DESIGN, IMPLEMENTATION AND COMMISSIONING OF A FUZZY-ADAPTIVE MOULD LEVEL CONTROL SYSTEM

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Keywords: Fuzzy control, adaptive control, continuous casting

Abstract

In this paper, a new fuzzy-adaptive mould level control to improve the steel quality in the continuous casting process will be described. The concept does not required additional hardware. The presented commissioning results show a better control behaviour e.g. in case of worn stoppers.

1 Motivation

Mould level control exerts a decisive influence on the quality of continuously casted steel. The conventional PID controller serves to maintain the desired level of the steel in numerous casters. However, this conventional concept is unable to react to changes in the stopper and flow characteristics (wear, build-up of steel, aluminium oxide and slag, or changes in steel viscosity) during the casting operation. Manual intervention is necessary whenever such problems occur. Severe conticaster defects which ultimately lead to conti-casting stoppage result, if the operator reacts too late, and the qualitative development of such changes are well-known among experts. Therefore, the use of fuzzy logic [1] was studied to solve these problems during the past few years [2-7].

The knowledge used in this connection is essentially based on former commissioning experience gathered at a steelmaking plant of Yieh United Steel Corporation, Taiwan [8].

It is the objective of this paper

- to present such a fuzzy adaptive control concept aimed at improving the quality of the conventional control strategy,
- to explain the implementation in a process management system [9], and
- to demonstrate the efficiency by means of the commissioning data gathered at a steelmaking shop of Baogang Steel in Baotou, China [9, 10].

2 Control design

Fig. 1 shows the principal structure of the continuous casting process. The molten steel is casted from the ladle into the tundish. The position of the ceramic stopper influences the steel flow into the mould. Here, a cooling system causes the solidification of the steel which can now be drawn continuously.

The level of the steel in the mould is detected radiometrically with the aid of a Co60 nuclear gauge. To assure the desired quality and avoid breakdowns it is necessary to maintain the steel level in the mould within a close tolerance band even in the off-normal case.

As wear increases (Fig. 2a), the characteristic curve of the flow of the steel to the mould becomes steeper as a function of the stopper position. Eccentricities of the stopper positions (Fig. 2b) and build-up on the stopper (Fig. 2c) exert an opposing influence.

These effects cause a non-linear and time-variant behaviour of the system. The static characteristics are displayed in Fig. 3. A conservative and robust setting of a PID controller leads to a dissatisfactory correction of off-normal situations in a normal characteristic stopper curve.

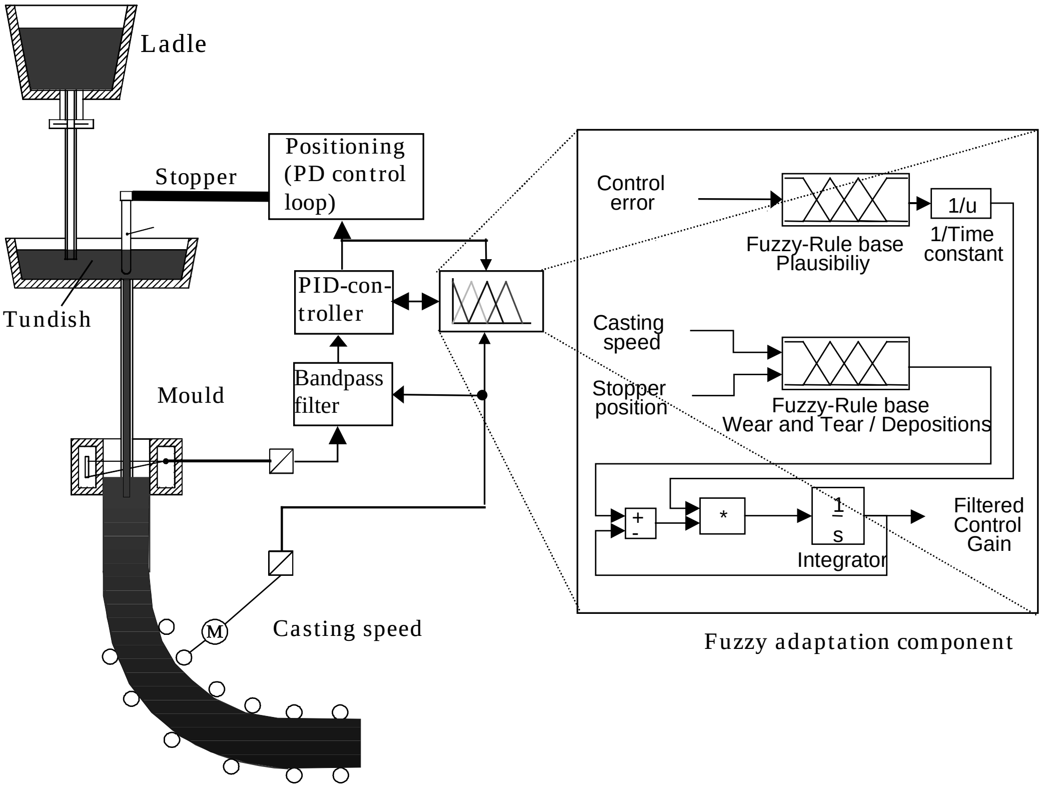
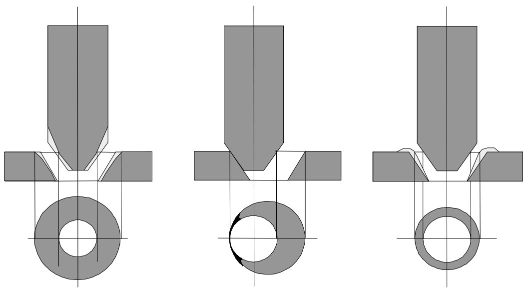


