DEVELOPMENT AND EXPERIENCE WITH IN-CHAIN CASTER MEASURING SYSTEMS[1]

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Abstract

Many operators of continuous slab casters use off-line monitoring systems to measure the condition of the casting strand. Such systems are attached to the dummy bar chain in place of the dummy bar head, and run between casts or during maintenance periods. The Sarclad Strand Condition Monitor (SCM) is such a system and is in use worldwide. The large amount of data collected can justify the down time taken to perform a measuring run. However, as production requirements change, there is a growing requirement for information on critical parameters to be made available more frequently, via on-line measuring systems. In the past, many suppliers, including Sarclad, have attempted to produce such systems with limited levels of success. The major problem is creating a stable measuring platform that is robust & maintainable, within a dynamic, hostile environment. Inaccurate and non-repeatable measurement data will result from instability. Through years of development and experience with continuous caster measuring, Sarclad has now developed and patented an "In-Chain" measuring concept, which overcomes previous problems. This paper discusses the evolution of in-chain caster measuring, through the early design and development, testing improvements and the innovative methods now employed to provide a successful on-line, continuous caster measuring solution.

Key words: Continuous casting; In-chain; Strand condition monitor.

DESENVOLVIMENTO E EXPERIÊNCIA COM SISTEMAS DE INSPEÇÃO *IN-CHAIN*

Resumo

Muitos operadores de lingotamentos contínuos de placas usam sistemas off-line de medição da condição do veio. Estes sistemas são acoplados à corrente da barra falsa, no lugar da cabeça da barra falsa e, são operados entre corridas ou durante períodos de manutenção. O *Sarclad Strand Condition Monitor* (SCM), monitorador da condição do veio é um destes sistemas e é usado mundialmente. A grande quantidade de dados coletados justifica o tempo gasto para realizar uma medição. Entretanto, as necessidades de produção mudam e, cresce a demanda por informações dos parâmetros críticos que devem ser disponibilizados com mais freqüência, através de sistemas de medição *on-line*. No passado, muitos fornecedores, inclusive a Sarclad, tentaram produzir estes sistemas com níveis de sucesso limitados. O maior problema estava em criar uma plataforma de medição estável que fosse robusta dentro de um ambiente agressivo. A instabilidade do sistema levariam a resultados imprecisos e sem repetibilidade. Com anos de desenvolvimento e experiência com medições em lingotamento contínuo, a SARCLAD agora desenvolveu e patenteou um conceito de medição *on-line*, que resolve problemas prévios. Este documento discute a evolução do sistema de medição de lingotamento *in-chain*, partindo do projeto antigo e seu desenvolvimento, melhorias testadas e os métodos inovadores agora empregados para proporcionar uma solução de medição do lingotamento contínuo *on-line* com sucesso.

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INTRODUCTION

To produce cast steel slabs to the required high standards demanded by the highly competitive global market for steel, it is essential that the variables, which affect the quality of the steel are closely monitored and controlled. Of the many variables directly influencing the quality and volume of steel production, the roll-to-roll gaps and fixed face roll-to-roll alignment are of high importance as demonstrated by O'Malley.(1) In order to ensure that the caster rolls are set and maintained at their optimum condition it is essential that accurate measurements are performed on a regular basis. Only by continually measuring and monitoring the trend of these variables will the quality of the finished slab be maintained, and remedial work and downgrading costs reduced. This is especially important when casting some grades of steel, e.g. pipe grades.

Even with the modern caster designs employing closed loop positioning control, the actual roll gaps and roll to roll alignment must be physically measured in order to determine the condition of the individual roller elements and overall strand alignments.

Regular measuring and trend analysis allows maintenance activities to be targeted and predictive maintenance strategies to be adopted.

Having the capability to predict problems and failures allows decisions and activities to be planned based on actual, rather than assumed, knowledge. This ensures the optimum and efficient use of maintenance resources, while minimising the impact on production activities.

OFF-LINE CONTINUOUS CASTER MEASURING

Traditionally, roll gap and alignment measurements have been obtained through manual measurement, which is a slow and labour intensive activity. The procedure has become less arduous using automated measuring instruments such as the Sarclad "Strand Condition Monitor" (SCM). The Strand Condition Monitor, also referred to as 'gap sled' and 'roll checker', is an off-line measuring device used to determine the condition of continuous casting machine strands. The original design was pioneered by Sarclad in cooperation with the British Steel Corporation, and the first commercial system introduced in 1988, at the IPSCO Regina plant in Canada. To date Sarclad has installed over 300 such systems in continuous casting facilities worldwide. These systems enable the essential roll measurements to be obtained in a fraction of the time previous required and with a minimum amount of effort. By using an automated computer based system the data is easily displayed and stored for comparative purposes and human variables are taken out of the process.

