Real-Time Controller design for harsh environment and safety critical EOT cranes applications

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Abstract - **This paper summarizes the most important advances of the used crane control technology in perspective of semi automatic operation of EOT (Electrical Overhead Travelling) cranes used in the harsh industrial environment. Most of these applications should comply with very strict safety categorized regulations for mechanical motions. Additionally, harsh environment is taken in consideration during design phase of control devices.**

Faster and more productive cranes demand a highly efficient Real-Time (RT) Controller as overriding system to control actuators in the closed loop system. Monitoring and production statistic as functional subset of the RT controller is not presented in details in this paper.

Storage capacity is the limitation for most application today; automatic operation offers optimum operation, density and peak capacity equivalent for continuous manning of every crane. As cranes become larger and faster, operations starting to be increasingly more difficult. To meet the increased demand, different automation strategies should be adopted. Automatic operation requires sensor systems for target position and load position, video equipment on spreader/crane, control and communication equipment on the crane and remote consoles for video and control signals. Automation as already accepted technology with proven benefits, helping the change in mindsets towards increased of automation concepts.

Keywords: EOT cranes, RT Real Time systems

I. INTRODUCTION

Requirements of modern EOT cranes result in demand for more and more sophisticated Real Time crane control automation systems and reliable connection to the customer overriding information systems. These systems continuously provide up-dated information about cranes moves and crane status.

To achieve an efficient and profitable modern factory design overall, following sequence should be applied:

- Select the optimum capacity for the factory
- Select the most efficient EOT cranes concept
- Select an conceptually economical EOT crane and
- Automate

Applied automation should consider follows:

- Reliability/quality – breakdowns are costly in automated terminals
- Serviceability, support and diagnostics
- Flexibility – capability to handle present and future environment, vehicles, container types, operation principles etc.
- Simplicity- not more equipment than needed
- Safety – present and executed future safety standards
- Standardization and experience

The unmanned *Crane's Control Systems* (CCS) supports basic and advance application function. In order to achieve a number of different possibilities to solve engineered problems, the crane control concept includes:

- Powerful process controller with advanced multitasking, capable of handling several real time critical control loops simultaneously;
- High speed communication links between different clients;
- Advanced sensors technology for accurate measurement and fast transmission of positions and speeds;
- Centralized interface for diagnostics of the complete system.

RT control system includes a wide range of well-proven solutions (including hardware and software) that are divided into blocks for easy adaptation to each client's specification. The control functions are standardized and built up around a basic core that is adapted on a project-to-project basis with add-on blocks. Usually, control system with its software specially developed for crane applications, coordinates the entire crane functionality and communicates with, remote I/Os, drive system, information stations and crane automation sensors.

Continuously increasing complexity of the modern EOT crane requires to use *Simulator assistance* in order to prepare crane operators in advance so as to achieve maximum productivity, and without compromising safety or failing to meet new work environmental challenges. Instead of taking cranes out of production and risking physical damage, customer can use a realistic in-house simulator to bring your operators safely up to speed.

What is unique about the advanced simulator is its incorporation of the latest technology, with state-of-the art, real-time physics simulation and advanced 3D graphics, which enable training in exceptionally life-like situations. Moreover, the training strategy enables customers to turn out trained operators with a high degree of conformity, due to the disposition of predefined scenarios, with trainees following a path from basic crane operation to advanced operation.

The Crane Driver Training Package contains a ‘full scale’ simulator, adapted to a specific crane (if desired), and includes correct environments as well as course Curriculum for both operators and instructors.

The Crane Driver Training Package scenarios include most of the common situations found in operations. Hoisting, controlling sway and safety checks are some of the basic exercises, [1], [2] and [3]. Discharging and loading to and from various types of situation are some of the more difficult exercises.

