

Development of Automatic Tapering Segments in a Continuous Slab Caster

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High carbon steel generally features high strength and increased hardness, which makes for it being rated at high grades and thus sold at higher unit prices. The quality of its production is one of the core competitive issues in an integrated steel mill. Central segregation was one of the defects that is normally observed in production, which can only be solved at the continuous casting process. The dynamic soft reduction is one of the methods that is able to deal with this, which is normally integrated into a newly built continuous casting machine. An automatic tapering system was developed in this study to upgrade traditional continuous casting segments with the abilities to respond to the commands of the dynamic roll gap control system. The benefits of the direct upgrades are the reduction in shutdown periods and manufacturing costs. The rigidity and the clamping forces of the continuous casting segments were also a concern. The development was successfully applied on the #6 to #8 segments in the #1 slab continuous caster of China Steel Corporation. A developing approach was made and done step by step. The robustness and the stability of the development were proven after a 36 days online usual production test. The causes of the internal crack defects observed at the test are also discussed.

Keywords: Central segregation, Dynamic Soft Reduction, Continuous Slab Caster

1. INTRODUCTION

Central segregation is one of the defects that constantly appears in the continuous casting process of high carbon steels, which can be restrained by the control of the casting thermal parameters, or the installation of additional apparatuses to stir or to weigh on the mush zone⁽¹⁻³⁾. Research projects to develop specific secondary cooling models, dynamic soft reduction technologies and electromagnetic stirring devices were carried out and sustained at China Steel Corporation (CSC)⁽⁴⁻⁹⁾. Direct-quenching steel plate production was started in the #1 slab continuous caster (#1SCC) of CSC in 2013. Two casting lines were configured for it. Even though the first continuous slab caster had been operated for more than forty years, the qualities of casting process were still maintained very well. A directly functional upgrade of the currently continuous casting segments was adopted to reduce the impact of production in an integrated steel mill. The development of an automatic tapering segment (ATS) was started to synchronise with the application of the dynamic soft reduction (DSR) technology.

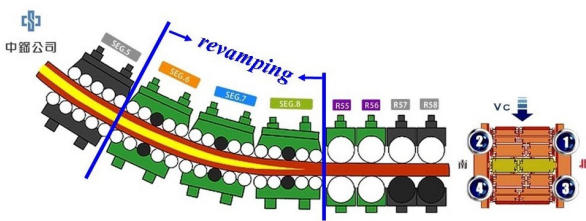
The hydraulic circuit of the current segments had to be modified from a logical open/closed control to a dynamic position control. The installation of both the position sensor and new blocks to the hydraulic

cylinders was limited by the narrow space of the current segments. The convenience of maintenance and the reliability of the modification had also been a concern in the design stage. The approach of the development was realized from one cylinder to a whole segment and then expanded to the segments on the mush zone. Ten sets of segments located from the #6 to the #8 in the #1SCC of CSC were revamped with the ATS. Functional validations had to be done offline at every stage and an extended online installing observation also been done to verify the reliability of the modification.

2. SYSTEM DEVELOPMENT

Referring to the capability of #1SCC, the mush zone of the continuously casting slabs would be located from the #6 to the #8 segments, as shown in figure 1, when the casting speed is ranged from 0.5 to 0.65 meter per minute. Three of the online segments in each casting line and four offline segments under maintenance were revamped with the function of dynamic position control for this study. The gap between the inlet and the outlet of the segments were controlled separately by a couple of hydraulic clamping cylinders.

A single cylinder of the #1SCC segments was isolated and machined to install a magnetostrictive position sensor in it, and also the hydraulic circuit was modified



Soft reduction range : Seg.6 - Seg.8
 Casting speed range : 0.5~0.65 m/min

Fig.1. Soft reduction revamping range.

simultaneously from a logical open/closed control to a position control, as shown in figure 2. The hydraulic block was separated into two parts due to the limited space around the cylinder in the segment. The block contained a directional solenoid valve which had to be installed outside but near the segment to reduce the fluid flow lag from the additional deployed pipes.