The off-line Strand Condition Monitor is attached to the dummy bar chain in place of the dummy bar head and passed through the caster strand during machine outages or between cast sequences, when steel production has ceased. Measurement sequences are initiated via a manual infra-red transmitter and data collated and recorded automatically from on-board sensors. On completion of the sequence the data is downloaded to a PC for analysis and presentation. The Strand Condition Monitor provides a comprehensive range of measurements to help users assess the condition of their continuous casting machines. These measurements can include; roll gaps at multiple positions across the slab width, roll to roll and segment to segment alignment, outer roll condition, roll bend, roll rotation, water spray analysis.

The total time for performing a single strand measurement is typically 45 minutes, depending on the design of the caster. This is drastically less than the time previously required for equivalent manual measurements to be made. However, due

to the scheduling logistics associated with co-ordinating measurements during a caster "turnaround", many users do not measure as often as they may desire. While some users manage 2 or 3 measuring runs per week, typically measurements are performed weekly or even monthly, during dedicated maintenance periods.
In the period between measurements, the caster condition may change significantly, particularly when product size or mechanical adjustments have been made.
Unfortunately, any changes may not be detected until production problems are encountered or until post analysis of the cast slab is performed, at which point the steel has already been produced and costs incurred. Reactive measurements and changes then have to be implemented to rectify the problem, which can lead to unplanned outages, delayed production and additional maintenance costs. For steel makers producing critical grades, this is an unacceptable risk.
The off-line Strand Condition Monitor remains a significant improvement over the manual alternative. However, having the ability to measure a caster on-line, without affecting production activities provides the user with a distinct operating advantage to produce quality assured product.

ON-LINE CONTINUOUS CASTER MEASURING – MODIFIED LINK DESIGN

Some in-chain systems were produced mainly for top fed casters, mainly for Japan. Following requests from customers, the initial Sarclad design for an on-line measuring system was produced in the 1990's and used standard components and techniques developed on the traditional off-line Strand Condition Monitoring system. The concept involved adapting dummy bar chain links to accommodate the Sarclad standard linear gap sensors on the inner and outer faces, and the associated electronics and battery modules. Measurements were limited to roll gaps this being the primary measurement that could be accommodated. The links were permanently installed midway down the dummy bar chain and attached using pin and fixed bush arrangements. These systems were not designed to provide automatic measurements every cast, but were manually initiated, so that measurements could be taken as and when desired. The principle of operation addressed the issue of having to wait for a machine outage before a measurement could be performed. However, it soon became apparent that the design did not provide the necessary stability or durability for accurate or repeatable measurements to be obtained.

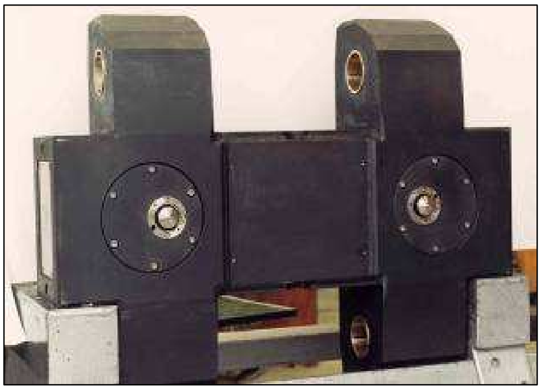


Figure 1 - Measuring system integrated into chain link.

Figure 2 – Measuring system during chain insertion.

Investigations during the dummy bar insertion and casting process discovered that the dummy bar chain goes through various stages of tension and compression. The chain was found to be under compression at the start of cast, when resisting the load of the slab and mass of the chain links, and then changed to periods of tension when the chain and slab were being pulled through the lower sections of the caster. The variation in loading caused the chain to lift off the outer face rolls resulting in instability of the measuring links. This instability affected the measurements being taken leading to inaccurate and non-repeatable data.

