Flexible, modular design of continuous casting equipment

VAI has applied the 'plug & play' philosophy to continuous casting by developing highly modularised technology packages using standardised interfaces. Improved mechanical, hydraulic, electrical and automation designs form the ‘Connect & Cast’ approach where the core components of these packages remain unchanged, so customers benefit from increased flexibility, speed of installation and commissioning, and overall plant operation.
upgrade existing electromechanically adjustable moulds.

Mould level control The LevCon level control system applies an advanced control algorithm which provides improved dynamic behaviour through consideration of...
CC-Explorer server provides HMI screens, on-line documentation and maintenance support. Any PC on the network can be used as a client and the server provides an OPC interface to the control systems of the technology packages (see Figure 6). CC-Explorer HMIs can seamlessly and easily be incorporated into existing HMI systems for plant upgrades.

STRUCTURE AND DESIGN RULES OF CONNECT & CAST SYSTEMS

Many factors influence the development of new and innovative components. The main technical ones are:

- Requirements of the process
- Necessary or contracted accuracy
- Reliability of the whole system
- Mechanical dependability.

However, in addition to these functional requirements many invisible requirements have to be considered. These are often the foundations of a successful system, namely:

- Structure of the whole system and how the components work together
- Clear and stable interface design
- Possibility of pre-testing and simulation of each single component to reach the Connect & Cast level
- Effective fail-safe and recovery concept
- Flexible modular and reusable system, which meets the functional requirements of most clients.

CORRECTNESS AND RELIABILITY

VAI technology packages comprise components, which contain sub-components, and so on. The first level is used to gain a mechatronic structure for components for mechanics, hydraulics, electrics, process control software (level 1) and metallurgical optimisation software (level 2). Most of the VAI components consist of about 50 sub-components. Figure 7 shows the connection between the number of components and the correctness. If each component has a correctness of 99%, the overall correctness is only 61% and such a product would prove to be extremely unreliable and maintenance-prone. Furthermore, commissioning of such a product takes much longer than intended, and therefore production cannot be established at the time and level that were desired.

Reliability, which is correctness over time, proves to be even more challenging as illustrated below:

\[
\lambda = \sum c(i) * p(i) \\
\lambda_c = \lambda * r
\]

CC-Explorer HMI CC-Explorer is a web-based HMI (human-machine interface) system with a client/server structure. Using the latest Internet technology, the delayed system reaction and clogging and mechanical wear of the tundish stopper. Automatic starting and resumption of the casting process are additional functions. Due to the modular concept, several types of mould level measurements, flow control mechanics and actuators can be used.
Thus the interface itself and the complexity of each individual input has to be minimised.

The following conclusions can be derived from correctness and reliability considerations.

**Interface design** A good example of minimising the interface and complexity of each input can be derived from the DYNACS development and its cooling practice interface. A practice is basically a set of parameters that can be very complex and which are used to adjust the model to the needs of different steel grades and casters. A practice tells a process optimisation model what to do, for example, ‘reach an aim surface temperature or a distinct roll taper for X70 grades’. The process model knows how to do it – each practice being defined by a name. A cooling practice has about 40 parameters, some of them being mathematical functions.

The DYNACS interface, being a minimised interface, only expects a name, represented by a string. The name corresponds to a file name, located on the server holding the complete practice information. By reading this file, which was prepared and checked by the Cooling Practice Maintenance System (CPSS), the use of a graphical user interface for defining practices is possible for each metallurgist or operator without special knowledge in computing. Similar considerations hold for the DynaGap model as shown in Figure 8.

The DynaFlex controller holds a table of parameter sets for the hydraulic oscillator so that, when changing to a different steel grade, the parameters are not changed, but instead a different, pre-configured set of parameters is selected. The message traffic can be minimised by reducing the number of layers. Thus the DynaGap process model software communicates directly to the level 1 DynaGap technological package. The DYNACS cooling package will use this approach in the near future.

If a component leaves the development state – typically after the second commissioning on site – it still has minor errors in its core routines. Most of the errors appear in connecting two components, ie, the interface part of the software. Normally these errors are detected very late, during integration tests.

A simple example illustrates this point. Consider a program that is copying characters typed on a keyboard to a printer (see Figure 9). Although the two low level components are readily reusable the copy component is not reusable in any context which does not involve a keyboard and a printer. This is unfortunate since the intelligence of the system is maintained in this component. The copy component can, of course, be extended to write to a disk file by a special switch, but this adds new interdependencies to the system. As development time goes on, and more devices participate in the copy component, it will be littered with switches and will depend on many lower level components. It will eventually become rigid and fragile.

How can we reuse the copy component be reused freely? The applied strategy is called dependency inversion.

**Dependency inversion** Consider the simple diagram in Figure 9. The copy component contains interfaces to an abstract reader and an abstract writer. One can easily imagine a loop within the copy component that gets characters from its reader interface and sends them to its writer interface, yet the copy component does not depend upon the keyboard reader or the printer writer. Thus the dependencies have been inverted. Now we can reuse the copy component independently of the
keyboard reader and the printer writer, and new kinds of reader and writer derivatives can be invented which we can supply to the copy component. The copy can be used in many different detailed contexts as it is mobile.