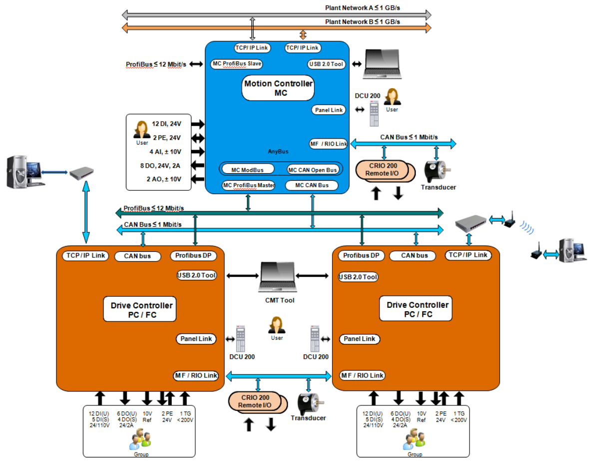

Fig 1. RT controller design – Block structure

II. CONTROL DESIGN PHILOSOPHY

Design of the control system for semi automatic or automatic operation of EOT cranes used in the harsh industrial environment must fulfill the heavy industrial standards and operational requirements. Typically, demanding conditions of the steel plant environment:

- High operational temperatures up to +70° C
- Conductive dust
- Very high electrical pollution

Continuous change/achievement of modern technology has significant impact on the currently applied technology and design philosophy.

Control system complexity is highly affected with continuous extension of functionalities processing capabilities:

- Needs for Integration into plant information systems
- Needs for extended system functionalities
- Stricter demands for safety
- Demands for high operational availability
- Improved performance to reduce mechanical stress
- Minimize maintenance

Additional requirements should be considered:

- Ready for future technology upgrade
- Backward compatible to the existing systems
- Power quality and energy saving

Depends of the processing complexity, cranes control system is built as cluster of one or more basic recursive building block. Each block represent distributed RT closed loop controller (Fig. 1). Block incorporates Motion Controller (MC) as local overriding system to control one or more Drive Controllers (DC) or actuators in general.

Logical data transfer between different blocks is virtual and horizontal and supervised with higher level for relevant cluster. Dual fast plant networks are used to communicate via MC with superior control system. Communication links are based on TCP/IP protocol and support fast bidirectional data transfer up to 1 GBit/s. Duality is required to fulfill demands for operational availability, redundancy and stricter safety as well. For flexibility with standard industrial applications, additional build in Profibus communication link is used to communicate with superior system. Link supports standard DPV0 slave protocol with data transfer speed up to 12 MBit/s. Optionally, MC is equipped with two Compact Flash™ slots for the standard plant and fieldbus communication links.

Drive Controller is equipped with high speed 1 GBit/s link and supported with TCP/IP protocol. Separate communication link is used for drive monitoring and parameterization only. Separations from internally used links by application minimize influence on communication latency and improve closed control loops properties as well.

For internal data transfer within the block (MC and DC), several CAN and Profibus communication links are used simultaneously. This approach secure redundancy and required communication data through put.

CAN links operate as multimaster and support 2B or CAN open protocols, speed up to 1MBit/s and they are used to link MC and DC units or to access remote I/O and transducer units.

Profibus operates as DPV0 master (MC) or slave (DC) up to 12 MBit/s and it is used via master to access all drive and Profibus transducer units.

Application process variables are connected to the RT (MC or DC) controller directly. Direct connection to the Digital Signal Processor (DSP) inputs secure a very fast signal processing and keep closed control loop properties in specified range.

III. MOTION CONTROLLER

Motion Controller, as part of the basic building block, is design as standalone real time (RT) unit. Fieldbus communication (Profibus and Can) are used to access another building block units. Preferably, field buses are used as local links to secure fast data transfer and communication latency. For access/control of the process data, Local I/O interface or Master Follower/Remote I/O CAN bus link are used. Local I/O interface, with very fast scanning secure critical closed loop control routines. Additional remote I/O units could extend number of I/O and access them with selectable scanning time. Local and remote I/O interface comply with standard I/O specification in general.