The testing results of the modified single ATS cylinder on a hydraulic bench are shown on the bottom left of figure 3. The unloading positioning error could be controlled equal to the resolution of the magnetostrictive

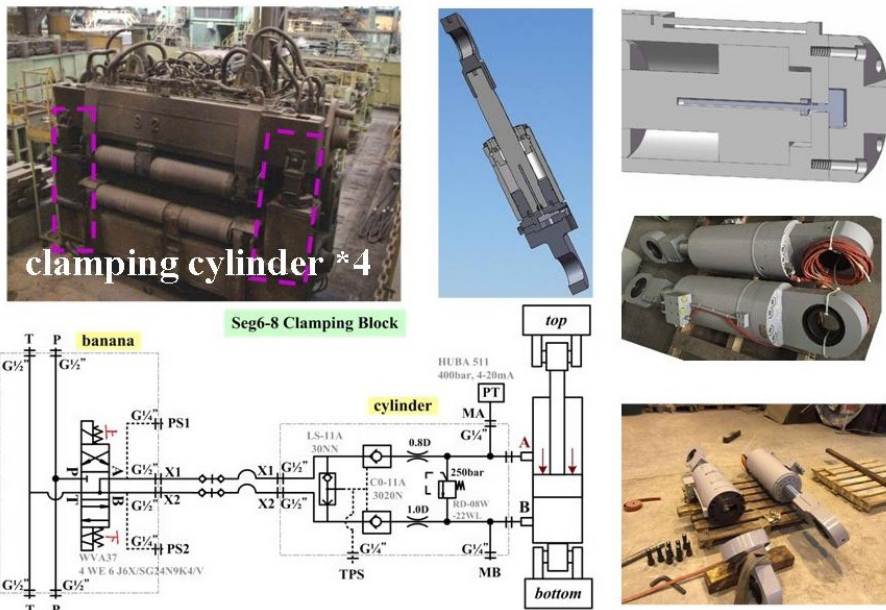
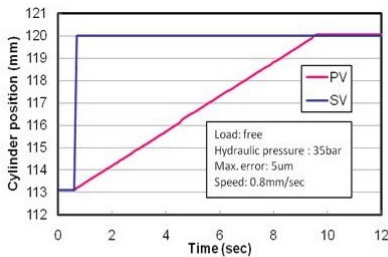
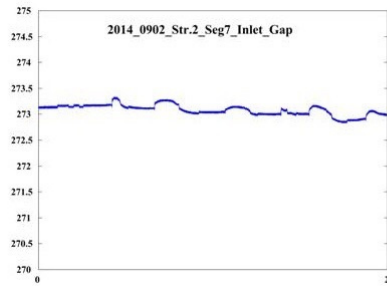


Fig.2. ATS hydraulic circuit modifications.



positioning error = 5 μm

six months online monitoring

- ☆ signal stability
- ☆ environmental tolerance

2014.08~2015.01

Fig.3. Testing results of a single ATS cylinder.

sensor under the adaptive self-tuning proportional-integral control method⁽¹⁰⁾ on a single-board micro-controller. A six months online test was done after the ATS cylinder was reloaded to the segment to validate the environmental tolerance and the signal stability.

An offset value is between the ATS cylinder position and the roller gap on the segment. The photo of the roller gap controller is shown on the top left of figure 4, which mainly composed of a single-board microcontroller and an industrial fanless touch panel as the human-machine interface (HMI). A physical key switch allows users to change the control function so as to activate the remote gap control mode, gap calibration mode and local operation mode. The HMI provides the function of roller gap and hydraulic pressure display, operation logging, sensor connection and communication state, online

roller gap setting, ATS cylinder manual operation, and controller version. Each gap controller is responsible for the control of its ATS, which receives four positioning signals in digital SSI output mode and four hydraulic pressure signals in 4-20 milliamps output mode, and it also controls the operation of four hydraulic directional electromagnetic valves. Due to the warm environment around the casting machines, an external cooling gas system was employed to maintain the temperature of the control box under 50 centigrade degrees.

