



## CONQUERING THE NEXT QUALITY LEVEL IN CONTINUOUS CASTING AUTOMATION<sup>1</sup>

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### Abstract

Sophisticated automation packages are prerequisite for state-of-the-art quality steelmaking. Siemens VAI has always been a driver of innovation in this area, especially also providing expert technological packages and models for continuous casting machines. This is impressively demonstrated by the recent advancements of SVAI automation solutions: Simetal VAIQ addresses quality issues during the early phases of steel production, i.e., during steelmaking, refining and casting. Based on the experience of more than 200 successful installations, Siemens VAI has developed a completely new VAIQ version. The latest generation of VAIQ provides completely new functionality, includes new operator guidance, higher data-tracking resolution and a flexible editor for quality rules and introduces machine learning components. Direct quality improvements during the solidification phase in the continuous casting process are augmented by the completely new suite of dynamic secondary cooling and soft reduction packages: Simetal Dynacs 3D, DynaPhase and Simetal DynaGap Soft Reduction. New developments for the test and maintenance packages assist the personnel in their quest for quality. SVAI tools are mainly the OsciBoy (for oscillator services) and the WamBoy (for mold width adjustment services). This paper describes the above mentioned solutions and packages particularly with regard to upgrade possibilities for legacy automation systems and outlines the E&A Services Siemens VAI is able to provide to its customers locally and globally.

**Key words:** Caster automation; Dynacs 3D; Dynaphase; Soft reduction; Quality control.

## CONQUISTANDO O PROXIMO NIVEL DE QUALIDADE EM AUTOMAÇÃO DE LINGOTAMENTO CONTÍNUO

### Resumo

Pacotes automatizados de automação são pré-requisitos para uma Aciaria no estado da arte. A Siemens VAI tem sido sempre um motor da inovação nesta área, especialmente provendo também pacotes tecnológicos e modelos especialistas para máquinas de lingotamento contínuo. Isto é demonstrado de forma impressionante pelos recentes avanços das soluções de automação SVAI: Simetal VAIQ trata dos problemas de qualidade durante as fases iniciais da produção do aço, i.e., na aciaria, no refino e no lingotamento. Baseado na experiência de mais de 200 plantas bem sucedidas, a SVAI desenvolveu uma versão completamente nova do VAIQ. A mais nova geração do VAIQ entrega uma funcionalidade completamente nova, inclui novas orientações ao operador, maior resolução de rastreamento de dados e um editor flexível de regras de qualidade e introduz componentes de aprendizagem da máquina. As melhorias diretas da qualidade durante a fase de solidificação no processo de lingotamento são ampliadas pelos suítes completamente novos dos pacotes de resfriamento secundário dinâmico e *soft reduction*: *Simetal Dynacs 3D*, *DynaPhase* e *Simetal DynaGap Soft Reduction*. Novos desenvolvimentos para os pacotes de teste e manutenção auxiliam o pessoal em sua busca pela qualidade. As ferramentas SVAI são principalmente o *OsciBoy* (para *service* em oscilação) e o *WamBoy* (para *service* em ajuste de largura do molde). Este trabalho descreve as soluções e pacotes mencionados acima particularmente com respeito às possibilidades de *upgrade* para sistemas de automação legados e esboça o que o E&A Services é capaz de prover a seus clientes localmente e globalmente.

**Palavras-chave:** Automação de lingotamento contínuo; Dynacs 3D; Dynaphase; Soft reduction, Controle de qualidade.

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## 1 INTRODUCTION

Automation and mechatronical packages improve and assert the quality of the continuous casting products (slabs, blooms and billets) in various ways. New challenges that stem from ever increasing quality demands as well as new ideas how to tackle well known issues in the casting process have led to the Siemens VAI innovations that are presented in the following paper.

It discusses the complete re-design of the well proven VAIQ package that allows flexible rule based quality control and assists with machine learning tools. The new Simetal Dynacs 3D and Simetal DynaGap Soft Reduction model suite takes the precision and control possibilities to the next dimension allowing completely new philosophies for secondary cooling and soft reduction. A new and successful approach feature of Simetal LevCon allows to stabilize the mold level even for critical steel grades that are prone to instationary bulging. Proper maintenance and testing of the Simetal DynaFlex oscillator and Simetal DynaWidth mold width adjustment package assure the installation of pretested equipment in the casting machine, therefore reducing down-time and additionally assuring quality steel being produced from the first heat on.

