mostly developed in the universities during the ”space travel boom” in the 70ths' and 80th s', but fairly little has found its way to general industrial use this far. At First Control, we have been installing adaptive control systems for more than 10 years in several different industrial processes. Our experience shows clearly that the adaptive control technology improves the process operation substantially. This has in turn lead to improved productivity, better quality and larger profits for the users.

The development of the AGC 2000X system was made in steps during several years. Most of the work was made in cooperation with customers, especially with Avesta-Sheffield Precision Strip at Långshyttan, Sweden.Each new adaptive control function was thoroughly discussed with the Avesta-Sheffield process experts before being implemented. This means that each part has been thoroughly run in production for several years by now. In addition, issues that were expected to improve strip quality and production speed was emphasized. The control functions resulting from this development will be described in section 3. As one result of this work, an old Sendzimir 231 cold rolling mill was uppgraded to the same thickness quality level as a complete new rolling mill with only minor mechanical changes, see section 2.2 below.

The self-adaptive control functions have also been implemented in a new Mitsubishi 12-High cold rolling mill at Avesta-Sheffield, described in section 2.1. The production experience within Avesta-Sheffield in using the adaptive controllers is also commented in another paper presented at this conference, see ref. [1].

2. Production performance

2.1 The new 12-High Mitsubishi cold rolling mill.

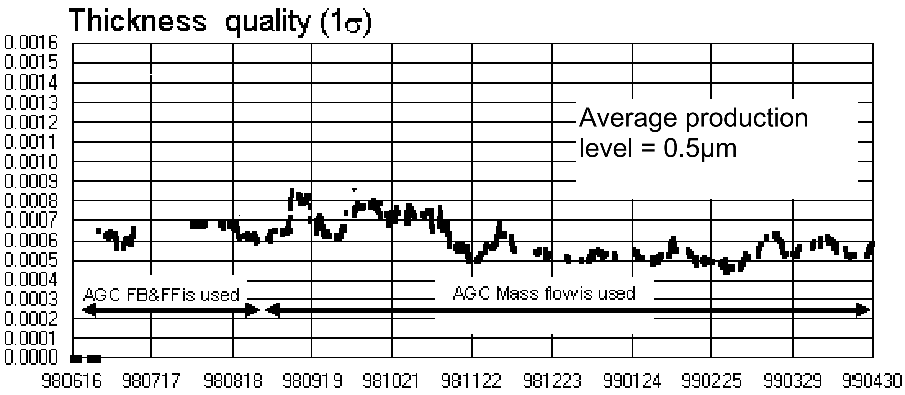


Figure 1. The thickness quality trend from June 1998 to April 1999 in cold rolling mill MA888 at Avesta-Sheffield Precision strip.

Nom. thickness (mm)	**1σ limit (68% limit)**	**3 σ limit (99.9% limit)**
0.100-0.199 mm	0.23 µm	0.69 µm
0.200-0.299 mm	0.42 µm	1.26 µm
0.300-0.399 mm	0.55 µm	1.65 µm
0.400-0.499 mm	0.58 µm	1.74 µm
0.500-0.599 mm	0.75 µm	2.25 µm

Table 1. Average thickness performance for all coils produced between June 16 1998 and April 30 1999 in the cold rolling MA888 at Avesta Sheffield Precision Strip.

The mill is a 12-High cluster mill, delivered by Mitsubishi Heavy Industries. The final thickness is ranging from 0.050 mm up to 3 mm and the mill operational speed is 18-800 m/min. The requirement from the customer was that 99.9% of the strip thickness must be within ± 1 µm for all strips below 0.2 mm and within ±1-4µm for thicker material.

The strip thickness control was in operation in March 1998 about one day efter rolling start. The comissioning time for the self-adaptive AGC is normally quite short since there is no need for extensive gain tuning for different steel grades or mill speeds. This also means that the AGC performance will be on a good production level directly after start-up. In this mill, all the AGC control functions are self-adaptive.

