A NEW AUTOMATION ARCHITECTURE FOR STRIP THICKNESS GAUGING SYSTEMS [1]

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Abstract

A new automation system architecture and data / signal exchange methodology has been developed for strip thickness gauging systems. A motivation was to provide high speed, fully numerical data exchanges in place of the traditional, long analog signal runs, to promote improved noise immunity and interference rejection along with the accuracy and precision of numerical data. Additionally, it was desired to place independent, networked, real-time controllers local to the gauging system's C-Frames, to provide complete control of an individual C-Frame's operations and measurements. Further, to interconnect and supervise a scalable collection of local C-Frame controllers over a dedicated network, arranged in a distributed / decentralized system architecture. Finally, to provide an open Graphical User Interface (GUI) capability having the ability to seamlessly accommodate a wide variety of commercially available Human Machine Interface (HMI) software packages. This paper introduces and discusses the concepts, components and implementation of a networked, multi-controller / computer architecture that has been successfully developed and applied to over twelve (12) installed gauging systems world-wide.

Key words: Gauging system; Gamma-ray; X-ray; Control system architecture;

Resumo

Foram desenvolvidas uma nova arquitetura de sistema de automação e metodologia de transmissão de dados / sinais para sistema de medição de espessuras de tiras. O objetivo foi prover alta velocidade, transmissão de dados de forma totalmente numérica (digital) em lugar dos tradicionais e demorados sinais analógicos, para propiciar melhorias na eliminação de ruídos e rejeição de interferências, aliada a precisão de dados numéricos. Adicionalmente era desejável colocar controladores locais independentes, interligados em tempo real aos sistemas de medição de forma "C", para propiciar completo controle das operações e medições de um particular sistema de forma "C", dentre eles. Alem disto, para interligar e supervisionar um conjunto escalonado de controladores de forma "C" sobre uma rede dedicada, dispostos numa arquitetura de sistema distribuído / descentralizado. Finalmente, para prover pacotes de software destinados a capacitar, sem descontinuidade, uma Interface Gráfica de Usuário (IGU) com habilidade de acomodar uma grande variedade de Interfaces Homem Máquina (IHM). Este artigo introduz e discute os conceitos, componentes e implementação de uma arquitetura computadorizada de multi-controladores em rede, que foi desenvolvida com sucesso e aplicada em mais de 12 sistemas de medição, instalados em varias partes do mundo.

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1 INTRODUCTION AND CLASSICAL GAUGING SYSTEM ARCHITECTURE

Transmission mode, radiation absorption / attenuation based, non-contact thickness measurement systems (employing isotope or X-Ray generated radiation) have been widely employed in flat rolled strip product processing and monitoring. A classical arrangement and interconnection of the components typically involved in this class of gauging systems is shown in Figure 1.