Upgrading possibilities for installed models and technological packages are available to support our customers with continuous improvements over the whole lifecycle.

This paper outlines that Siemens VAI serves as a reliable partner with a comprehensive global network for our customer's maintenance and operational teams in electric and automation related issues.

## 2 SIMETAL VAIQ – THE UTMOST FLEXIBILITY IN QUALITY CONTROL

To minimize quality-related non-conformance costs it is important to detect quality deviations as early as possible so that appropriate rectification measures can be taken in time. VAIQ addresses quality issues during the early phases of steel production – from steelmaking and refining up to and including continuous casting and product disposition. On the basis of the experience acquired from the installation and successful operation of the VAIQ system at more than 200 steel plants worldwide, Siemens VAI has developed a completely new version of VAIQ to further improve quality supervision.

VAIQ determines the necessary process setup for quality-related process parameters, tracks the actual process parameters during production, predicts the quality of the liquid steel and cast products, and automatically determines subsequent product disposition. The latest generation of VAIQ improves the functionality of the previous system and includes comprehensive new operator guidance, high data-tracking resolution and a completely new flexible editor for quality rules. Thus even complex automated quality checks and evaluations of product quality can be configured into the system without any need to change the VAIQ software package.

Quality rules can be tested offline using input data from pre-defined test cases. This input data can be entered manually into the system or selected from real production data. Additionally, the expected rule output is incorporated into the test-case data. In this way, the method of so-called "automated testing" is supported, which immediately informs the user which of the pre-defined test cases have succeeded or failed. Thus, the reproducibility of quality assurance is highly enhanced. Besides executing test cases in a batch mode, stepwise execution of the rules and output



evaluation after each step of rule execution is also supported. The rules are released to production after sufficient testing and applied during the steel production processes.

To even further facilitate and improve the VAIQ setup and maintenance machine-learning algorithms are supplied for the generation and training of models for quality prediction. Sufficiently trained models can be run by the rules engine during steel production for the online prediction of product quality. Manually entered quality rules and automatically trained models can be combined into a hybrid overall quality-prediction model.

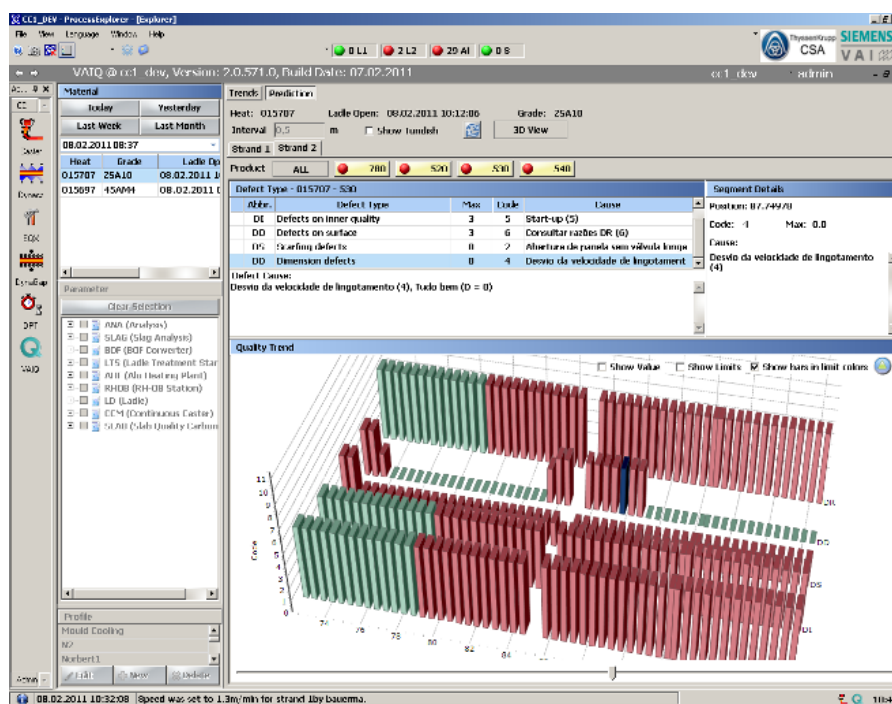


Figure 1. Predicted quality levels of produced slabs.