A prototype of the ATS was prepared, and the positioning tests under loading and unloading state were both performed. A hydrostatic test bench was generated to simulate the loading from the online casting slabs to the segments by twenty small hydraulic cylinders, as shown on the top left of figure 5. The positioning error of the

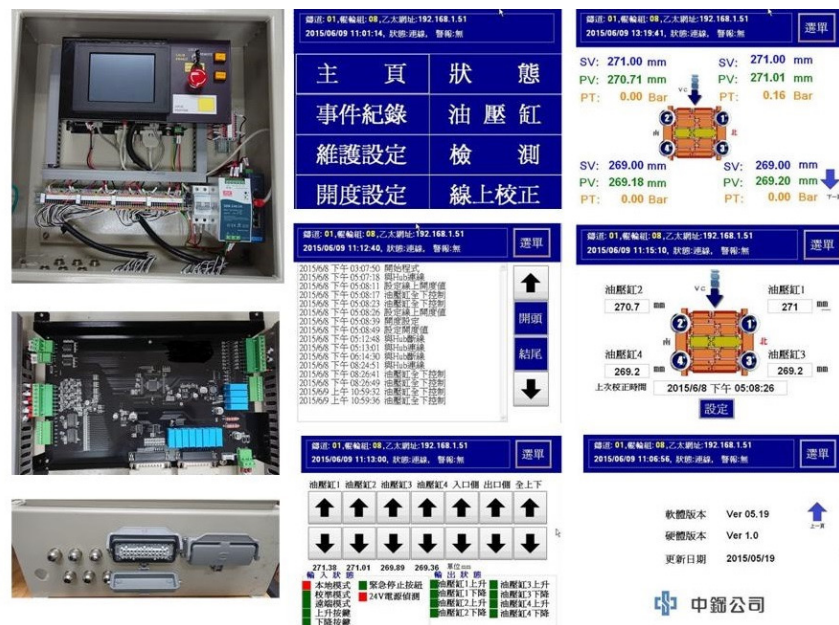


Fig.4. Scheme of the gap controller.

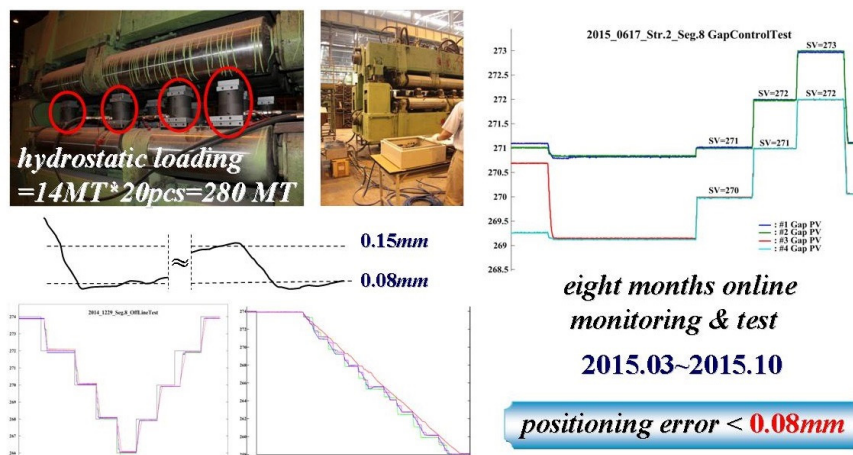


Fig.5. Testing results of the prototype ATS.

prototype ATS under hydrostatic loads could be controlled within 0.08 millimeters, satisfying the request of the system specification. An eight months online installation of the prototype ATS was carried out to prove its robustness, and also the online unloading positioning controls were tested at several scheduled shutdowns.

The scheme of the developing DSR technology is shown in figure 6. The calculated roller gap setting values of a secondary cooling model and a reduction rate calculating model were sent to gap controllers through a hub-server by networks. The offsets between the roller gaps and cylinder positions of the ATS were measured offline at the maintenance zone and recorded in a gap reader, as shown on the top right of figure 6, and then uploaded to the gap controllers through the hub-server while the specific ATS was online. A hub-server receives the roller gap setting values, cylinder operating commands, control modes, and control patterns from DSR and transfers them to the gap controllers. The roller gap present values, cylinder clamping hydraulic pressures, action numbers of solenoid valves, connection states, and alarm codes were also communicated from the gap

controllers to the DSR by hub-server.

A hub-server was built in the electrical room of #1SCC. Gap controllers were set up beside the walkway outside off the cooling chamber, as shown on the left of figure 7. The hydraulic units were installed underneath the cooling chamber in order to shorten the distance of hydraulic pipes to increase the response speed of the gap control. However, the space inside the cooling chamber is very narrow and full of steam while casting, the life cycle of the solenoid valves and signal wires of the hydraulic units may be unfavorable over time.