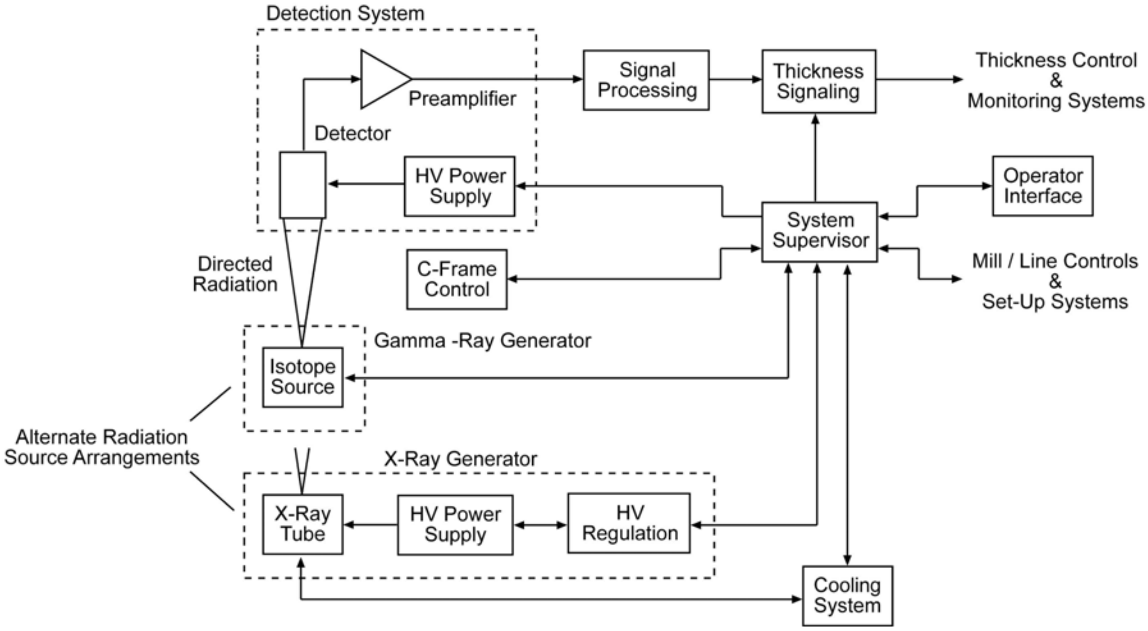

Figure 1 – Block diagram illustration of the typical components, their arrangement and interconnection involved in radiation absorption / attenuation based, non-contact thickness gauging systems. Both isotope and X-Ray radiation generators and associated equipment are shown.

1.1 Primary Components

The primary components are as follows:

<u>C-Frame Control</u> – This subsystem handles the control / operation of all C-Frame related equipment, including: profiling and translation motion control, air wipe and purge, shutter, samples, indication / warning lights, etc.

<u>Radiation Generator</u> – This equipment provides a directed beam of collimated high energy photons of mono- or poly-chromatic spectra. The radiation generator is typically located beneath the strip with its beam's optical axis directed vertically (perpendicular to the strip's major width / length axes).

<u>X-Ray Generator</u> – This subsystem employs the controlled emissions of an X-Ray Tube to generate high energy polychromatic, photonic radiation.

<u>X-Ray Tube</u> – Polychromatic photonic radiation is generated by drawing thermally excited electrons from a heated filament and accelerating them to a high kinetic energy, electrostatically focusing the beam to impact the surface of a tube's target material. Interactions between the high energy electrons and target material atoms release Bremmstraulung and recombinational spectral line radiation. The radiated spectral energy and intensity are adjusted by the applied potential and beam current. The tube is typically immersed in dielectric oil, acting as an insulator and thermal dissipation media.

<u>High Voltage Power Supply</u> – The applied tube voltage, beam and filament currents are provided by a programmable high voltage power

supply (10kV to 160kV, typically). The high voltage circuitry and electronics are either immersed in a bath of dielectric insulating oil, or contained within a dry, potted insulating compound.

High Voltage Regulator – The high voltage potential and associated beam and filament currents are controlled and precisely regulated to provide the prescribed, stable radiation intensity and spectral energy.

Cooling System – Thermal dissipation of the tube is provided by internal / external equipment operating in either a passive or active arrangements. Dielectric oil thermal expansion must also be compensated.

Isotope Source – This subsystem provides nearly monochromatic photonic (gamma) or electron (beta) radiation resulting from the natural breakdown of a radioactive isotope. The radiated energy and intensity are constant and defined by the strength and nature of the isotope.

Detection System – Incident radiation penetrating the strip is collected and measured by the detector, located above the strip, aligned to the optical axis of the radiated beam. The beam's collimator and detector aperture are sized to provide the detector an optical over-containment of the transmitted beam.

Detector – Collected incident radiation is converted to an electrical signal that is functionally related to the radiation intensity. Ion chambers and photomultipliers are often employed, operating in the electrometer mode.

High Voltage Power Supply – Detector sensitivity (gain) is related to the applied potential. A high voltage power supply provides the detector potential with sufficient current capacity to provide the necessary charge recovery.

Preamplifier – The feeble detector signal is amplified to usable amplitudes by a high gain, low noise electrometer / transconductance amplifier. To reduce signal noise and interference, it is desirable to place the preamplifier as close as possible to the detector.

Signal Processing – The amplified detector signal requires wide bandwidth signal processing (in both time and amplitude) to render a calibrated measurement of the intensity of the received radiations (i.e., related to material absorption / attenuation). This processing can be provided by discrete electronics and instrumentation, real-time digital signal processors or Field Programmable Gate Arrays (FPGAs).

Thickness Signaling – This system component provides the final determination and distribution of the calibrated measurement of strip thickness. Calibration and alloy compensation curves reside in and are supplied by the System Supervisor. The measured thickness is typically transmitted via analog signals or high speed networked numerical data exchanges.

System Supervisor – This system component oversees and coordinates the gauging system's control, measurement, calibration and operational activities, along with any operational interfacing to the mill / line control systems.