Online decision support and operator guidance is facilitated by the rule-based component. This allows continuous quality ratings to be carried out on the heats approaching the caster and during casting. Operators in the control rooms for steel refining and casting are guided by the information displayed on special screens to achieve the quality goals. Furthermore, the quality rating of the steel currently being processed is also shown and continuously updated.

VAIQ features high-performance and high-resolution process-data tracking and fast rule execution to support online decision-making. In the new system version the process-data-tracking resolution was improved in such a way that each value transmitted from a basic automation system to VAIQ is permanently recorded and a projection is supported for each value to the cast length of the strand.

The Discovery System – part of the suite of VAIQ packages – provides the metallurgists with a database containing general production information, process data as well as quality inspection results such as those originating from surface-inspection systems. Data which is of interest can easily be selected from the huge amount of information, and thus routine work, which is normally necessary for data collection, is eliminated. Frequently used methods for data evaluations are readily available in the system. Reports and graphs can be generated with overviews and details of process and quality. The cause-effect relationships between process parameters and quality results can be analyzed.



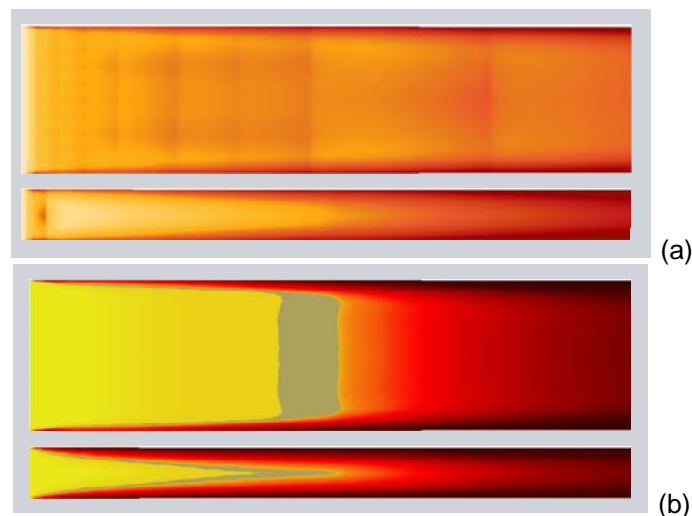
**Figure 2.** A new generation of VAIQ for even better quality control in steelmaking and continuous casting.

Application of VAIQ leads to a number of advantages for steel producers. These include:

- Improved and reliable product quality thanks to operator guidance for achieving consistent and systematic production processes;
- cost savings resulting from reduced product inspection and conditioning;
- assured product quality during direct or hot charging when visual operator inspection is not possible.

### 3 SIMETAL DYNACS 3D – THE NEW DIMENSION IN SECONDARY COOLING

More than 100 Simetal Dynacs secondary cooling systems have been installed in slab casters worldwide as of January 2011. The first-generation Dynacs solution, introduced in the 90's, was characterized by a two-dimensional temperature calculation of the strand center. The strand corners were largely neglected by the process model. Continuous improvements in computer performance have now made it possible to calculate the temperature at any point within the entire strand in real time, in a full three-dimensional mode and in a sufficiently fine discretization yielding very detailed temperature profiles as can be seen for strand surface and strand center in Figure 3.



**Figure 3.** (a) Calculated temperature profile of strand surface (top and side view, true colors; and (b) calculated temperature of strand cross section (center view, enhanced colors indicating the mushy zone area).





Special temperature ranges are made visible by shading the corresponding strand ranges (Figure 4). The ductility range e.g. is shown in blue.



**Figure 4.** Visualization of the ductility range in the cross-section view.

The model is based on an explicit finite-volume approximation that solves the heat-transfer equation and takes into consideration temperature-dependent density as well as the position-specific slab thickness and width. Simetal Dynacs 3D accurately assesses the heat transfer from the slab surface resulting from radiation, heat transfer to the rolls, natural convection and spray water. Furthermore, Dynacs 3D can be applied for both spray cooling and air-mist cooling and takes into account the spray-distribution pattern of the nozzles. This ensures an accurate spray-cooling heat transfer prediction to temperatures below 700°C when the Leidenfrost phenomena disappears. The result is an even more precise determination of the strand surface-temperature profile and the final point of strand solidification.