The AGC system has now been in operation for about 16 months. The AGC performance for all coils rolled from June 16 1998 to April 30 1999 is shown in figure 2 and in table 1. The statistical curves show that in average 99.9% of the strip thickness is kept within ±0.69µm for thin materials (below 0.2 mm). For thicker materials, the deviations are slightly larger, but still well within the required limits.This performance is regarded as very good indeed, considering the fact that the standard deviation figures include all the phases of rolling, i.e. low speed, speed change, flat speed and strip ends.

The Cpk process capability measures for the same production period are around 10, which also indicates that the mill is showing an excellent production performance with a large margin to the tolerance limits.

2.2. The old Sendzimir 231 cold rolling mill .

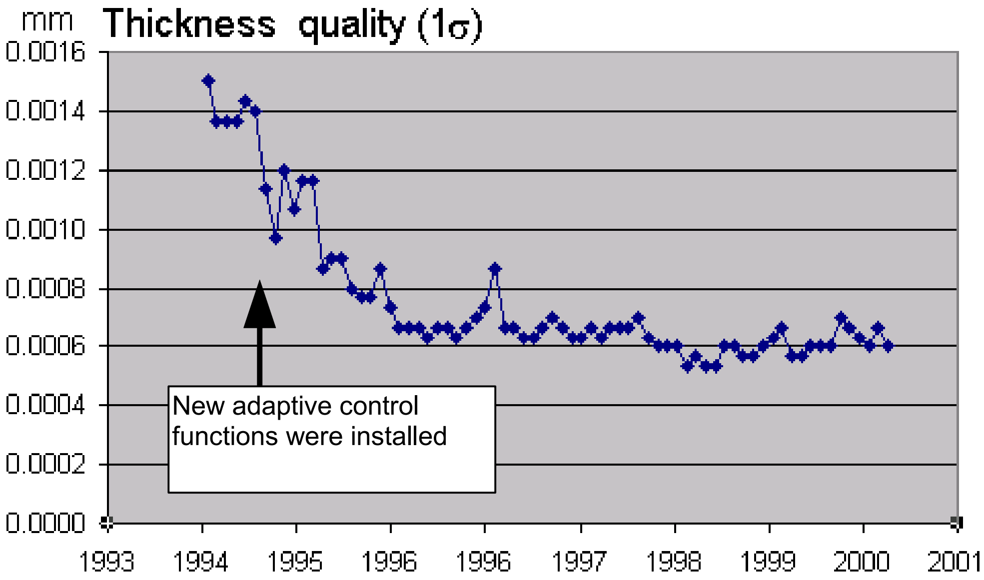


Figure 2. The long-term thickness quality trend in cold rolling mill Sendzimir 231 at Avesta-Sheffield Precision strip. Each point corresponds to the average thickness standard deviation during one month of production.

Some 15 years ago the main task of the mill was to feed a tube mill with steel strips.The requirements on the strip thickness quality were fairly moderate. Today the customers are all around the world. The product range has changed completely and the requirements on the strip thickness are much harder. The average final thickness produced today is around 0.3 mm.

The AGC system was upgraded with adaptive control functions in several steps during the years 1994-96, which resulted in large improvements in thickness quality, see fig.2. The different steps can easily be seen in the quality trend curve. For instance, at the arrow in the fig.1, the mill was equipped with a very fast self-adaptive feedforward control which immediately resulted in a 50% reduction in strip thickness deviations.

Note that the improvements have been made from a fairly good starting level (1.4 μm) down to an average of about 0.6 μm today, which is better than what is achieved in many completely new cold rolling mills. This is in fact a remarkable improvement considering that the mill is fairly old. The thickness deviations are, of course, far below the tolerance limits. The main benefit is that more strip will be kept within tolerance and fewer production problems. The high thickness quality of the produced coils is a major reason why the customer has been able to increase the sales and the profit of the production.