Additionally the performance of the measuring system was severely affected by the lack of mechanical durability that existed with the modified link design. Pinching and cold rolling from drive rolls at full strand pressure caused mechanical deformation of the measuring link sections, which formed part of the measuring calculations. Also, during the delivery and retrieval of the dummy bar chain from the dummy bar car, the links were stressed and deformed by the mass of the lower links, which resulted in further mechanical problems and the linear gap sensors became jammed through casting powder and chill scrap being rolled into the gap housings. Repair of the equipment was hindered by the restricted access and captive nature of the overall design, and the system generally failed to deliver the desired level of performance.

ON-LINE CONTINUOUS CASTER MEASURING – "FLOATING LINK" CONCEPT.

Learning from these early setbacks, Sarclad continued to research and develop the concept of on-line measuring systems. In order to provide accurate and repeatable data any measuring system has to be isolated from the movements of the dummy bar chain. Making the equipment independent of the chain and its effects allows a stable attitude to be achieved, from which accurate measurements can be taken. This lead to the development of the Sarclad patented "floating link" concept.

Rather than integrating the Strand Condition Monitor into a link section of the dummy bar chain, a separate body was designed, which housed all of the sensors, electronics and batteries.

Figure 3 – Floating link concept.

Figure 4 – Measuring system installed in chain.

The body was attached to the dummy bar chain via an arm with a double pivot arrangement. This design provided the equipment with the ability to "float", so that it could assume an attitude independent to that of the dummy bar chain.

Due to the space and size restrictions, the system could not accommodate springs to bias the measuring body onto the outer face rolls; instead, the design relied on the overall mass of the equipment and gravity to provide the necessary biasing. To aid the stability during the critical period of measurement, the length of the mechanical body was designed so that it would span the longest roll pitches of the caster. The gap measurements were still determined from a pair of opposing linear sensors and alignment measurements from an inclinometer attached to outer face of the equipment body.

Now that the measuring equipment was no longer an integral part of the dummy bar chain it was possible for the entire assembly to be removed, enabling offline maintenance and calibration activities to be performed. It was also hoped that this would help alleviate some of the durability issues experienced with the previous design, however this proved not to be as successful as initially hoped.

The gap sensors, which had been redesigned with additional seals and scraper rings to be less susceptible to jamming, still suffered durability problems caused by the ingress of casting powder and chills into the sensor mechanism. Also for operational reasons, the measuring stroke of the gap sensors had to be limited to a maximum range of 30mm to prevent the sensors catching on vertical edges that existed at the mould and dummy bar disconnect areas. The measuring range of the gap sensor determines the overall required thickness for the main assembly body. In this case, to ensure the gap sensors contacted the inner face rolls, the main body had to be thicker than that of the dummy bar chain. This now made the equipment susceptible to damage from mechanical debris and crushing from pinching drive rolls.

However, the biggest problem still proved to be the overall instability of the equipment during measuring. Despite being allowed to float independent of the dummy bar chain, the lack of positive spring biasing allowed the SCM to assume attitudes other than tangents of the outer rolls. This inconsistent positioning affected the roll measurements, which ultimately resulted in inaccurate and inconsistent data being obtained.

ON-LINE CONTINUOUS CASTER MEASURING – NEW SARCLAD IN-CHAIN CONCEPT

Sarclad realised that to achieve a successful In-chain Strand Condition Monitoring system, an entirely new concept would be required. The new In-chain measuring system had to address all the problems previously encountered, whilst still fulfilling the basic fundamental principles of measurement. To achieve this goal we have worked closely with major steel manufacturers in the USA and UK to develop the necessary components and measuring techniques required.

Tested initially at the ArcelorMittal plant in Indiana USA, the first prototype of the new generation of In-Chain measuring systems performed over 2000 caster measurements up to the end of 2009, at a rate of around 25 measurements per week. Within the arduous environment of a continuous casting machine, this frequency of use has provided the harshest of possible testing grounds. Throughout the development, weaknesses have been identified and addressed, to improve both the durability and operational performance of the equipment.

The result is an In-Chain measuring system that now delivers the level of measurement and performance that meets the demands of the steel manufacturing industry.

Figure 5 - New In-Chain system installed in dummy bar chain.

To achieve this success a radical departure from the previous methods of on-line continuous caster measuring was required. A main body assembly housing all of the system components was replaced by a series of individual assemblies dispersed throughout the dummy bar chain. The assemblies separate the functions of measurement from those of power and control. Adopting this modular concept provides a degree of flexibility in the overall scheme, which enables the system to be easily adapted and integrated into the majority of dummy bar chain designs for both top and bottom fed systems.