Considering the expected heavy maintenance requirement on hydraulic units inside the cooling chamber, a set of backup units and controllers were installed at the hydraulic pressure engine room, as shown on the left of figure 8, to avoid waiting for replacements during future production. The distance between the hydraulic units and the ATS cylinders was approximately 30 meters. An offline positioning test with 30 meters of metal pipe from cylinder to solenoid valve was adopted to ensure the gap control error still met with the design specification.

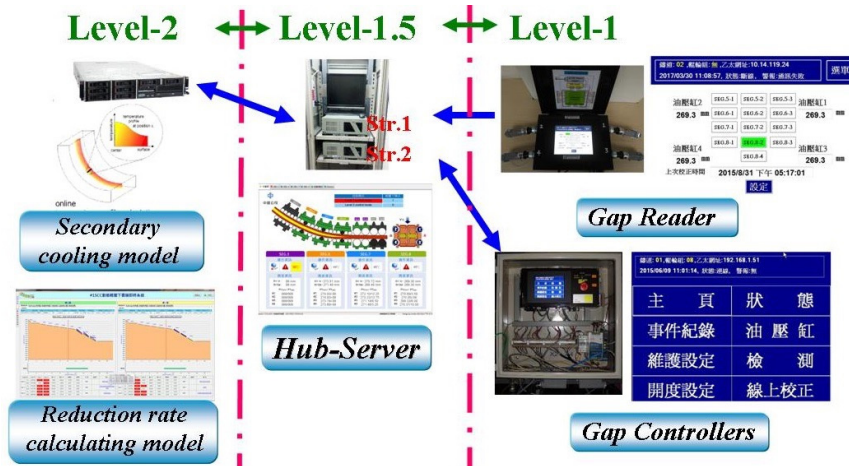


Fig.6. Scheme of the developing DSR technology.

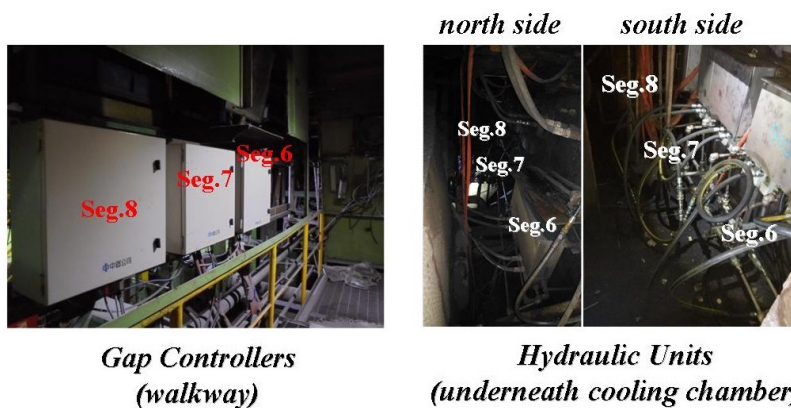


Fig.7. Arrangements of ATS at #1SCC Str.2.

3. SYSTEM VALIDATION

The testing of the DSR development was arranged into two phases. The first phase was to test the function and reliability of the self-modified ATS, while the second phase was to test the metallurgical quality of the DSR. The ATS test was subdivided further into three stages, as shown on the right of figure 9. The ATS was installed one by one at monthly shutdowns starting from March of 2016 from segments #6 to #8 on the second strand of CSC #1SCC. The hydraulic circuit would not be changed over to the solenoid valve until the ATS test was started. The first stage, A-1, online ATS test was

implemented 24 hours after the scheduled shutdown of June 2016 to validate if the operation of ATS fulfilled its functional design. An alloy composition near to the SS400 group was adopted to be cast during the first 24 hours of the shutdown for the slab metallurgical quality examination. After the sulfur print quality results were done, the second stage, A-2, online ATS test was sustained for 48 hours at the next scheduled shutdown of July 2016. Non-specific alloy composition castings were carried out at the A-2 test, and the slab quality examinations were also passed later on. Furthermore, A-3 test was practiced for 36 days to verify the reliability of the ATS before a 3 months shutdown for the revamping of