Operator Interface – Depending on the nature and extent of the system's function, a dedicated operator interface may be included. The operator interface can range from simple operator control and data entry devices, to sophisticated graphical user / human machine interfaces (HMIs).

Interfaces to External Control and Automation Systems – The gauging system must communicate and interact with the mill / line's related control, automation and high level production systems. Measured thickness indications are often transmitted as analog signals or numerically via dedicated network links. Set-up, operational and status data (i.e., nominal gauge sets, alloy / composition, profile / positioning, shutter, etc) are often exchanged via network, serial, or even discrete logic (BCD) interconnects.

1.2 Discussion

Traditionally, the above components have been implemented in a variety of configurations and combinations of a broad spectrum of technologies, ranging from discrete electronics to highly automated systems. A key common issue is the length and integrity of critical signal runs, primarily those implemented via analog signals (i.e., preamplifier and thickness deviation signals). It is highly desirable to minimize analog signal runs by closely locating digitizing equipment to the source / receiver of the analog signals, thereby transmitting only signal processed, numerical data over any appreciable length of signal / cable runs. In addition, to accommodate lines having physically separated equipment, it is desirable to have remote controllers handling control / measurement / signal processing activities local to the equipment.
Recent developments in commercially available real-time control, signal processing, networked data exchanges and Field Programmable Gate Array (FPGA) technologies, have offered new opportunities to reorganize the gauging system's architecture and obtain improved system performance, noise immunity and accuracy. Using these new technologies, a networked, distributed / decentralized control system architecture can be constructed that accommodates all of the analog signal run concerns by providing the ability to render complete thickness measurements local to the gauging system C-Frames, and transmitting only numerical data over networked interconnects.
The remainder of this paper describes a newly developed system architecture that incorporates these components and features. The distributed network architecture is discussed and compact real-time controllers / signal processors mounted local to the C-Frames are described. Network based signal exchange methods, system supervision and Graphical User Interfaces (GUIs) are discussed. A method of interfacing to modern and legacy systems is described. Finally the resulting compact, modular system component arrangement is illustrated and discussed.

2 A NETWORKED / DISTRIBUTED ARCHITECTURE

The main focus of this work was to provide partitioning, distribution and decentralization of the overall gauging system's control and measurement architecture by combining new technologies in real-time control, signal processing, Field Programmable Gate Arrays (FPGAs) and numerical networked data exchanges. The work followed five (5) primary objectives:

1) Provide complete independent control of an individual C-Frame system with a localized real-time controller.
2) Provide immediate digitization of the preamplifier's analog signal with complete, calibrated real-time signal processed thickness measurement local to the C-Frame, and provide only digital / numerical indications of the measured thickness from that point onward.
3) Provide broad, networked, high speed, numerical thickness measurement distribution, both within and external to the gauging system.

4) Offer digital / numerical and / or analog thickness measurements to other systems (e.g., Automatic Gauge Control (AGC), Statistical Process Control (SPC), other monitoring systems, etc.), and should analog signals be required, provide minimal length signal runs, regardless of the receiver's proximity to the gauging system.
5) Support a wide variety of Graphical User Interfaces (GUI) and associated commercially available Human Machine Interface (HMI) environments.

The overall system architecture is based on a distributed control concept that is supported by a highly networked arrangement. Figure 2 provides a hierarchical description of the system's network topology and the interconnection of the primary components in a typical three (3) C-Frame system arrangement. The primary features of this arrangement are:

- Networked, multi-computer arrangement employing a dual / partitioned network configuration:
  Dedicated Gauging System Network - A protected, dedicated network with critical time response characteristics
  External Networks - Standard networks that provides interfacing to external control and automation systems
- Local C-Frame Controller - Each C-Frame is independently controlled and operated by a dedicated real-time controller residing on or local to the C-Frame. This controller communicates on the Gauging System Network.
- Supervisory Computer - Handles all high level system operations, support of the user interface and interfacing to the mill / line's higher level automation and operational systems. Communication with the local C-Frame controllers is provided via the Gauging System Network.
- Graphical User / Operator Interface - The Supervisory Computer supports the user interface, typically implemented with commercial HMI packages.
- Remote Interface Controller – Provides high speed data and analog signal exchanges with external control equipment (AGC, SPC, etc.).