3. Self-adaptive strip thickness control

3.1. The adaptive controller StregX2.

An adaptive control system creates a model of the process directly from measurement data. The model is used to compute a control strategy which in some sense is optimal for the process. Using the model, the control system can predict how the process will react on control actions. The creation of the model and the computation of the control strategy are done completely automatically by the control system.

A schematic picture of the self-adaptive control function is shown in fig 3

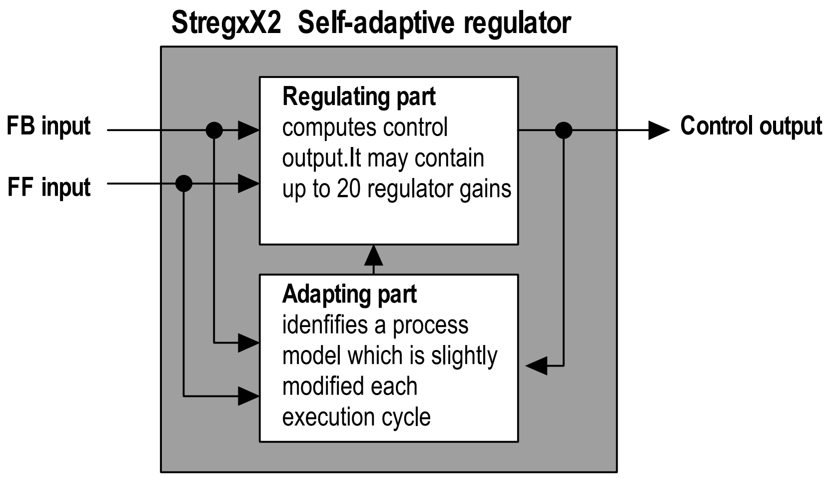


Figure 3. The structure of the self-adaptive regulator.

The software design of a PID regulator is very simple, and therefore the regulator accuracy is about the same irrespective of design. The adaptive regulators, on the other hand, are quite different in this respect. The software design made by the supplier is crucial for the regulator performance. It will depend on the methods used for the process identification, the control strategy and the protective network surrounding the software. There are several hundreds of different methods to choose from. This means that the regulator accuracy may differ and should be measured in the same way as is done for e.g. sensors, i.e. from practical results.

The regulator StregX2 in the MicroController 2000X (see fig. 10) function library is a general-purpose adaptive controller based upon an extended recursive least-square identification method and a general pole placement method for regulator gain calculation. It may contain up to 20 regulator gains for feedback and/or feedforward control which are automatically tuned during rolling. The basic algorithms are supplied with extensive protective software, based on a long experience in using adaptive control in industrial applications.The purpose of the protective software is to make the regulator insensitive to abnormal process behaviour and robust in practical use.

3.2.The self-adaptive AGC 2000X system

The major difficulty in strip thickness control in cold rolling is the high speed combined with the high accuracy that is required from the control system. The control system will face a "new process" for each new strip entering the mill. The strip thickness, which is a major quality variable, is disturbed by e.g. variations in mill speed, strip hardness, strip tension and thickness of the incoming strip. Changes in process parameters may mean that the process will react in different ways to control actions. The purpose of the adaptive functions is to compensate for these disturbances automatically based on previous rolling experience.
The control structure in the AGC 2000X system is shown below.