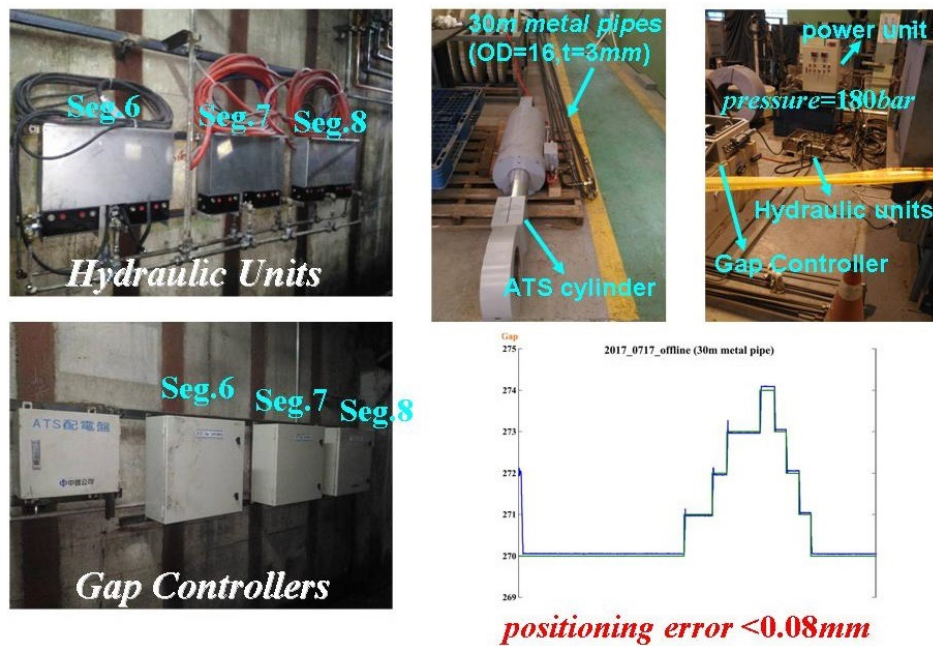


Fig.8. Long distance offline positioning test.

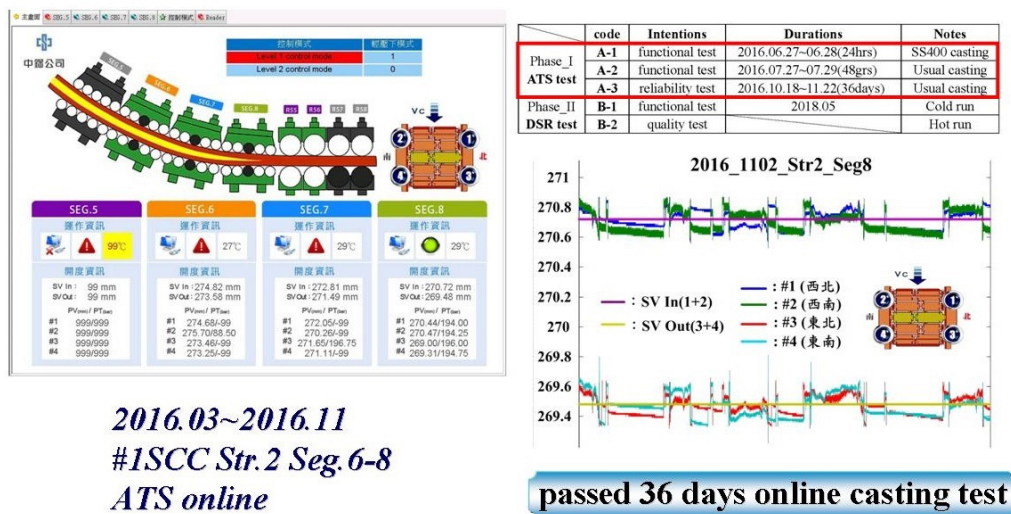


Fig.9. Online casting validation results.

electronic control equipment. The first installed ATS had been operated online for nine months till the third stage test was finished.