At the core of this new system architecture are digital, real-time controllers / signal processors placed as close as possible to the detector preamplifiers to minimize analog signal runs. These controllers perform immediate digitization and complete signal processing, allowing calibrated and compensated strip thickness measurements to be determined local to the gauging system C-Frames. This numerical data is distributed via dedicated network interconnects, thus eliminating signal noise and interference. This form of signal digitization is achieved with commercially available compact real-time controllers that combine FPGA technologies along with high speed processors.

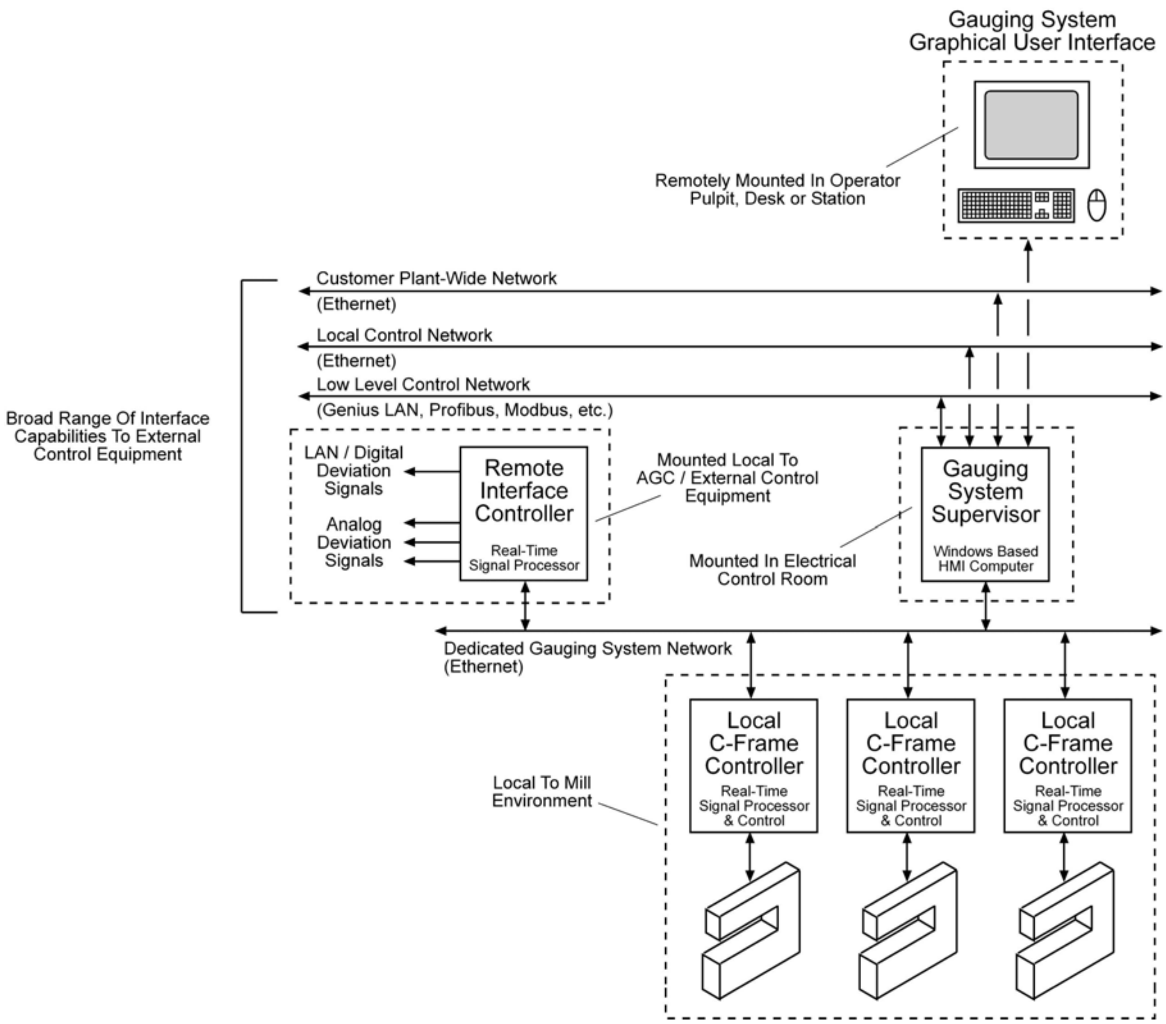

Figure 2 – Block diagram illustration of the system's network topology and interconnection of the primary components in a typical three (3) C-Frame arrangement.