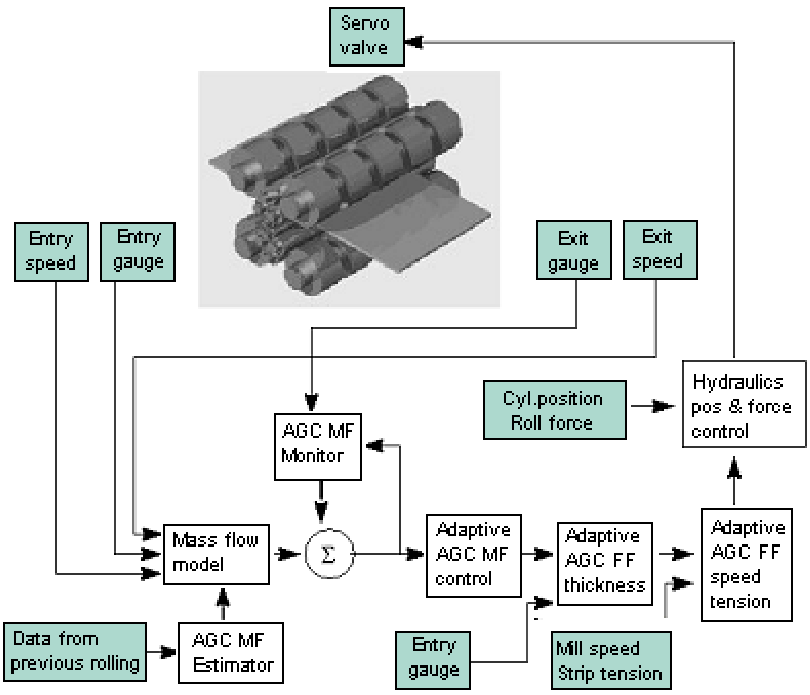


Figure 4. The AGC 2000X control structure

As can be seen, the control structure is fairly standard, i.e. the AGC is run in several different control modes including feedback, feedforward and mass flow. The major difference compared to conventional AGC control is the extensive use of self-adaptive technique to automatically adjust the regulators to optimal performance:

- The self-adaptive feedback control
- The self-adaptive mass flow control.
- The self-adaptive feedforward control
- The automatic AGC start-up procedure.
- The thick end disturbance reduction.
- The adaptive roll gap preset function.
- The adaptive mass flow preset function.

First Control

3.3 The automatic AGC start up procedure.

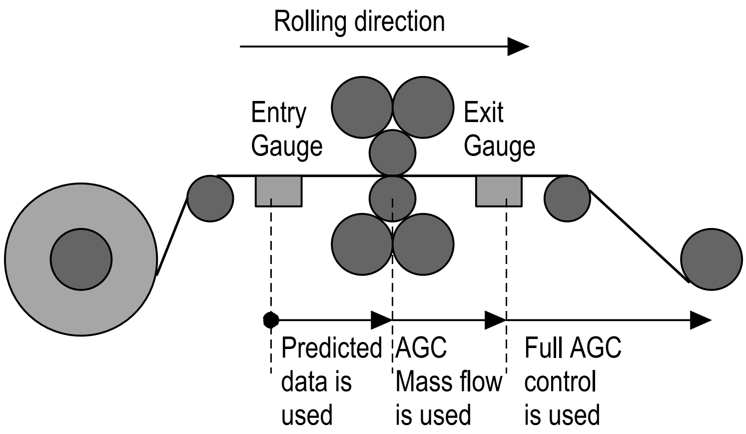


Figure 5. The AGC start-up sequence

In order to maximize the amount of strip within tolerance, First Control has developed a new AGC start-up procedure that will quickly take the thickness to the correct target. Normally the thickness will be within a few µm from the correct target after only 2-5 m rolling, see the recording in fig 8. It has been estimated that as much as 20-40 m strip can be gained in this way in the final pass. The adaptive control functions normally need about 2-5 m rolling to be fully adjusted to the process parameters in the new strip.

The operator activates the automatic start-up sequence by switching on the AGC before the strip starts moving. The control system will then activate the different control functions in a specified sequence to minimize the setting time to correct output thickness. The control system also uses an adaptive mass flow preset function based on previous rolling, which essentially predicts the mass flow thickness before it can be seen (and corrected) at exit gauge.

See also the recordings from actual rolling in fig. 8 at the end of this paper.

Remark. In fig.1 in Section 2.1 it is possible to see the improvement in thickness quality when the automatic AGC start-up was taken into operation in November 1998.