Before the A-1 test, the phenomenon of gap open was observed online while casting, as shown on the right of figure 10. This phenomenon was not caused but detected after the ATS modification. Roller gaps were regularly measured and adjusted online by inserting shims between upper roller and spacer to ensure the roller gaps were well within the setting values. However, the shims were compressed under the clamping force of the hydraulic cylinders. The deformation of the shim would be a constant displacement of about 2 millimeters as observed from the hydraulic pressure variations in a positioning step test. The hydraulic clamping force was counteracted by the shim's elastic force. After that, the roller gaps cannot be held during the action of slab

hydrostatic force while casting. The inserted shim is not necessary at the ATS after the roller gaps were measured.

A higher ratio of internal cracks were found in the ATS cast slabs near the end of A-3 test. Some additional discussions and tests were carried out to find out the possible reasons for the defects. In addition, the random interruption on gap controls caused by the Ethernet communication lagging between DSR server and hub-server also delayed the finishing of the DSR cold run test. However, the existing fine-tuned gap setting values implemented online for decades can not be adopted by the ATS directly due to the removal of the shim and the effect of bearing loading. Further experiments to reset the gap values may produce more slabs with defects. Considering the costs to continue the DSR hot run test, the developing of the DSR was suspended in June 2018.

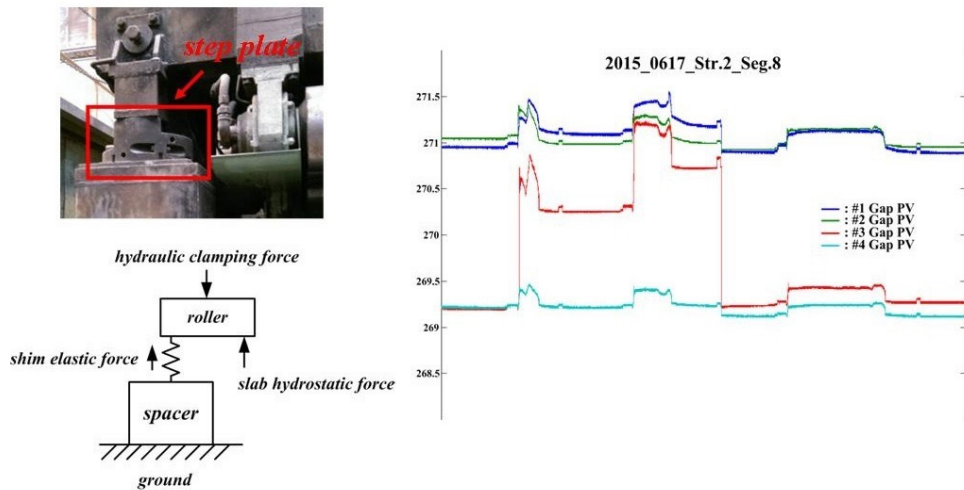


Fig.10. Gap opening phenomenon.

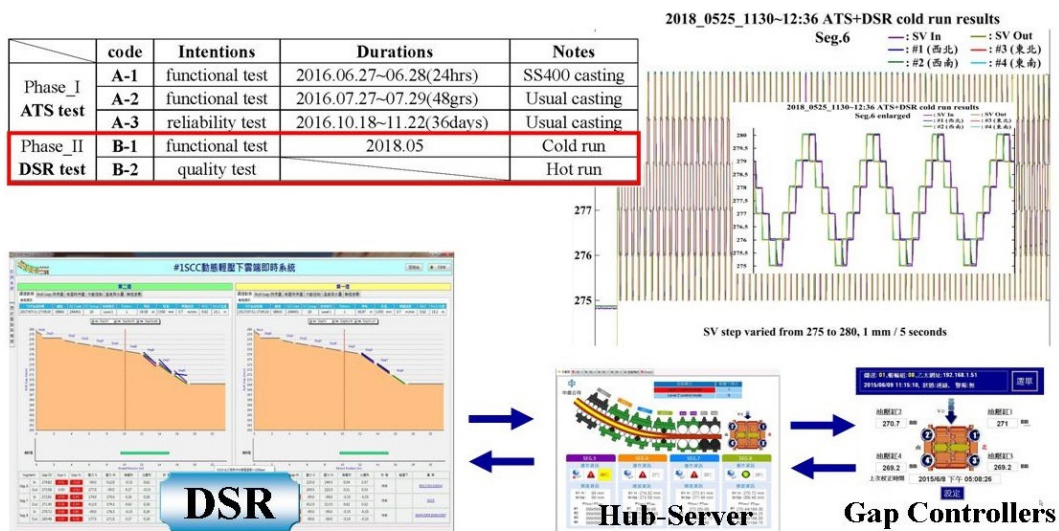


Fig.11. DSR cold run testing results.