The system architecture employs a supervised, scalable set of these compact, fully networked real-time controllers arranged in a distributed configuration. A supervisory system provides operational oversight, calibration curve storage, graphical user interface support and networked interfacing to high level automation systems. Interfaces to external equipment (either modern or legacy) are provided by a separate, dedicated real-time controller mounted local to the external equipment. Analog signals or numerical data exchanges are provided through this controller. All system components are interconnected over a dedicated high speed network and can be mounted virtually anywhere within the constraints of the network cable runs.

3 LOCAL C-FRAME CONTROLLER

In the past, the objectives (outlined in Section 2.0) where out of the reach of reasonably affordable commercial controllers and those that could provide these capabilities where physically large and required additional support equipment, making them cumbersome and awkward when considered in this application. Recent developments in off-the-shelf controller technologies, not only provide compact physical arrangements, but also offer high speed real-time processing and embedded FPGA circuitry, allowing them to tackle exceedingly fast signal processing, interfacing and control problems.

One such family of devices is the National Instruments Compact Remote I/O (cRIO) Programmable Automation Controllers (PACs) [1,2]. This family of PACs offers extensive, high resolution interfacing, full network compatibility and a flexible framework from which to accommodate a variety of applications. The PAC contains a real-time programmable CPU and an underlying FPGA layer that can be programmed to perform Digital Signal Processing (DSP) functions. Both components are programmed with National Instrument's LabView language and the target code is stored in onboard Flash memory. Figure 3 shows a typical installation of cRIO PAC and associated power supplies and support equipment.

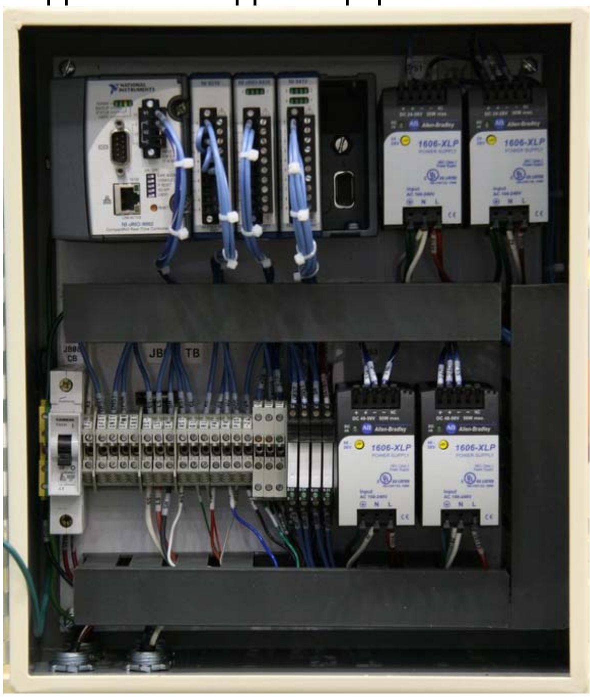

Figure 3 – Photograph of a typical National Instruments cRIO PAC and associated equipment.

A PAC controller and associated support equipment reside in an environmentally protected enclosure, located in direct proximity to each individual C-Frame based gauge. The PAC's FPGA component is responsible for high resolution digitization of the preamplifier's analog signal and the immediate rendering of a calibrated thickness measurement, while the real-time controller component is responsible for all C-Frame equipment control and operational activities, including the setting and supervision of the monoblock X-Ray generator. The real-time control components also provides key calibration and alloy compensation parameters to the FPGA circuits. Figure 4 provides a block diagram illustration of the equipment and components local to each C-Frame.