3.4 The thick end disturbance reduction.

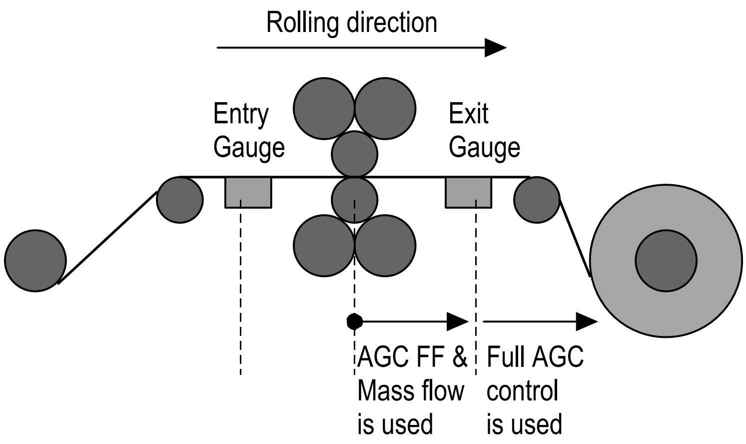


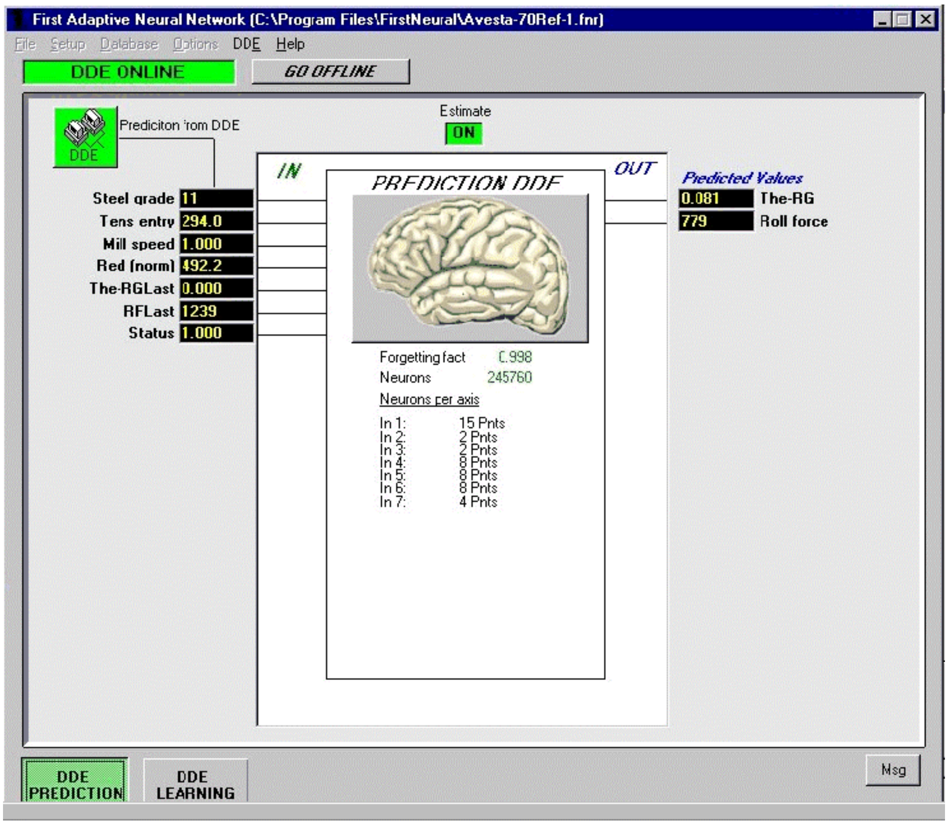
Figure 6. The AGC stop sequence

At the strip ends there are normally fairly large thickness disturbances originating from the thickness setting in the preceding passes (”thick end”) or from some problems in the preprocessing. The thick end disturbances are mainly controlled by efficient feedforward control. Since the feedforward control is self-adaptive, it can remove nearly 100% of the disturbance. Experience from rolling shows that the AGC is capable to reduce thickness deviations of an magnitude of 10-30µm down to 1-4µm, see the recording in fig 8. In this way more strip will be kept within tolerances.