4. METALLURGICAL QUALITY

ATS installed on #2 casting strand in #1SCC. The casting slab quality from #1 casting strand could be a comparison group to the ATS. A higher ratio of internal cracks on ATS casting slabs were observed near the end of the A-3 test, as shown in figure 12. The hydraulic cylinders are always clamping on the step plate in the original design, as shown on the left of figure 10. The bearings on the segments are always clamped in the original design, so that the gaps inside the bearing were in the same direction, as shown in figure 13. The step plate will be turned to a lower stage after the roller gaps were calibrated for the practice of soft reduction while casting. The rollers at the upper segment will be floating on the ATS during non-casting periods. The changes in loading direction of the bearings after every casting would cause the variations on the calibrated roller gaps. Otherwise, the removal of shims as shown in figure 10 to eliminate its elastic effect would also cause the variations on the calculated roller gaps. The variations on roller gaps would create an issue on higher ratio internal cracks in ATS cast slabs.

5. CONCLUSIONS

The ATS developed in the study successfully passed

the functional and reliability tests step by step. The functional design was done and one single ATS cylinder was modified and installed online for the positioning signal quality monitoring in the first year. A prototype of the ATS was made and tested online in the second year. Ten segments numbered from 6-1, 6-2, ..., to 8-4 in #1SCC were modified to ATS. In spite of the DSR hot run test being suspended due to the problem on the settings of the roller gap values caused by the shim elastic effects and the bearing loading changes. The ATS can still be adapted for use as an online monitoring system. Hydraulic leakage inside the ATS cylinder could be observed immediately from the larger open displacement during casting to increase the stability of the quality on cast slabs.

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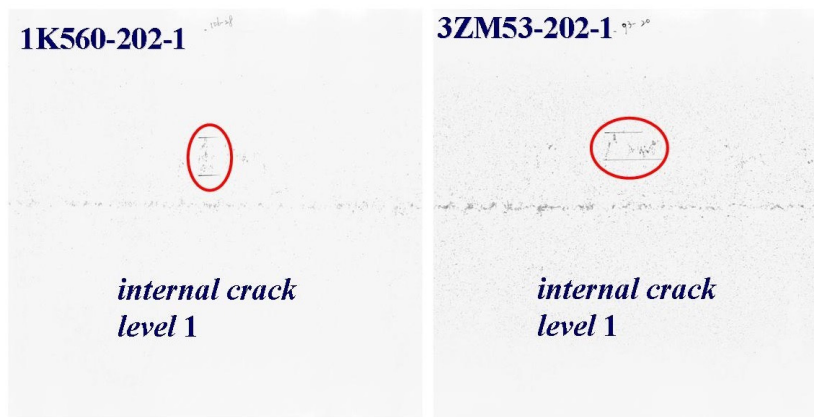


Fig.12. Internal cracks appearing at ATS test.

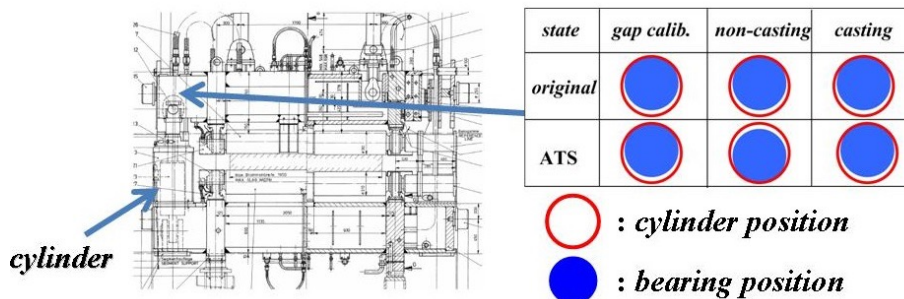


Fig.13. Effects of bearing loading.

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