The general form of the dependency inversion principle is as follows:

- High-level components should not depend on low-level components
- Both should depend on interfaces
- Interfaces should not depend on details
- Details should depend on interfaces

When components use the dependency inversion principle, developers are able to continue developing independently from each other, as long as the interface stays the same, syntactically and semantically. For example: DynaGap uses 2D thermal tracking for slab casters and a 3D one for bloom casters; the DynaGap MasterController software was running on a MicroController until 2000 and then changed to a PC; the SMART segment changed from eight positioning cylinders to four, and for bloom casters, one strand controller PLC controls all pinch rolls of a stand, whereas for slabs casters one segment controller controls one SMART segment.

Even with all of these changes, the interfaces are still the same and DynaGap is able to handle them.

Similarly the DynaWidth controller component can handle several types of electromechanical and hydraulically based narrow side drives, but, due to the dependency inversion principle, the surrounding components did not change.

This concept is used for control algorithms which have reduced their dependency on special input and output devices. It is also applied in order to remain independent of a database, a database design or HMI systems. As an example, the CC-Explorer HMI can be integrated into any HMI system and each PC on the network can be used as a client of the VAI CC-Explorer HMI.

Another advantage of the dependency inversion concept is the possibility to develop test adapters for simulation of input and output devices. This enables automated testing and simulation of integrated functionality before delivering to the site.

Fail-safety An efficient fail-safe system has to consider all components of the system, including mechanics, hydraulics, electrics and automation. Any component has a possibility of failure and all others have to react to...
prevent danger to life, equipment or product quality.

The worst scenario is if high-level components start to handle malfunctions of lower-level components. In this case the modularity collapses to non-transparent chaos. To prevent this, each component has to handle its own functionality as long as possible and inform the next higher level component about its actual state. The higher level component reacts in accordance with this information and, if necessary, the functionality will be reduced.

For example: DynaGap soft reduction depends on the thermal tracking model (TTM). If the TTM or the data link to the TTM computer does not work properly, soft reduction will be kept static, maintaining the last set points. In the case of a communication breakdown to a segment controller, segments will be kept at the last valid position by the segment controllers. If there are hydraulic or electric problems on the segment the actual gap will be kept by check valves. For a modular system, it is essential that all components keep their independency to higher-level components in the case of an error. Together with the fail-safe concept, a recovery strategy following the same concept has to be developed.

Another requirement is the possibility of reusing components for different projects. This enables quick installation and fast ramp-ups of the new machine. During the pre-project phase, the clients are able to see simulations with the software identical to the one to be installed on their machine. The numerous repetitions lead to the very high, yet still increasing reliability of VAI's technological package units, thus confirming the Connect & Cast philosophy.

SUCCESS STORIES USING CONNECT & CAST

POSCO Gwangyang VAI received its first order from POSCO Gwangyang in 2001 to revamp a 2-strand slab caster to increase flexibility and product quality. The 'new' caster is equipped with DynaGap soft reduction, DynaWidth hydraulic mould width adjustment, DynaFlex oscillator and LevCon mould level control (see Figure 10).

The start-up period was just 11 days to full production and was only made possible due to the fact that, by following the Connect and Cast philosophy, VAI’s technological packages were fully operational from the first heat.

UGINE&ALZ The scope of this revamp project was to replace the old single strand slab caster, starting top-down at the ladle operating platform, including tundish, mould, oscillator, the strand-guiding system, with the steel structure (see Figure 11). The challenge was to revamp the machine and perform the start-up of the installed components after a 21-day outage window. Due to the fact that the disassembly of the old equipment, as
well as the installation of the new equipment, that is, the mechanical portion of the revamp, was the most time-consuming part, the short time duration could only be achieved by using VAI’s well-proven technological packages that are pre-tested and ready to use. The start-up was achieved in the very short scheduled time period and provided the design functionality from the beginning.

**PANGANG** To produce rails of at least the same quality as its European competitors, PANGANG ordered a 6-strand bloom caster to replace the existing ingot casting route (see Figure 12).
The caster is equipped with a DynaFlex oscillator, LevCon mould level control and Bloom DynaGap soft reduction – the first such installation on a bloom caster. After activating DynaGap soft reduction, the internal quality of the blooms showed extremely low centre segregation and no centre cracks. Commissioning was completed within 21 days.

**ANSHAN** After successful commissioning of caster No. 5 in March 2003, ANSHAN ordered an upgrade of caster No. 4 to enable hot mould width adjustments. DynaWidth was installed and after only three days of cold commissioning and tests, hot commissioning and all hot adjustments for final acceptance were carried out within one day. The system is being operated from the CC-Explorer HMI package, which was fully operational from commissioning.

**CONCLUSIONS** VAI has applied the plug & play philosophy to continuous casting by developing highly modularised technology packages using standardised interfaces. Called Connect & Cast, the approach uses improved mechanical, hydraulic, electrical and automation designs where the core components of these packages remain unchanged, so customers benefit from the improved flexibility, speed of installation and commissioning and general plant operation.

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