Normally, the operator will keep the AGC in operation until the very stop of the mill to remove as much thick end disturbances as possible. The AGC will be automatically switched off when the minimum speed is reached.

See also the recording in fig.9 at the end of the paper.

3.5.The adaptive roll gap pres-set function



<u>Figure 7</u>. The on-line adaptive rollgap preset is made on a PC in communication with the AGC control system MicroController 2000X.

First Control has also added a special roll gap setup function based on an on-line learning network, see fig 7. The learning network is a form of neural network which is very fast and is capable of handling large input/output dimensions.

The learning network will estimate the gap position and force in the next pass based upon data obtained from previous rolling. After each pass of rolling, the learning network will be fed with setup data and data from the previous rolling pass. Based on this data, a new roll gap position/roll force is predicted for the next pass or coil. At the same time, the network will slightly modify itself depending on the outcome in the previous pass. In this way, the network is made to ”remember” previous rolling to be used the next time a similar mill setup situation arises.

For the moment, the network is capable of estimating the roll force with an average error of about 6 tons, according to a test run made on data stored in the production database. Work is still going on to improve the accuracy of prediction.

The predicted gap/force value is used to preset the roll gap position at a starting point for the AGC so that the thickness will be as close to target as possible when the rolling starts.

3.6 Recordings from actual rolling.

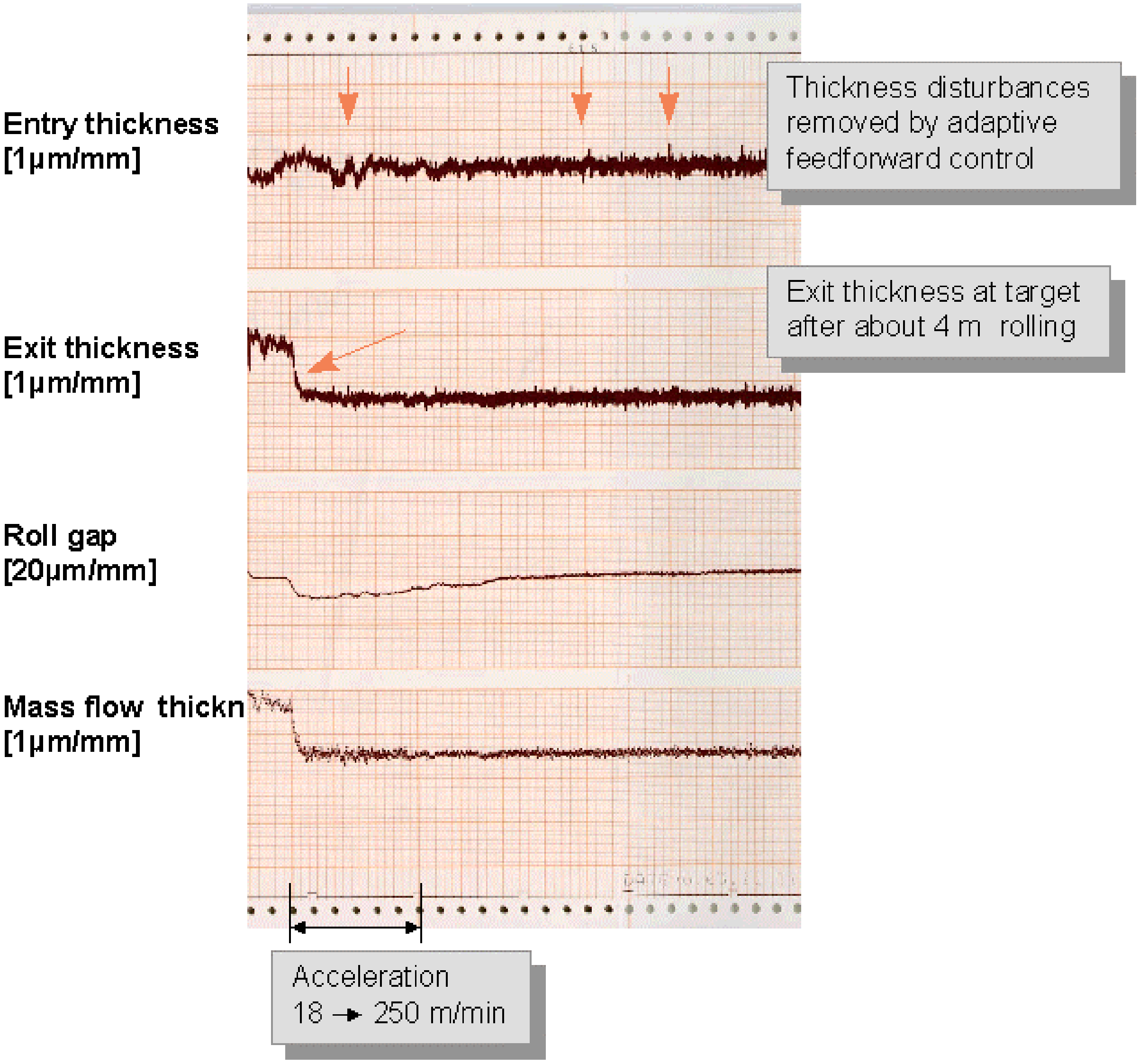


Fig:7: Chart recordings illustrating the AGC start-up sequence in the cold rolling Mill MA888.The thickness was controlled to target within about 4 m rolling in this case. Note also the efficiency of the self-adaptive feedforward control immendiately after start-up and during acceleration from 18 m/min to about 250 m/min.