To communicate with superior control level, dual plant network in conjunction with profibus link are used. Multiple connections secure redundancy to fulfill safety requirements category for this type of application.
Operator's panel and Commissioning and Maintenance Tool are used as Man Machine Interface (MMI). Operator's panel is standalone unit connected with fast serial link. CMT is PC based graphical tool. Both are used for MC parameterization and monitoring.

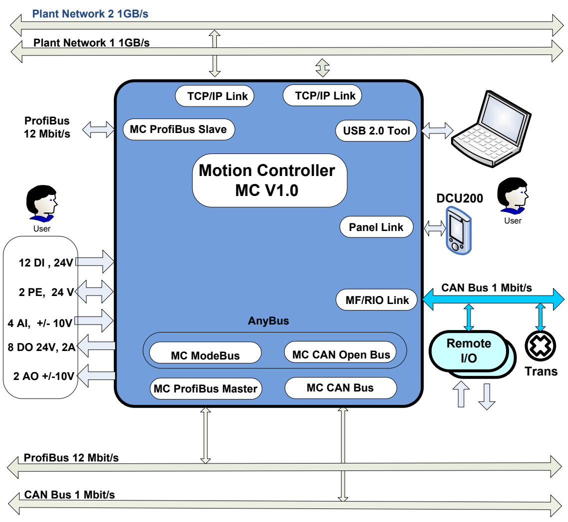

Fig. 2. Motion Controller - Internal Structure

MC is specially design robust control system for cranes and another heavy duty material handling systems.
Dual core approach is used to support a real time and safety critical cranes applications. To comply with safety regulations, duality requires usage of different processor type. This approach minimizes the influence of component's errata.
Three separated and isolated links are used for internal DSP core to core communication. Multiple users' communication links are supported with both cores to increase system's availability.
Local I/O interface as part of the safety critical application is directly controlled by both processors to secure fast and safe disconnection of the process variables in the case of single core malfunctioning.

Each core and corresponding glue logic is fed with physically and galvanic separated power supply circuitry. MC is design to support external power supply redundancy.

Optionally, MC is equipped with two Compact Flash™ slots for the standard additional communication modules. This option gives more flexibility to communicate with superior control system. Today, modules are available in different Fieldbus versions (CANopen, ControlNet, DeviceNet, Profibus, etc) and Ethernet versions (EthernetCAT, EthernetNet/IP, Modbus TCP, Profinet, etc).

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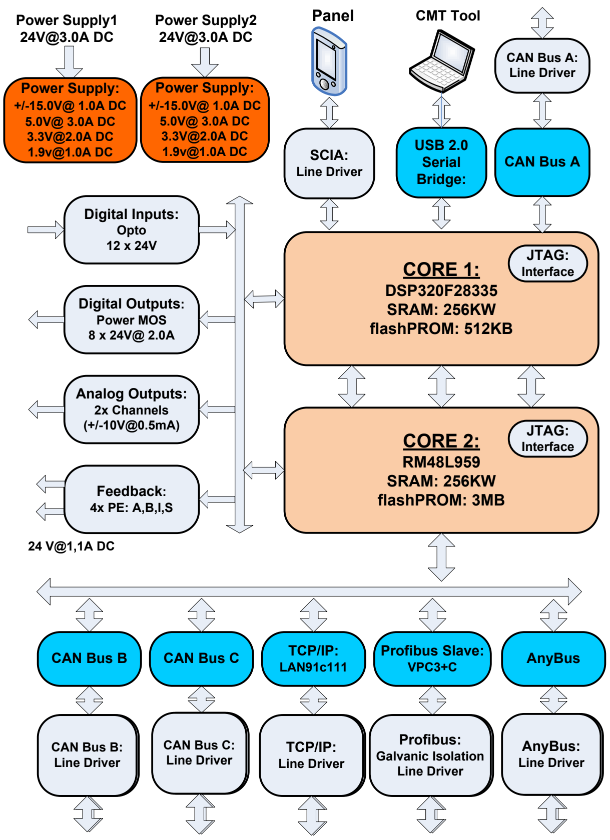