MEASURING ASSEMBLY MODULE

The measuring assemblies for the In-Chain stand Condition Monitoring system use a unique, Sarclad patented, measuring principle to provide simultaneous roll gap and roll alignment measurements from a single unit. The number of measuring assemblies is customised to the design of the caster and to the requirements of the individual end user.

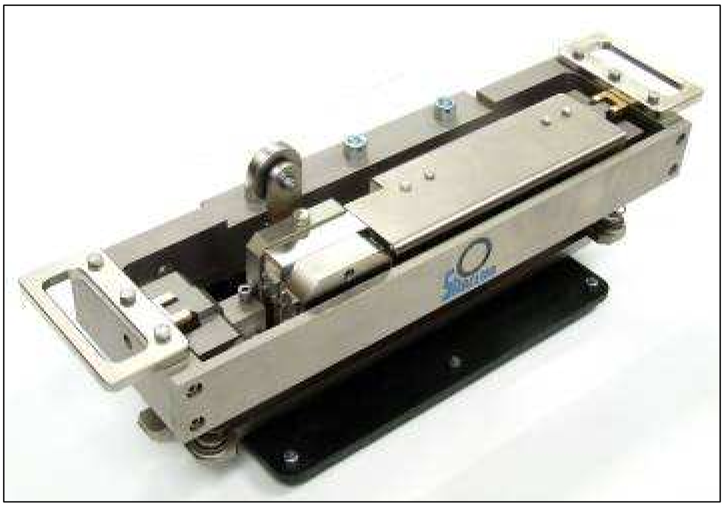


Figure 6 –Measuring assembly module.

The assemblies are mounted to the side face of the dummy bar chain links, rather than being an integral part of them. This ensures that the strength and load-carrying integrity of the chain is maintained as no significant link material is removed. The measuring assemblies are design to be permanently attached to the dummy bar

chain to provide measurements each time the dummy bar chain is inserted into the caster, but can be easily removed for offline maintenance and calibration activities.
The measuring assembly consists of a spring-loaded measuring blade, which creates a stable platform for the gap sensor and inclinometer modules. The gap sensor is used to determine the distance between the opposing rolls of the strand, whilst the inclinometer produces the relative angular alignment of the outer face rolls of the strand.

Figure 7 – In-Chain Strand measurement.

The length of the measuring blade is designed to span the largest pitch of adjacent outer face rolls in the caster and is pushed from the dummy bar chain to the outer face rolls by springs. This ensures that the blade remains independent of the dummy bar chain movements while at the same time providing a known and repeatable measuring platform. The roll gap and roll alignment measurements are logged during the stable period of travel, when the blade is a tangent across a pair of rolls.

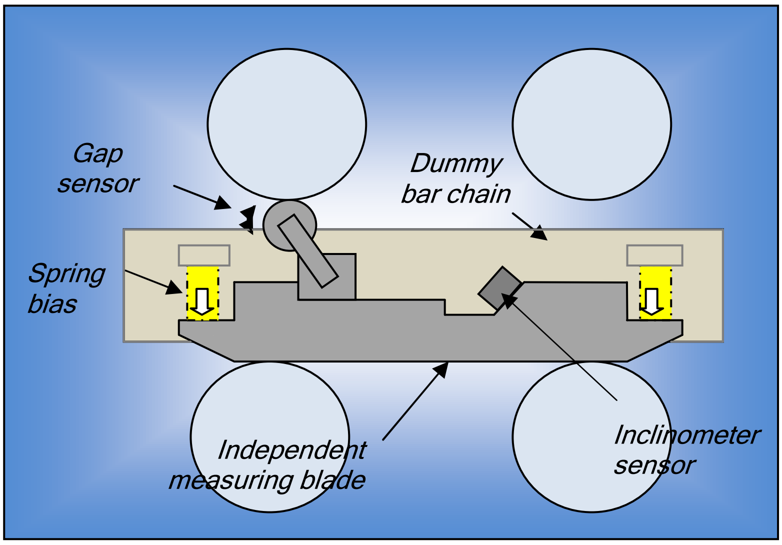


Figure 8 – Sarclad patented measuring principle.

Mounted from the measuring blade is a gap sensor incorporating a rotary device mounted on a spring-loaded arm, which contacts the inner rolls during the measuring sequence. The arm is spring biased to a vertical rest position and is able to rotate ± 90° from rest. This freedom of rotation prevents th e arm from becoming damaged when passing through machine guides or during mould entry. The rotary action also permits the length of the arm to be optimised to provide an extended measuring range. Where the previous design using a linear sensor was limited to a range of no more than 30mm, the rotary action allows the operating range to be safely increased to over 80mm. This enables casters of multiple thicknesses to be measured from a single assembly design.