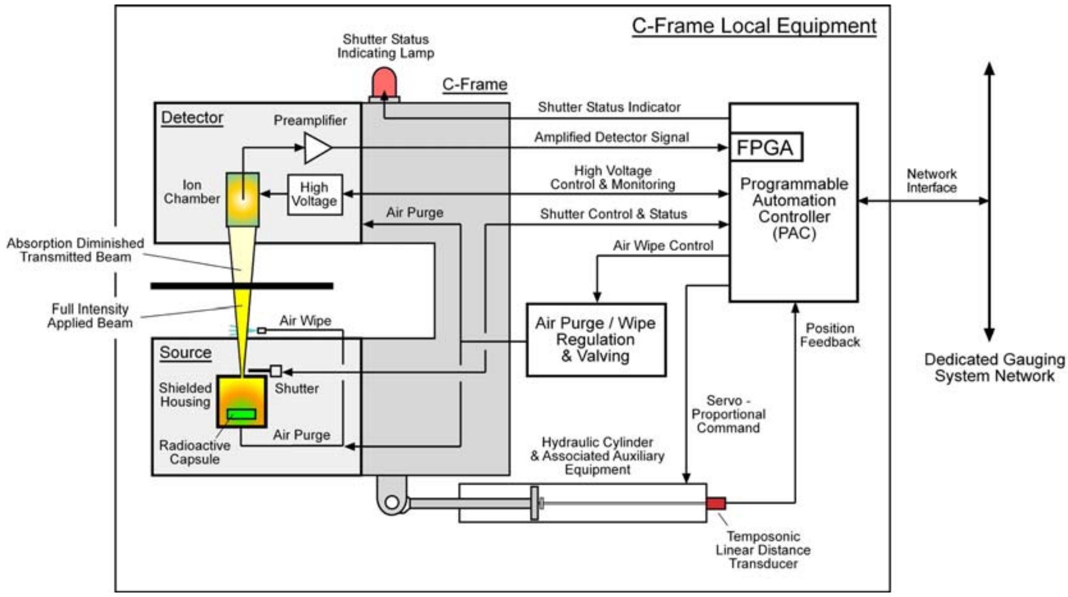

Figure 4 – Block diagram illustration of the equipment and components local to each C-Frame, and the interfacing with the cRIO PAC mounted local a C-Frame, for a typical Gamma-Ray based system.

As noted above, individual PAC controllers (local to each C-Frame) provide all active and supervisory real-time control and signal processing for the respective C-Frame. Essentially, each C-Frame operates as a completely self-contained, autonomous gauging system. Complete thickness measurements are rendered by each PAC. Individual instrument calibration data (curves) and material absorption characteristics (alloy compensation) are stored on and provided by the network interfaced Supervisory HMI Computer. Thickness measurements derived in each C-Frame PAC are digitally transmitted via the gauging system's local dedicated network (a high speed, pseudo-deterministic communications link).

4 NETWORK DATA / SIGNAL EXCHANGE PRINCIPLES AND METHODS

A key component in this networked architecture is providing high speed, unencumbered data / signal transmissions over a dedicated, Ethernet based network interconnect. Executing on the Supervisory HMI Computer is a Machine Intelligence software component that oversees and orchestrates communications with the pool of C-Frame controllers (or potentially any other compatible devices). It's reconfigurable behavior is defined by device plug-ins and communication plug-ins, allowing the computer it executes on to act in any, arbitrary role within the control system it resides. The Machine Intelligence component has been developed to operate in a broad range of control and automation applications, gauging systems being one.

In gauging system applications, the primary communications mechanism between the Supervisory HMI Computer and C-Frame controllers is a lightweight, custom protocol based on TCP sockets [3]. This communication method has the benefit of being fast and very reliable. Both ends of the communication link are constantly aware of the connection, should a fault occur on either end, both sides reset and re-establish their connection. This mechanism has been extensively tested to ensure proper reconnection in conditions of controller / computer reset, cable disconnection or malfunction, severe noise in the system or network hardware failure. This was the main guiding principle in this communication design. Under any circumstance, the two sides must reconnect with no exceptions.

The initial TCP connection is controlled by the Machine Intelligence component through its Dynamic Port Router. First, the C-Frame controller initiates a connection to Machine Intelligence, and sends a string gauge enumeration identifier and a communication direction. If the gauge enumeration is acceptable, the Supervisory HMI Computer responds with a new port number, or ignores the request and recycles the connection if the connection is found to be unacceptable (as in the case of an unknown system trying to connect by accident). Once the port is sent, both sides disconnect. The Dynamic Port Router then opens a whole new thread devoted to monitoring and processing the new connection and returns to its original duty of listening for additional gauges. The gauge reconnects on the port number it received, and starts to stream it's data or accept the streaming data returned from the Supervisory HMI Computer depending on the traffic direction it specified in the original connection string.

The Machine Intelligence component takes the data in and routes it through one of its configured communication plug-ins. These plug-ins enable a consistent, and easy to develop standard, which make the Supervisory HMI Computer very extensible. Any number of HMIs, gauges, or other qualifying systems can connect through a multitude of communication methods and read and/or write gauge data. In many environments it is desirable for two HMI screens to both have control over the same gauge. This is all routed through the Supervisory HMI Computer. Systems in the field have utilized Profibus, Modbus, OPC, binary serialized data over TCP sockets, .NET remoting, and National Instruments shared variable to communicate with HMIs and other systems.