Fig. 1: Principle of the continuous casting process



a. Wear and Tear b. Eccentric position c. Depositions

Fig. 2: Changes of the flow characteristics

The control loop is a cascade loop with a PID controller (steel level) and a PD controller (stopper position). The original set of parameters of the PID controller is initially taken from a database and is adapted already at this stage to the steel grade and the strand size. The PID controller output is supplied to a lower-level control loop. Faster response setting guarantees in such cases satisfactory reactions to problems, but when the stopper is heavily worn, it may result in oscillations and finally even stability problems.

The fuzzy controller additionally adapts the control gain K_R of the PID controller. The decisive factor regarding the practical acceptance of the fuzzy controller is the fact that the existing PID controller is retained. The system design follows a strategy illustrated in [11, 12] and the following rules:

A wear of the stopper causes a shift towards a lower stopper position *y*, if the strand withdrawing speed *v* is constant. Such effects will be described by fuzzy rules as

- IF the stopper position is extremely small (ES) AND the casting speed is normal (NO) THEN the characteristic curve is extremely steep AND the requisite controller gain is very low.
- IF the stopper position is small (S) AND the casting speed is normal (NO) THEN the characteristic curve is normal AND the requisite controller gain is normal.

The principle of these fuzzy rules is displayed in Fig. 3. The fuzzy sets of stopper position and casting speed describe a position in a characteristic field for different process states. This fuzzy block (wear and tears, depositions) proposes a new control gain $K_{R,\ Fuzzy}$.

This procedure allows the acquisition of build-up information (e.g. steel film on the stopper). An evaluation of the stopper position and of the strand withdrawing speed also yields indirect information about viscosity changes.

However, these rules only provide information about the equilibrium condition when the flow of steel from the tundish is equal to the amount of steel being withdrawn. Otherwise, dynamic transients exert an influence on wear evaluation.

Therefore, additional lowpass filtering is effected. The gain of the controller is corrected the faster the clearer process situation control commencement is recognised if it shows no deviations from the setpoint steel level (fuzzy block plausibility). This block computes a time constant *T* which is used for filtering the control gain K_R of the PID controller by

$$T(e) \cdot \dot{K}_R = K_{R,Fuzzy}(v, y) - K_R \,.$$

In addition, the steel level measurement is filtered with a bandpass (Tschebyschew filter) to damp the effects of mould oscillation. As the oscillation frequency depends on the casting speed, the filter parameters are modified on-line by means of interpolation equations.