Fig. 3. Block diagram of RT controller

IV. MOTION CONTROLLER - APPLICATION

MC as part of RT control system includes a range of well-proven time critical control solutions for client's specification. The control functions are standardized and supported with built in Operating system and user interfaces. Control system with its software specially developed for crane applications, coordinates the entire crane functionality and communicates with, remote I/Os, drive system, information stations and crane automation sensors.

Typical RT and time critical function such as anti-sway could be used in different mode of operation (with or without sensors). Most of the EOT application located in harsh environment requires sensor less approach ultimately. Sensors sensitivity is the limiting factor.

Sensor less anti-sway could be classified in the different approaches:

- Open loop
- Vision based
- Artificial neutral network
- Reference modification

For the Open loop approach (Fig. x), the positive reference signal is passed through an adequate Band-stop or Notch filter to dump the natural load swinging frequency.

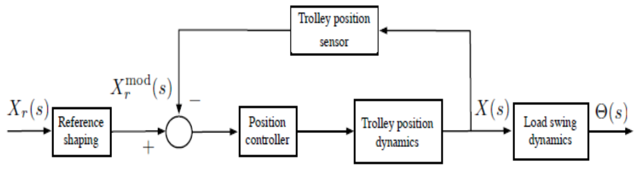

Fig 3.1 Anti-sway control loop

Most of the EOT crane installations require a supervising and protection facilities for critical mechanical parts (shafts and gearboxes).

In the case of shaft breaks, time is very critical and appropriate action must be taken within few milliseconds. MC (hardware and software) supports fast measurement and safe action in redundant configuration.

Gearboxes should be monitor for:

- Bearing failure
- Coupling problems
- Unbalanced loading
- Overheating
- Cracking, scuffing, pitting

Gearbox monitoring and diagnostic require acoustic data acquisition and appropriate tool for diagnostic (FFT).

V. DRIVE CONTROLLER

Drive Controller (FC) is designed as integrated regenerative frequency drive. The complete energy transfer from line to motor is achieved inside each unit. The power factor on the line side is unified.

The design takes consideration to the special conditions of heavy duty industry with high heat and conductive dust. The distances in the air and across isolators are lager then for standard industrial drives used in the normal ambient conditions. This has also led to integrate such functions as brake control, time relays, control logic and thermistors relays into drives. Dual fast serial links (Profibus, CAN) are used to communicate with superior overriding controller (PLC, MC). Different control strategies are used to achieve higher availability.

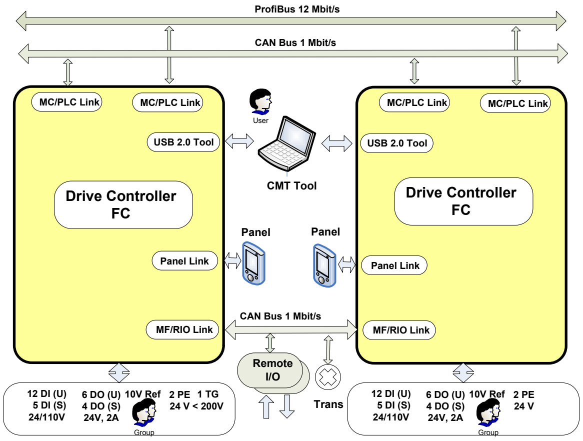

Fig 3.2 Drive Controller

A. Drive Controller – Operational principle

FC is frequency control drive design to to control squirrel cage induction machine. Active Front End (AFE) principle is used to control bidirectional power flow, [6].

AFE is method how to control regenerative voltage to achieve 4Q mode of operation with full control of incoming power and Total Harmonic Distortion (THD) or quality factor [4]. According to the standard, Total Harmonic Distortion (THD) of line current is less than 4%.