5 SUPERVISION AND GRAPHICAL USER INTERFACING

The gauging system's Supervisory HMI Computer is a Windows-based PC compatible computer that provides supervisory support of the X-Ray gauging system. It also supports and drives the system's interactive, Graphical User Interface (GUI) screens. All gauging system parameters, set-up, calibration, tuning, monitoring, and utilities are orchestrated through the screens of this interface. The key supervisory support functions include:

- Storage and distribution of all calibration and instrumentation specific data sets
- Mill systems interfacing and distribution of nominal gauge sets from either operator entered or the mill's Level 2 system scheduling and set-up
- Interpretation of alloy / material chemistry data and distribution of compensation curve data
- General gauging system mode selection and activation
- Specific C-Frame mode selection and activation (e.g., on / off strip command, profile command, standardization / calibration, etc.)

The computer is housed in an industrial, 19 inch rack mounted 2U chassis (typically mounted in the freestanding control system enclosure or possibly the operator pulpit). Due to the distributed nature of this system, the physical location of this computer is irrelevant to the extent of the length limitations of the network cable runs. This computer interfaces to the local C-Frame PACs and Remote Deviation PAC via the Dedicated Gauging System Network. Interfaces to other mill system components and customer plant-wide systems are provided by a variety of available network interfaces employing standard protocols and mechanisms (e.g., OPC, TCP/IP, Modbus, etc.).

The Supervisory HMI Computer supports and drives the system's GUI. The user interface consists of a high resolution touch screen video monitor (typically mounted in the main operator desk or in a free-standing operator console). Depending on the application, a keyboard and pointing device (i.e., mouse, trackball, etc.) can be provided to accommodate operator interactions. The GUI is based on the .NET Framework's Windows Presentation Foundation (WPF) graphical subsystem [4] (directly related to the Extensible Application Markup Language (XAML)). WPF provides a consistent programming model for building applications and provides a clear separation between the user interface and support logic, and can be deployed on the desktop or hosted from a web browser. The arrangement is extremely flexible and can support commercially available (off-the-shelf) HMI software packages (e.g., Siemens WinCC, GE Cimplicity, Intellution, Wonder Ware, Interact X, etc.) and is open to end user modification and adjustment.

6 INTERFACING WITH MODERN AND LEGACY SYSTEMS

The networked architecture provides a convenient means of interfacing to arbitrary external automation and control equipment. High level systems can interact with the supervisory computer via standard network data / file exchange mechanisms and protocols.

A remote interface controller converts digital / numerical thickness indications to analog signals for interface to legacy or non-network supporting AGC or other control / monitoring systems. This unit accepts network transmitted numerical deviation signals from the respective C-Frame local controller and converts them to analog representations. This unit can be remotely located (to within the length limits of the network cable runs) and mounted in the enclosure housing the equipment requiring the analog thickness / deviation signals, thereby minimizing analog signal transmission lengths. The analog signals can represent the deviation about the nominal gauge set in either an absolute or percentage, or absolute thickness.

Modern AGC or other control / monitoring systems can be directly networked to the gauging system, where digital / numerical gauge thickness indications are transmitted via UDP packets.

7 COMPACT, MODULAR SYSTEM ARRANGEMENT

The resulting overall system is highly modular and very compact. Figure 5 provides an illustration of a typical monoblock based X-Ray gauging system.