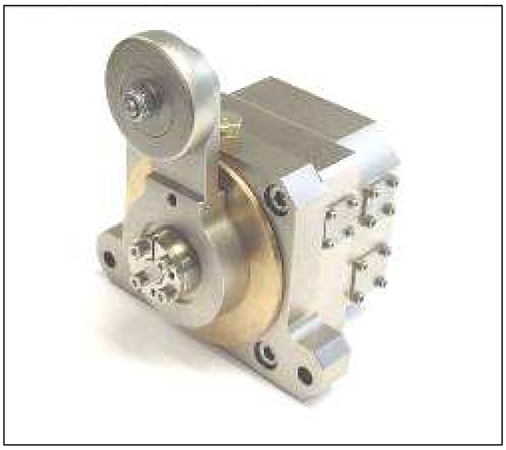


Figure 9 – Gap sensor.

A further advantage of adopting a rotary measuring arm is the reduced susceptibility of the sensor to become jammed with debris. As previously discovered, the plunging action of linear style sensors encourages the ingress of debris into the gap housing mechanism, which can quickly build up. The rotary movement of the new gap sensor provides a wiping, self-cleaning action, which makes the design far less susceptible to failure.

Figure 10 - Measuring assembly with 80 mm measuring range.

To protect the complete measuring assembly from pinching by drive rolls, the design retracts fully behind the profile of the dummy bar chain link. This feature ensures that all of the drive pressure is applied to the original chain and not the measuring equipment thus preventing damage and eliminating the need to adjust the pinch roll sequencing of the strand drive rolls.

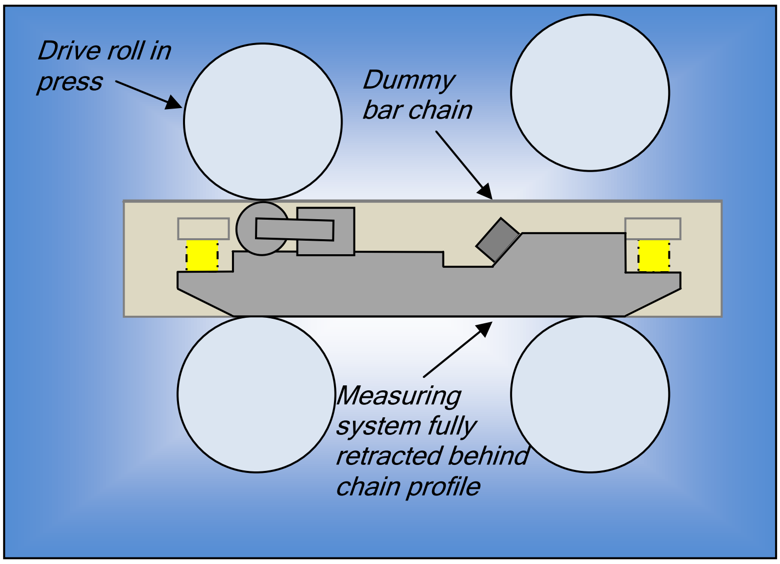


Figure 11 – Retraction behind dummy bar chain profile.

ON-BOARD COMPUTER TECHNOLOGY

The on-board computer of the new In-Chain measuring system is provided by a new custom designed electronics card. The development was necessary for dummy bar chain designs, where space is limited. The dedicated card uses the latest microprocessor technology to provide a higher level of operation than that previously provided by four electronics cards. Power sequencing, 16-bit signal conditioning, communications, data recording and memory storage, are all functions of just a single card. Reducing the number of cards provides not only size benefits, but also improves the overall level of reliability of the equipment since interconnections are eliminated and the component count is reduced. The microprocessor technology is also extremely low power, consuming only a fraction of the power required by other technologies. This benefits the batteries, which have a greater demand placed on them by the frequency and duration of use, as well as the relatively short charging duty cycle, which exists between casts.

Figure 12 – Electronics enclosure.

Figure 13 – Combined battery & electronics enclosure

To maintain the modular design concept, the electronics and rechargeable batteries are housed within in robust, easily detached enclosures. The enclosures are custom designed for each application and may be separate or combined housings depending on the available space on the dummy bar chain.