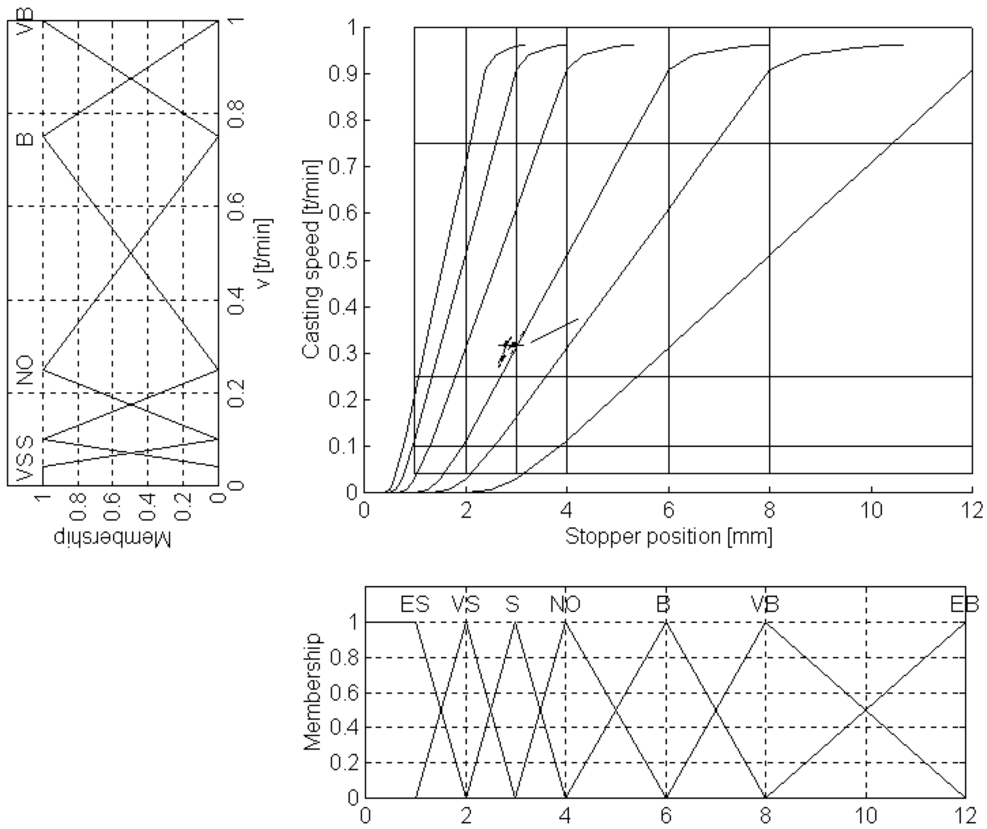


Fig. 3: Static nonlinear characteristics of the steel flow to the mould as a function of the stopper position including the fuzzy sets to describe the actual process state

3 Implementation and commissioning

The casting facilities are a four-strand rounds caster (sizes 180, 230, 270, 300, and 350 mm) and a four-strand bloom caster (280x325, 280x380, 319x410 mm) of Baogang Steel in Baotou, China. The casters came on stream between July and December 1997.

The configuration of the four-strand billet caster with Siemens SIMATIC S5® components is illustrated in Fig. 4. The structure is characterized by multi-processor operation in which the first CPU is responsible for the strand-related program and the second CPU contains the implemented control structure. The latter loop, with its PD controller, is implemented analogously on a Rexroth circuit board which serves to control the hydraulic stopper system.

Siemens SIMATIC S5® offers a standard software package for the implementation of control systems [13]. The modular control package comprises the conventional algorithms and additionally fuzzy modules. Using the SIFLOC S5® program system it is possible to define the fuzzy applications and rules and translate them into machine language by means of the SIMATIC S5® AWL-Editor/Batch-Compiler (v2.2). The control routines generated in accordance with this variant are runnable in PLC SIMATIC S5® 135/155 U (CPU 928B/948). The software package offers modular components for the commissioning and on-line optimization of the designed control structure.

There are similar algorithms for the implementation in the ABB Master Piece® 200 process operating and monitoring system, in which, however, only pre-defined function modules of system inherent programming language AMPL are employed [12].

The control concept can be easily implemented by means of SIMATIC® S7 / M7 400. The program structure can be overtaken in a SIMATIC® S7 / M7 400 S PLC without important changes.