Based on the precise temperature calculations the Dynacs 3D model allows to specify the desired surface temperature not only along the strand length, but also across the strand width. Even individual control of the water flow and positioning of each cooling nozzle is possible. The control algorithms of Dynacs 3D calculate the water-flow setpoints to achieve the target strand-surface temperature values.

Another highlight of Dynacs 3D is its capability to calculate the natural shrinkage taper of the strand. This enables the roll gap to be dynamically adjusted exactly according to this strand taper, minimizing the influx of excessive liquid steel into the segregation area. The result is considerably improved internal homogeneity of the strand.

The offline maintenance and setup system allows the cooling-relevant settings to be configured in such a way that the spray-water distribution in the cooling zones and the application of cooling practices are optimized for slab and bloom casting machines. Customers' metallurgical know-how can be easily incorporated into the Dynacs 3D automation setup. A built-in offline simulation system enables comprehensive testing of new parameter settings prior to application in the production process.

The Dynacs 3D secondary cooling model has already been successfully installed in the No. 6 Slab Caster of voestalpine Stahl, Austria, as well as in the CCM 3 Slab Caster of the Chinese steel producer Qinhuangdao Shouqin Metal Materials Co., Ltd. Pyrometer measurement results (Figure 5) at voestalpine Stahl show an excellent fit in between calculated and measured lateral strand temperature profile.

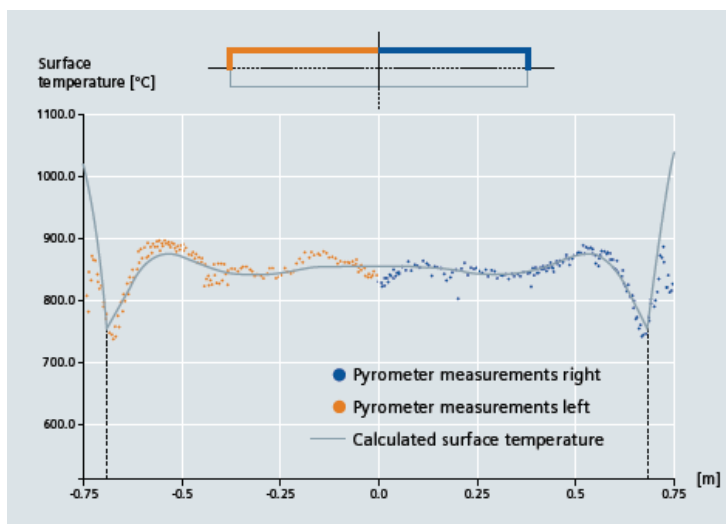


Figure 5. Pyrometer measurement results.

Application of Dynacs 3D allows to introduce completely new philosophies to set up cooling practices for upcoming challenges in continuous casting. The combination with moveable spray nozzles yields unprecedented quality results.

### 3.1 DynaPhase

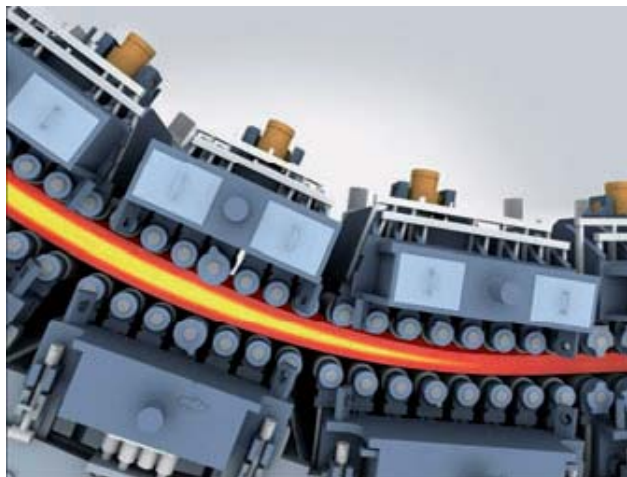
Parameters and functions like enthalpy, solid fraction, density and conductivity are prerequisite to calculate the 3-dimensional temperature field along the strand. In order to support the metallurgists Siemens VAI has developed the DynaPhase model, which is capable to calculate the parameters from any given steel chemistry using the thermodynamic Gibbs free energy and the Avrami model, instead of entering these in the maintenance system of Simetal Dynacs 3D.