Overview of the power components is shown on Fig 4.1.

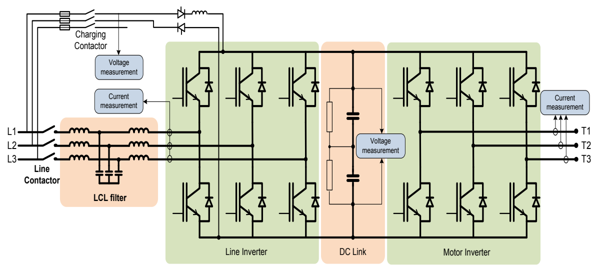

Fig 4.1 Power components

Drive Structure:

- Charging circuitry – Thyristor based fast charging circuit for internal main DC link.
- LCL filter – Used together with line inverter for AFE and THD control.
- Line Inverter – Three phase IGBT bridge, AFE, THD and bidirectional energy flow.
- DC Link – Optimized for AFE operation intermediate energy storage.
- Motor Inverter - Three phase IGBT bridge, operates in Scalar or Vector.

FC is fully regenerative drive with active line inverter only, braking chopper is not used. Applied drive control technology allows inductive or capacitive KVAr production to compensate industrial plant requirements to reduce the overall utility bill.

Integrated static charging is not anymore limiting factor for cranes operations (Fig 4.2). The crane can be switched off when is not in use, and switched on when needed, without restrictions what is not allowed with 'classical' resistors charging principle. Magnetization of the motors start simultaneously with static charging and crane is fully operable in less than 2 seconds. Charging time is adjustable according to the drive current state.

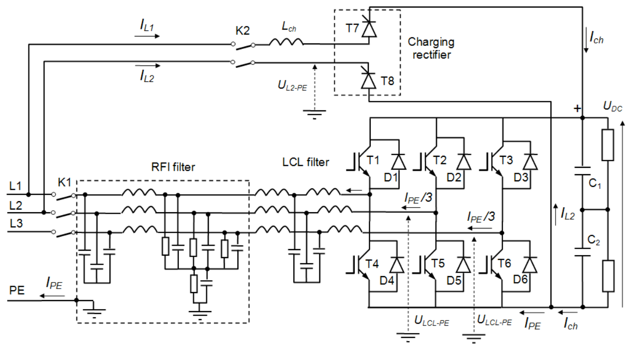

Fig 4.2 DC Link charging

During the charging sequence, capacitors are charged with well defined amount of charge and monitored simultaneously (Fig 4.3). In the case of irregularity charging will be safely stopped and request for service will be issued. Typically, if drives are not used for very long period of time, capacitors must be reformed with long charging time (app. 1 hour).

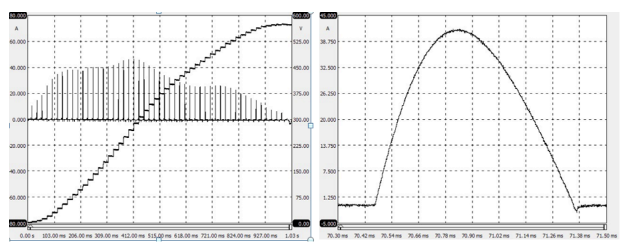

Fig 4.3 DC Link charging Voltage/Current

VI. CONCLUSION

It is important to emphasize that advances of the used crane control technology in perspective of semi automatic operation of EOT cranes used in the harsh industrial environment needs much more attention during design phase.

EOT cranes applications should comply with very strict safety categorized regulations for all type mechanical motions and for personal. For more productive and safety oriented canes, a highly efficient Real-Time Controllers as overriding systems are needed. Most of the RT units operate as multiple fast closed loop controller supervised with local operating system. Monitoring and production statistic as functional subset should be minimized for RT involved in the time critical and safety operations. Redundancy policy should be taken in consideration during design phase.

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