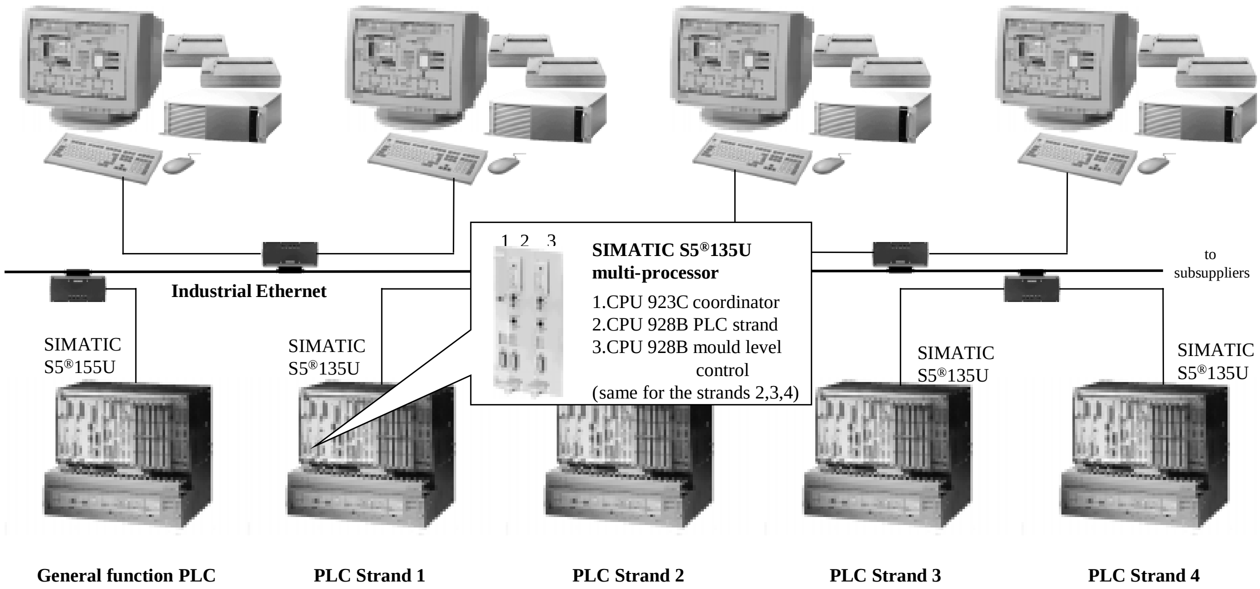


Fig. 4: Implementation by means of SIMATIC S5® 135U - BAOUTOU STEEL, PR CHINA

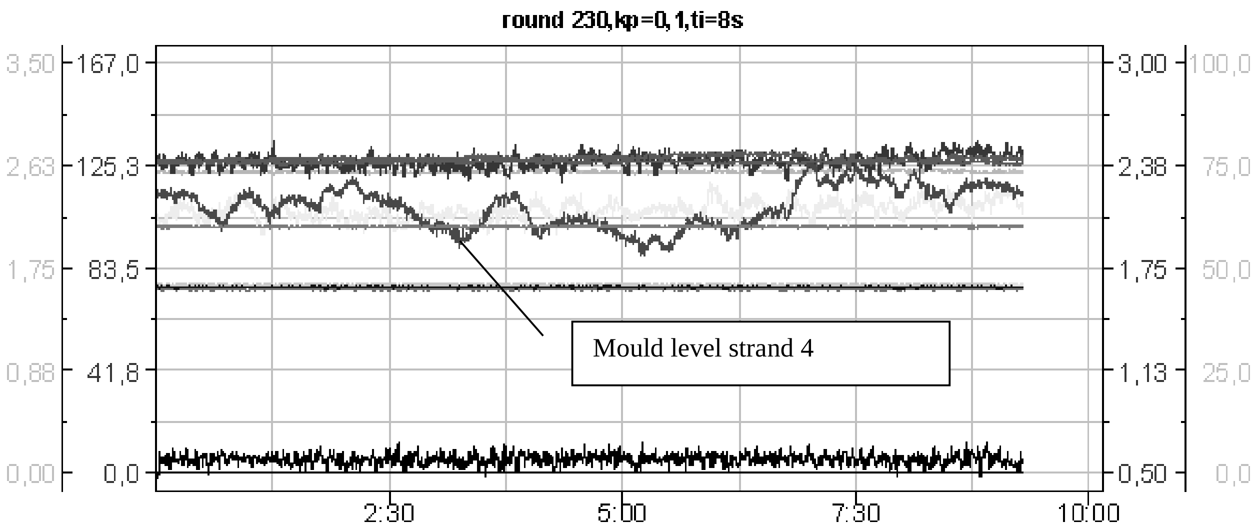


Fig. 5: Progression of steel levels and stopper positions in the case of PID control (steel levels are shifted towards each other for better illustration)

Practical tests demonstrated that a conventional PID controller causes oscillations of steel level (see e.g. strand 4 in Fig. 5) in case of a worn stopper. The fuzzy components are capable of ensuring good control quality even in case of major problems and irrespective of the wear situation (Fig. 6). The fuzzy adaptation sets different control parameters in spite of identical strand constructions, because each strand shows different wear behaviour (Fig. 6).