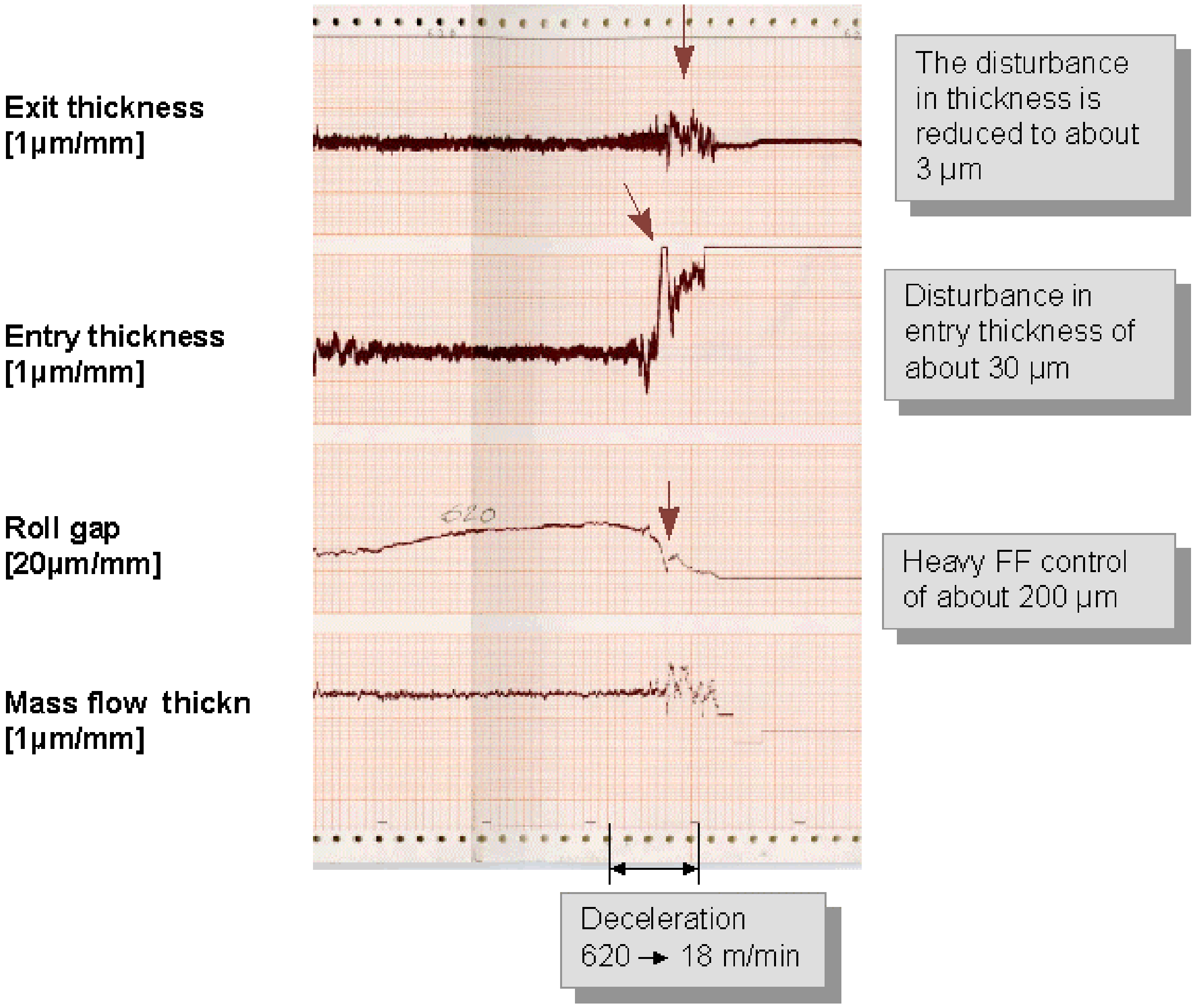


Figure 9. Chart recording illustrating the thick end disturbance reduction. A thickness disturbance of about 30µm at the very end of the strip is reduced by the AGC control to about 3µm. The mill speed is simultaneously reduced from about 600 m/min down to 18 m/min. The operator keeps the AGC in operation all the way up to the very stop of the mill.