The DynaPhase add-on package can also be integrated into the Simetal Dynacs 3D online system. It dynamically calculates the grade properties based on the steel chemistry currently in use.

## 4 SIMETAL DYNAGAP – THE NEW DIMENSION IN SOFT REDUCTION

DynaGap Soft Reduction stands for dynamic roll-gap adjustment in continuous casting. This is made possible by specially designed strand-guide segments – known as Smart Segments – in which the roller gaps can be remotely adjusted for strand-thickness changes and for improved internal strand quality (Figure 6).

On the basis of the online information provided by the Dynacs 3D thermal-tracking model (see previous chapter), DynaGap dynamically calculates the setpoints of the adjustable roll gap. The new DynaGap Soft Reduction model also takes into consideration the steel shrinkage as calculated by Dynacs 3D, which allows a more precise adjustment of the roll-gap settings to be achieved. This minimizes steel flow into the liquid or mushy strand center and also results in a significant reduction of macrosegregations along the entire length of the solidifying strand. Supervision of the roll engagement, depending on the state of solidification (liquid, mushy or solid) and the calculated strand-thickness profile, is a decisive factor for precise roll adjustments and thus improved product quality. An optimized roll engagement also reduces excessive forces on the strand and decreases roller wear.



**Figure 6.** Optimized adjustment of the roll-gap profile and highest internal strand quality with Simetal DynaGap Soft Reduction.

The more accurate control of the roller gaps allows additional casting strategies to be implemented such as liquid-core reduction and intentional bulging soft reduction. I.e. intentional dynamic gap increase before the soft reduction area allows for higher thickness reduction in this area. This further increases casting flexibility and product quality. DynaGap Soft Reduction makes it possible to freely define start-up and tailing strategies based on the strand thickness, steel grade, casting status or other events.

In this way roll damage and production interruptions, which may arise from the different casting behavior of the cold strand head or end, can be avoided.

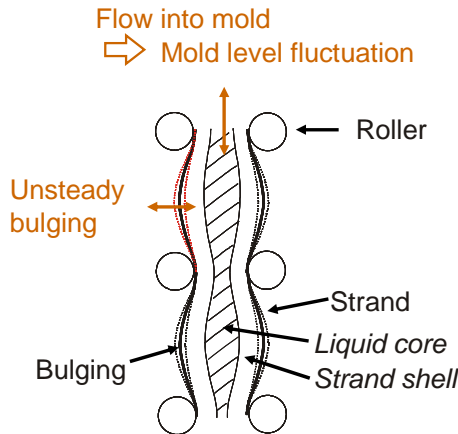
Due to the modular setup the new DynaGap Soft Reduction model can be installed on existing caster equipment and basic automation systems even from other suppliers.

## 5 MOLD LEVEL CONTROL – COMPENSATION OF UNSTEADY BULGING

The Simetal LevCon mold level controller package combines state-of-the-art mold level control with additional features that reduce clogging effects, submerged entry nozzle (SEN) wear and mold level fluctuations that stem from bulging effects. The highly configurable yet standardized design according to the 'Connect & Cast<sup>®</sup>' philosophy assures full functionality with a pre-configured system from the first heat onwards.

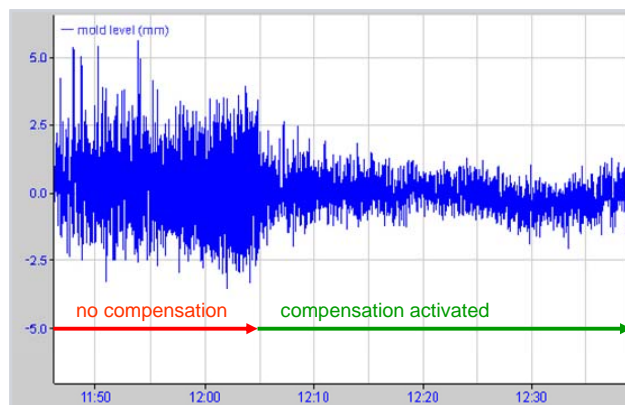
In case of a non uniform strand shell (especially at peritectic steel grades) bulging between rollers is varying over time and creates an oscillating steel flow in the liquid core. So mold level fluctuations are generated which have additional influence on irregular shell growth. This self amplifying effect can cause mold level fluctuations up to +/-10 mm.