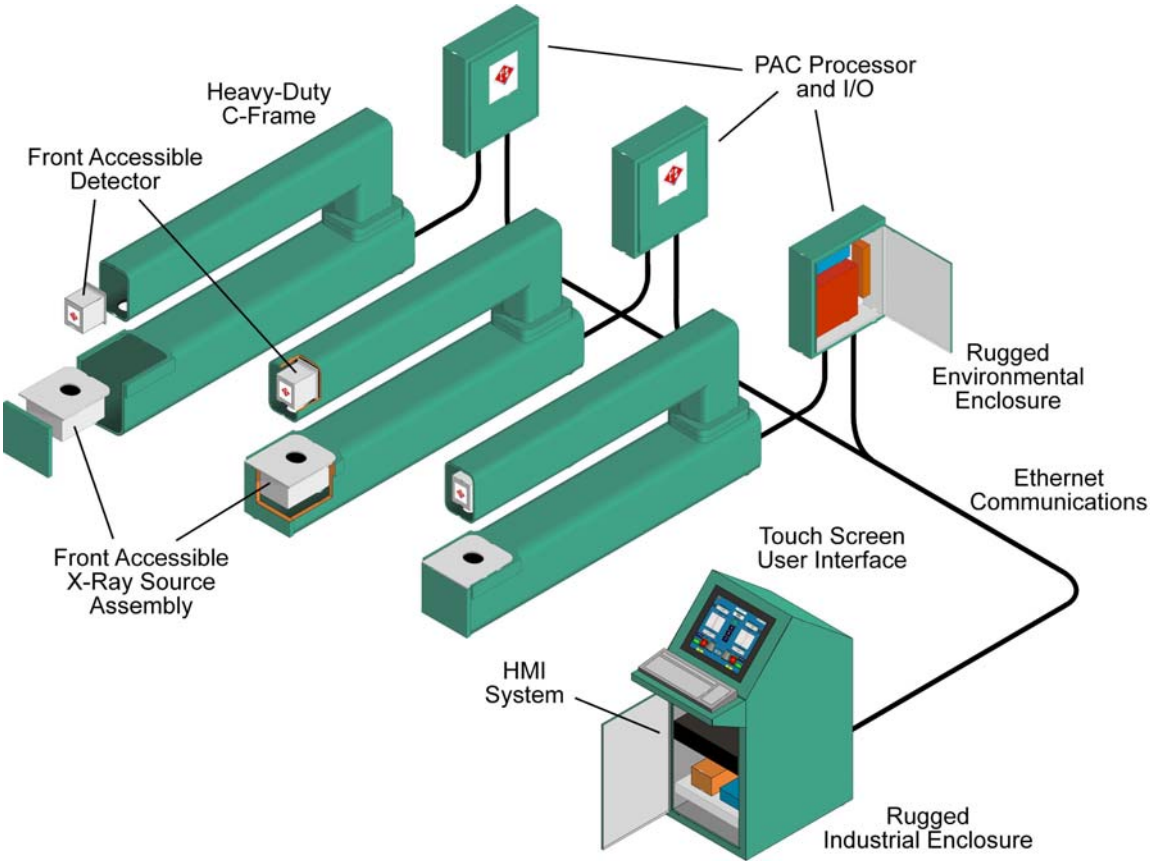

Figure 5 – Illustration of the compact, modular equipment arrangement resulting from this system architecture for a typical monoblock based X-Ray gauging system.

It is important to note that this distributed control / signal processing concept and networked arrangement provide an extreme reduction in field wiring requirements and installation engineering. Only AC power, Ethernet cabling and E-Stop string wiring must be provided to each C-Frame. The networked interconnects allow the individual subsystems to be located remotely and virtually anywhere within the constraints of the network cable runs, thereby simplifying mounting requirements. The electronics, computer, support equipment and Graphical User Interface may be housed in a dedicated console, thus making the system suitable as a stand-alone upgrade of an existing mill. Alternately, computer and monitor may be incorporated into Computer Cabinets and Main Operator Desks thus making the gauge part of an overall integrated system containing other specialized entities.

8CONCLUSION

A new gauging system architecture has been presented and discussed. The modular system architecture employs a supervised, scalable set of compact, fully networked real-time controllers arranged in a distributed / decentralized configuration. Real-time, FPGA based controllers / signal processors have been placed local to the C-Frames and detector preamplifiers to minimize analog signal runs. These controllers perform immediate digitization and complete signal processing, allowing calibrated and compensated strip thickness measurements to be rendered local to the gauging system C-Frames. This numerical data is distributed via dedicated network interconnects, thus eliminating signal noise and interference. A supervisory system provides operational oversight, calibration curve storage, graphical user interface support and networked interfacing to high level automation systems. Interfaces to external equipment (either modern or legacy) are provided by a separate, dedicated real-time controller mounted local to the external equipment. Analog signals or numerical data exchanges are provided through this controller. All system components are interconnected over a dedicated high speed network and can be mounted virtually anywhere within the constraints of the network cable runs. An advanced GUI support capability provides flexible interfacing to commercially available HMI packages.

This new architecture and signal processing arrangement has been successfully implemented and installed on twelve (12) gauging systems world-wide. It has shown that the FPGA circuitry combined with real-time signal processing and high speed networked data exchanges can achieve the necessary performance in time critical gauging applications. Measurement accuracy and precision have been improved over the traditional analog signal runs due to the inherent noise immunity of the numerical data signals.

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