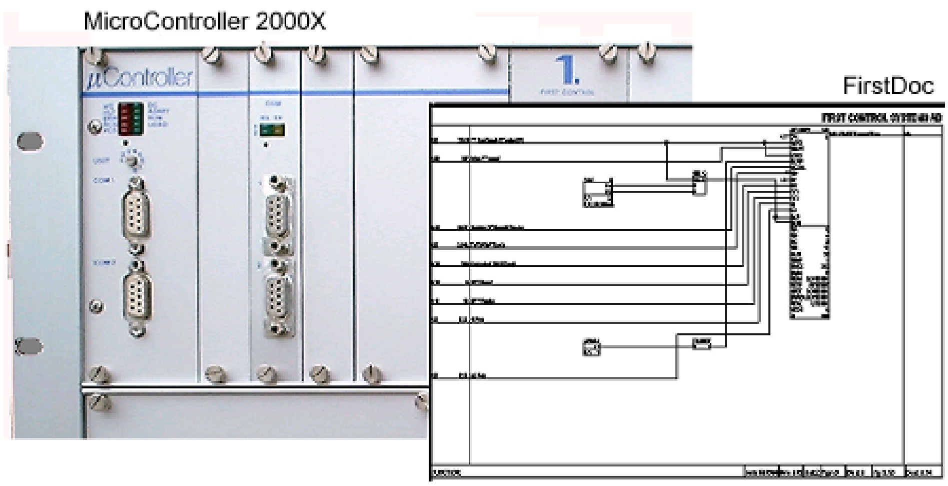


Figure 10. The MicroController 2000X system with self-adptive regulators for AGC control.

First Control

4.References

1. Bartholdsson K. ”Experience from rolling thin strip in a Mitsubishi CR cold rolling mill”, presented at 2nd European Rolling Conference (session III).