The operation of a continuous casting machine involves a number of equipment inherent problems which cannot be encompassed by pure control functions. This refers to dealing with breakouts as discussed in detail in [3] and, in particular, mechanical strand withdrawal problems, the complete clogging and stopping of the submerged nozzle and the destruction of the stopper.

Casting abort can be prevented in some problem situations by means of sequence oriented binary monitoring functions. As soon as a critical situation is detected automatically, strand withdrawal is stopped, the stopper is closed, and operation is changed over to manual. The casting operator clears the submerged nozzle by means of vigorous stopper movements and then switches back to the automatic mode of operation [9].

The control concept additionally includes algorithms for

- the automatic start of casting,
- a fuzzy-adaptive disturbance variable compensation for changes in the same way as adaptation of the control gain,
- the automatic zero balancing between steel level measurement and the steel level in the mould,
- the bumpless transfer between the manual and the automatic operating mode,
- the injection of a slow 20-minute period oscillation into the reference variable for the purpose of reducing submerged nozzle wear, and
- monitoring functions serving to detect breakouts and excessively high steel levels conducive to overflow danger and to limit the extent of consequential damage.

Summing up the above shows that only the variants with fuzzy components provide satisfactory results when departures from the original operating point occur.

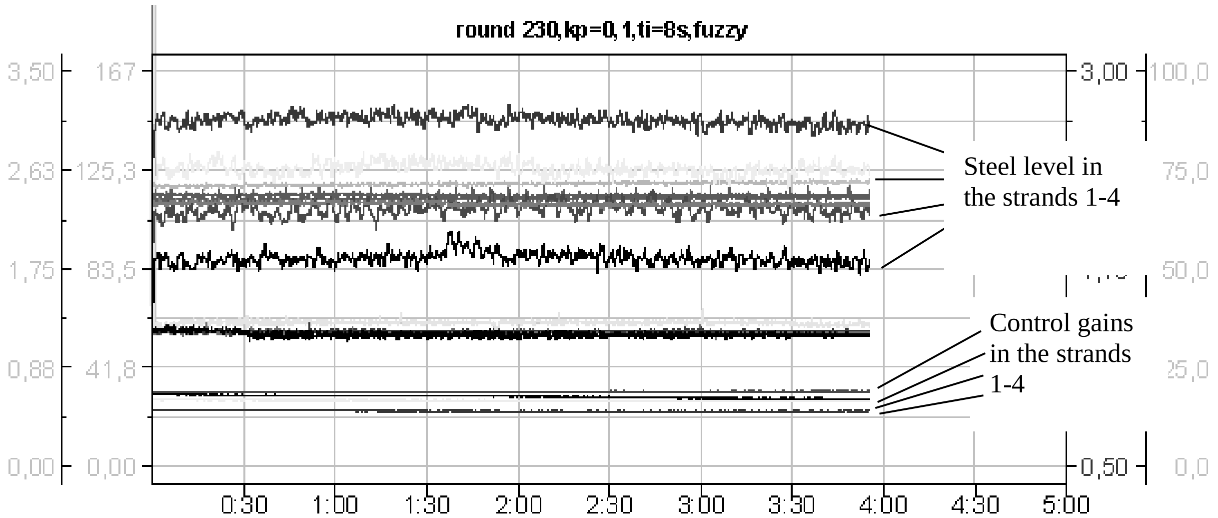


Fig. 6: Progressions of steel level and controller gains during the operation with fuzzy-adapted PID controllers (steel levels shifted towards each other for better clarity)

4 Conclusions

A fuzzy-adaptive mould level control concept was developed within the scope of this project. It was implemented in existing process control systems, and tested in practice at a steel plant of Baogang Steel in China.

The control system described here has been in continuous operation since September 1997. The concept ensures clear quality improvement by having control over wear and build-up events in the stopper region. Additional research work is focussed especially on the early detection of caster-inherent problem cases.

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