At Hyundai Steel a new LevCon feature for compensation of mold level hunting due to unsteady bulging is installed the first time. With this new algorithm the mold level can be kept in normal range during transient bulging. Without the new LevCon feature only a reduction of casting speed can stabilize the situation.



**Figure 7.** Unsteady bulging resulting in mold level fluctuations.

The new algorithm compensates flow oscillations in the liquid core with an adequate steel flow modulation in the SEN by means of stopper movements. It includes a mathematical model of the level disturbance generated by unsteady bulging which is depending on casting speed and the roller pitches of the bulging sensitive zone. Due to a reliable estimation of this disturbance an effective compensation is possible as shown in Figure 8 (Hyundai CCM 2).



**Figure 8.** Reduced mold level hunting.

By means of this new feature mold level fluctuations due to unsteady bulging are reproducibly suppressed and a smoother strand shell is produced. So also the oscillation of liquid steel is improving, which means that the bulging effect itself is influenced positively.

## 6 OSCIBOY – ASSURING QUALITY BY OFFLINE TESTING OF THE DYNAFLEX OSCILLATOR

The Simetal DynaFlex hydraulic oscillation drive system enables dynamic adjustment of frequency, stroke and waveform during casting. Installation of this advanced technological package optimizes the performance of the casters to meet demands for productivity, product quality, production flexibility and economic operation.

The OsciBoy unit features an operation panel with graphic display and function keys (touch sensitive) for local operation. All operation modes on DynaFlex, except Automatic Remote, are also available on its offline maintenance package the so-called OsciBoy controller. Test and diagnostic routines include single-cylinder testing in standalone mode; all operation modes (manual, positioning or automatic local



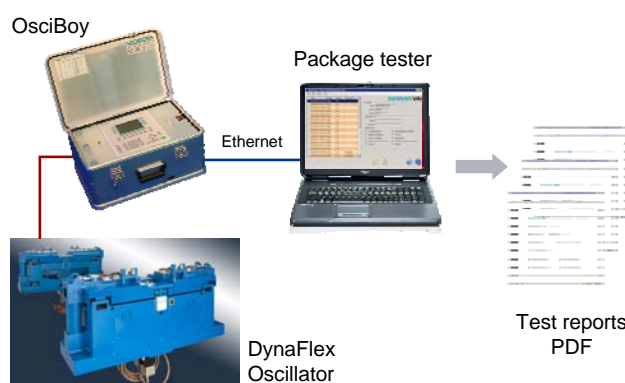


mode); operation, manual positioning and automatic oscillating of one or two oscillators; and a function check of electrical oscillator equipment. OsciBoy is connected to the cylinders of the oscillators. Via Ethernet the package tester receives and sends data to OsciBoy, which is responsible for the execution of the tests.

OsciBoy controls all movements of the cylinders and checks interlocks for correct operation of the hydraulic oscillation cylinders, mechanical assembly tolerances and automatic run of oscillator units. OsciBoy communicates with the package tester PC from which the maintenance technician can intervene in the testing process. The main features of this standardized tool to test technological packages are:

- Advanced functionality check of equipment (position sensors, pressure transmitters);
- monitoring of all measurements;
- intuitive user interface;
- easy operational handling due to the operator-guided menu;
- automatic test of complete functionality (repeatable);
- test certificate for maintenance to assure proper work for operation;
- informative test reports in a PDF file.

With a few simple clicks the user can select the test sequences, which then run automatically. To aid both on-site and online troubleshooting, signal and error logs are attached to the protocols. The package tester software is available in a wide variety of languages. Also included is a user-guided offline calibration function for maintenance personnel, which can be used for training. A pack-and-send function for customer support and feedback is also part of the package.



**Figure 9.** Quality assured testing in the maintenance area.

The same philosophy is applied for the Simetal DynaWidth mold width adjustment with the WamBoy package. Automatic testing of functionality as well as calibration of the hydraulic cylinders can be performed in the maintenance area. Calibration values are stored in the position transducers, thus assuring immediate availability of the equipment once installed in the plant.