In-Chain measuring systems need to integrate into existing production activities with minimal operator involvement. The Sarclad In-Chain Strand Condition Monitor system has achieved this goal by fully automating the data collection, storage, transfer, analysis and presentation of results. During the insertion of the dummy bar chain into the continuous caster strand, the In-chain measuring system powers on automatically and commences data recording. The system requires no specific start sequence or location before commencing data collection. Intelligent position analysis ensures that data is always correctly allocated to the correct caster rolls, providing the ultimate measurement flexibility. When the dummy bar chain exits the strand, data recording stops and the measurement is saved to memory. Automatic data transfer to a base station PC occurs once the charging plug and socket are connected.

Once the data has been transferred, it is analysed and stored, before being made available for display, printing or remote viewing over a client’s network. The measurements obtained provide absolute roll gap, and roll to roll, segment to segment strand alignment results for precise analysis of the caster strand condition.

PRESENTATION OF MEASURED DATA

Clear presentation of the measured data is essential if an accurate assessment of the caster strand is to be made. For this reason a range of displays are made available for each measurement type, to suit the user’s preference.

One of the many gap results displays is the “Gap Error Graph”, shown in Figure 14. The “Gap Error Graph” provides a complete overview of the entire casting machine, for each individual roll. The graph is plotted against the amount of gap error for each pair of rolls, so that the required corrective adjustment can be easily determined. The data can also be compared with previous caster measurements so that the rate of gap degradation can be assessed.

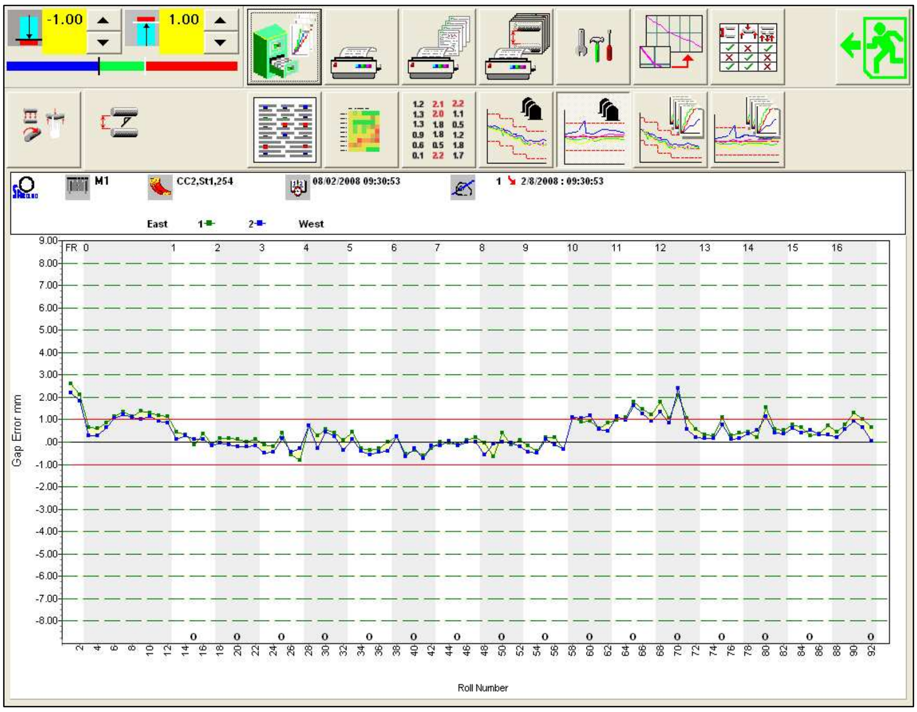
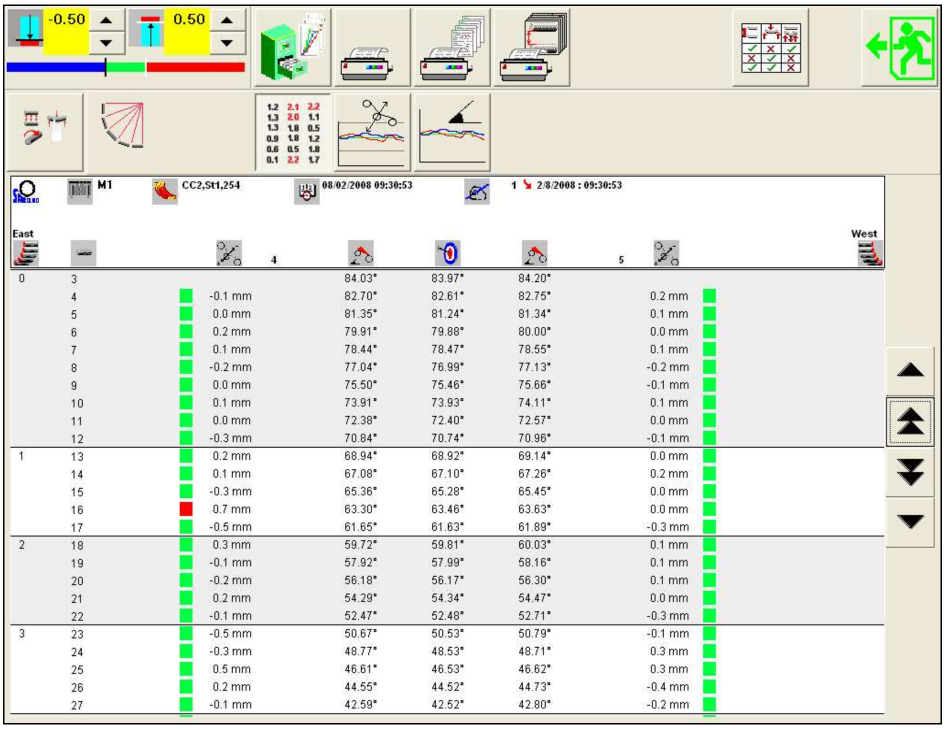