## 7 UPGRADES TO PREVIOUS INSTALLATIONS

Over the years Siemens VAI has developed a respectable portfolio of technological packages and models in order to improve the casting process. With the experience of hundreds of installations worldwide useful improvements to the packages have been established. In order to provide these enhancements to our customers Siemens VAI provides upgrades to these models and packages.



An upgrade from Simetal Dynacs to Dynacs 3D leads to a number of advantages. Changes in the interface to the basic automation system are not necessary. The new maintenance and simulation system assists the metallurgists with more tuning possibilities. The calculations of the edge temperature and of the natural shrinkage are new unique features. Optionally, the DynaPhase model can be easily integrated into the Dynacs 3D.

Various new algorithms for sticker detection and reduced false alarms to an absolute minimum are the major highlights for our customers for upgrading Simetal Mold Expert breakout prevention system. The new “Oscillation Expert” monitors and diagnoses the oscillation behavior to prevent loss of productivity and supports condition-oriented maintenance. The “Surface Expert” provides information to ensure uniform feeding of the casting powder by temperature monitoring of the casting powder surface. An improved Analysis tool is used for investigating critical situations and helps to identify the origin of product defects.

An upgrade of the Simetal LevCon to the new feature antibulging as described in this paper is easily possible on Siemens VAI installations with an existing S7 400 CPU type. For previous installations a HW upgrade is necessary in excess to the SW upgrade.

The installation of the new package tester, which is an additional feature to the well-known OsciBoy of the DynaFlex oscillator, is carried out by a SW-update to the OsciBoy and the installation of the package tester unit. The HW compatibility must be checked on occasion.

## 8 HIGH QUALITY SERVICE FOR CC AUTOMATION

One challenging issue is to keep our highly sophisticated packages in shape over the entire lifecycle. Often our customers face limited and overloaded resources or experts are not available in all areas. This situation leads to consequences as

- Automation system is not touched except in case of emergency (no extensions, improvements, etc.);
- automation system is not exploited fully;
- modifications take a lot of time and are a bit risky because of unknown side-effects;
- process optimization performance is reduced due to lack of maintenance.

To overcome such difficulties Siemens VAI offers tailor-made annual service contracts with the aim to work in close cooperation with our customers to achieve jointly the best possible performance of the plant. A unique advantage to render fast and highly qualified service is the global Siemens VAI network. It makes sure that in more than 40 countries a first contact can be established with local Siemens VAI personnel, which is especially applicable in the Chinese market. As a backup an expert pool at Siemens VAI headquarters is available to assist our local colleagues or to give direct support to our customers using safe, reliable remote connections. On request our headquarter specialists will be delegated to customer's premises within contractual agreed ready-to-travel times.

A Siemens VAI service contract focuses not only on trouble-shooting but also on small modifications or add-ons to continuously improve the installed process automation exactly to the specific needs of our customers. Depending on the complexity these changes are carried out via remote connection or on-site.

Beside above described annual service contracts Siemens VAI offers a comprehensive spectrum of services such as:



- Spare Part and Component supply where Siemens VAI acts as a single source supplier for Siemens VAI plants having complete knowledge about the installed base;
- standardized migration and Upgrading Packages;
- Customized Training Packages;
- health Check Services for planned maintenance shut-downs;
- consulting Services utilizing the huge experience in all areas of a metallurgical plant;
- maintenance contracting acting as a partner for our customers regarding maintenance outsourcing strategies.

Summarizing this topic Siemens VAI sees it as a challenging target to become the preferred life-cycle partner for our customers with the mutual goal to reach a competitive edge.

## 9 CONCLUSION

Siemens VAI provides a renewed suite of packages that either directly influence product quality by improving mold level stability even for critical steel grades (Simetal LevCon), enhancing product quality by applying next level cooling and soft-reduction philosophies (Simetal Dynacs 3D and Simetal DynaGap Soft Reduction) or by assuring best and reproducible configuration of the SIMETAL DynaWidth or Simetal DynaFlex oscillators (by means of WamBoy and OsciBoy).

Another way of assuring and controlling quality is by precisely supervising, guiding and documenting the production process before the and on the continuous casting machine as is done in a completely re-designed way by Simetal VAIQ.

Siemens VAI's continuous improvements of the technological packages and models over the whole lifetime are provided to our customers by upgrade packages to existing installations.

Tailor-made services are offered to our customers locally, backed by global assistance in order to achieve best possible performances of the customers' plants.