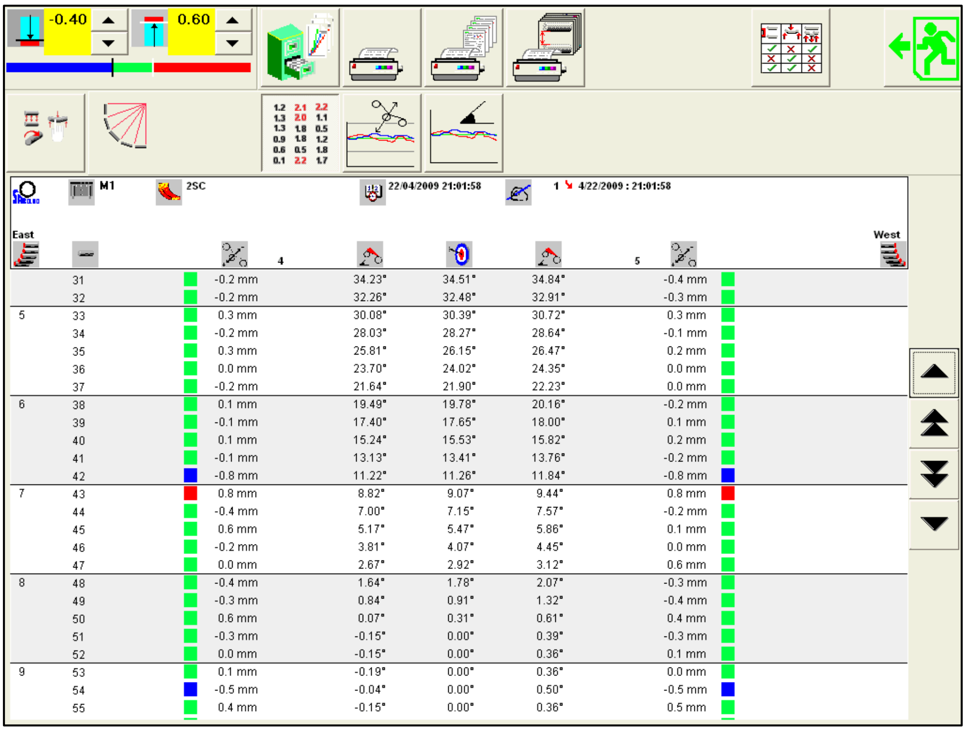
Figure 14 - Example of In-Chain roll gap error results.

The strand alignment information can be used to identify individual roll bearing problems and segment interface problems. Poorly aligned segments lead to slab quality issues, premature wear and failure of entry and exit roll bearings.
The location, sign and magnitude of any errors is used to identify which type of error exists and how to rectify the problem.



0	3		84.03°	83.97°	84.20°	
	4	-0.1 mm	82.70°	82.61°	82.75°	0.2 mm
	5	0.0 mm	81.35°	81.24°	81.34°	0.1 mm
	6	0.2 mm	79.91°	79.88°	80.00°	0.0 mm
	7	0.1 mm	78.44°	78.47°	78.55°	0.1 mm
	8	-0.2 mm	77.04°	76.99°	77.13°	-0.2 mm
	9	0.0 mm	75.50°	75.46°	75.66°	-0.1 mm
	10	0.1 mm	73.91°	73.93°	74.11°	0.1 mm
	11	0.0 mm	72.38°	72.40°	72.57°	0.0 mm
	12	-0.3 mm	70.84°	70.74°	70.96°	-0.1 mm
1	13	0.2 mm	68.94°	68.92°	69.14°	0.0 mm
	14	0.1 mm	67.08°	67.10°	67.26°	0.2 mm
	15	-0.3 mm	65.36°	65.28°	65.45°	0.0 mm
	16	0.7 mm	63.30°	63.46°	63.63°	0.0 mm
	17	-0.5 mm	61.65°	61.63°	61.89°	-0.3 mm
2	18	0.3 mm	59.72°	59.81°	60.03°	0.1 mm
	19	-0.1 mm	57.92°	57.99°	58.16°	0.1 mm
	20	-0.2 mm	56.18°	56.17°	56.30°	0.1 mm
	21	0.2 mm	54.29°	54.34°	54.47°	0.0 mm
	22	-0.1 mm	52.47°	52.48°	52.71°	-0.3 mm
3	23	-0.5 mm	50.67°	50.53°	50.79°	-0.1 mm
	24	-0.3 mm	48.77°	48.53°	48.71°	0.3 mm
	25	0.5 mm	46.61°	46.53°	46.62°	0.3 mm
	26	0.2 mm	44.55°	44.52°	44.73°	-0.4 mm
	27	-0.1 mm	42.59°	42.52°	42.80°	-0.2 mm

Figure 15 - Example of In-Chain roll alignment results identifying an individual roll problem.



	31	-0.2 mm	34.23°	34.51°	34.84°	-0.4 mm
	32	-0.2 mm	32.26°	32.48°	32.91°	-0.3 mm
5	33	0.3 mm	30.08°	30.39°	30.72°	0.3 mm
	34	-0.2 mm	28.03°	28.27°	28.64°	-0.1 mm
	35	0.3 mm	25.81°	26.15°	26.47°	0.2 mm
	36	0.0 mm	23.70°	24.02°	24.35°	0.0 mm
	37	-0.2 mm	21.64°	21.90°	22.23°	0.0 mm
6	38	0.1 mm	19.49°	19.78°	20.16°	-0.2 mm
	39	-0.1 mm	17.40°	17.65°	18.00°	0.1 mm
	40	0.1 mm	15.24°	15.53°	15.82°	0.2 mm
	41	-0.1 mm	13.13°	13.41°	13.76°	-0.2 mm
	42	-0.8 mm	11.22°	11.26°	11.84°	-0.8 mm
7	43	0.8 mm	8.82°	9.07°	9.44°	0.8 mm
	44	-0.4 mm	7.00°	7.15°	7.57°	-0.2 mm
	45	0.6 mm	5.17°	5.47°	5.86°	0.1 mm
	46	-0.2 mm	3.81°	4.07°	4.45°	0.0 mm
	47	0.0 mm	2.67°	2.92°	3.12°	0.6 mm
8	48	-0.4 mm	1.64°	1.78°	2.07°	-0.3 mm
	49	-0.3 mm	0.84°	0.91°	1.32°	-0.4 mm
	50	0.6 mm	0.07°	0.31°	0.61°	0.4 mm
	51	-0.3 mm	-0.15°	0.00°	0.39°	-0.3 mm
	52	0.0 mm	-0.15°	0.00°	0.36°	0.1 mm
9	53	0.1 mm	-0.19°	0.00°	0.36°	0.0 mm
	54	-0.5 mm	-0.04°	0.00°	0.50°	-0.5 mm
	55	0.4 mm	-0.15°	0.00°	0.36°	0.5 mm

Figure 16 - Example of In-Chain roll alignment results identifying a segment alignment problem.

Summary

The Sarclad In-Chain Strand Condition Monitoring System is an everyday maintenance tool for continuous slab casting machines. The range and frequency of the measurements provided by these systems enables a comprehensive and up-to-date assessment of the strand, without affecting production activities. Having the ability to monitor and control the condition of the strand rolls on a cast by cast basis allows maintenance and production decisions to be made on known data rather than assumed information.
Maintaining the continuous caster rolls to the optimum condition will ensure that quality cast slabs are efficiently produced, while substandard and scrap product are kept to a minimum - all of which are vital in today's competitive market of steel manufacturing.

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