SPS Electric Automation America Systems and Components Exhibition & Conference

AUTOMOTIVE CUT TO LENGTH APPLICATION
EAGLE MANUFACTURING - EAGLEMATIC
LARGEST US ETHERNET POWERLINK APPLICATION WITH 22 MOTION AXES

Markus Sandhoefner,
B&R Industrial Automation
Roswell, GA 30076

Markus.Sandhoefner@br-automation.com

Abstract *– Increased raw material prices, skyrocketing labor cost and huge customer incentives at car dealerships force the Automotive Industry in the United States to use more efficient machinery in order to cut overall production cost. As an answer to that urgent demand Eagle Manufacturing designed a new machine concept with 22 different interacting servo-axes. This case study presents the automation solution, which meets the challenging requirements for precision and throughput by reducing waste with the help of "In-line & On-the-Fly" changeover between part formats without interrupting the flow of the upstream extruded material.*

Different motion control strategies are considered. As a critical point for success, various control and communication architectures are evaluated. The influence of deterministic, real-time communication and the integration of hardware and software on machine performance, cost, and time to market is assessed.

I. INTRODUCTION

The Automotive Industry in the United States has been challenged by increasing raw material prices and skyrocketing labor costs. This, along with the overall decrease in American automotive spending, has brought about the need for more efficient machinery to make vendor parts more effective, thus reducing overall production costs. A Highly Respected Tier One Automotive Supplier therefore decided to search out and purchase a machine that could guarantee higher throughput while at the same time reducing excess product scrap. This same Tier One Supplier presented their "wish list" of requirements to Eagle Manufacturing Corporation. Eagle Manufacturing was given and met the challenge to develop an In-Line innovative notch & cut-to-length fabrication system for which the profile fabrication industry was desperately waiting.

Eagle Manufacturing Corporation, located in Shelby Township (USA, MI) is a recognized leader in the design and fabrication of a series of punching, sawing and notching systems for the Automotive, Home Building, Medical, Aerospace, and Appliance Industry along with many other plastic, rubber, aluminum extrusion, and roll-forming industries.

After incorporating a mix of technologies from different manufacturers in the past, the timing was right for Eagle Manufacturing Corporation to look for a new control architecture that would offer an alternative solution for a new system requiring 22 servo axes. Eagle broke new ground with the application, since that amount of axes had never been used on a single machine before.

This newly developed EaglematicTM notch & cut-to-length fabrication system was designed and built for their Tier One Automotive Customer fabricates multi-durometer extrusions for automotive window trim components. This system incorporates four independent fabrication stations any of which can be automatically placed “In-Line” (within 5 seconds) to match the car model’s two door coupe and four door sedan production run requirements. This instant tool change does not require the line’s shut down or even the pausing of the other upstream stations that are feeding the EaglematicTM. This system is currently the largest ETHERNET Powerlink developed machine in the US market.

Figure 1. EaglematicTM notch & cut-to-length fabrication system.

Brent Short, the owner of Eagle Manufacturing and designer of the Eaglematic states: “This single machine combines six different tools into a single operating set-up that automatically moves the required tool into place when called upon to do so via the controller. The tools are all changed utilizing a combination of 22 different servo mechanisms “In-Line & On-the-Fly” without interrupting the flow of the upstream extruded material.”

II. INFLUENCE OF AUTOMATION ARCHITECTURE ON PERFORMANCE, COST AND TIME TO MARKET

Eagle Manufacturing was faced with the challenge of realizing a 22 axis machine with a throughput of 50 feet per minute and required product tolerances of no less than 0.04 inches. For the desired rate of 10 position updates per 0.04 inches, a communication cycle time of 400 μs needs to be achieved. Therefore an architecture which provides high performance motion control and a fast, deterministic machine communication backbone is required.

The following motion control strategies and their implications on the 22 axis machine application are evaluated in the following chapters.

II.I MOTION CONTROL ARCHITECTURE

II.I.I CENTRALIZED MOTION CONTROLLER

A motion controller, which in some cases is already integrated into the main control system, takes over the task of coordinating the 22 axes. The motor position is transferred from the drive to the motion controller and used to calculate a new set position for the drive inside the motion controller. Two types of centralized motion controllers exist:

MOTION CONTROLLERS WITH SPEED INTERFACE TO THE DRIVE

The differentiation of the position feedback signal is used to determine the current speed of the motor inside the motion controller. The position control loop is closed inside the motion controller. The drive only has to perform current and velocity control. The motion controller communicates the set speed to each drive and receives the position feedback signals.

MOTION CONTROLLERS WITH POSITION INTERFACE TO THE DRIVE

Position and speed control loops are both closed inside the drive. The motion controller does the coordination of the axis and sends a set position down to the drive.

II.I.II DECENTRALIZED MOTION CONTROL

There is no centralized motion controller in the system. The tasks of the centralized motion controller are split up and realized in the drive. The set positions for each axis are not calculated by a centralized CPU, but inside the drive. The drive receives the master position over the network and calculates the resulting setpoint for the position control loop internally.

II.II EVALUATION

IMPLICATIONS ON COMMUNICATION CYCLE TIME

Current, velocity, and position control loops are closed at different cycle times. Typical cycle times for the current control loop are 50 to 100 µs, 150 to 200 µs for the velocity control loop, and 300 to 500 µs for the position control loop. For systems in which the control loops are closed inside the centralized motion controller, the communication needs to be fast enough to supply sufficient bandwidth to transfer setpoints and feedback values back and forth. As a consequence, compared to a completely decentralized system at the same performance, the centralized system needs to transfer information up to 4 times faster. This becomes increasingly challenging for digital communication systems such as Sercos, ProfiBus, and DeviceNet, which provide a more reliable and more economical interface but are only able to communicate in the multiple millisecond cycle range. The Eaglematic application requires a synchronized position update time of 400 μs, which is more than 10 times faster than the cycle time of the above mentioned networks. Additionally, for greater numbers of axes connected to the motion controller, there is increased traffic on the network, since every axis communicates the same amount of information to the motion controller and receives the set points in return.

Table 1. Comparison of motion control architectures.

	Tasks in Centralized Motion Controller	**Tasks in Drive**	**Cycles per position control loop cycle**	**Comment**
Centralized Motion Control with Speed Interface	Position Loop Axis Coordination	Current Loop Velocity Loop	4	2x velocity setpoint 2x position feedback
Centralized Motion Control with Position Interface	Axis Coordination	Current Loop Velocity Loop Position Loop	2	1x position setpoint 2x position feedback
Decentralized Motion Control		Current Loop Velocity Loop Position Loop Axis Coordination	1	1x master position broadcast

IMPLICATIONS ON PROCESSING POWER OF THE CPU

When increased communication bandwidth is needed, processing power inside the motion controller CPU must also increase. As the number of axes on a machine and the depth of closed loops inside the motion controller increase, more CPU power is necessary in the motion controller.

LIMITATIONS OF CENTRALIZED MOTION CONTROLLERS

The increased need for processing power and communication bandwidth lead to limitations, which can be observed by looking at currently available centralized motion controller products on the market. The majority of products limit the number of axis to be operated with one motion controller either to 8 or 16. The closer the number of axis grows towards the limit, the slower the cycle time of the control loops, resulting in a motion control performance, which strongly depends on the number of installed axis. In an environment, where mechanical line shafts are replaced by electronic cams and an ever increasing number of servo motors provide additional functionality, it is no longer acceptable for motion controller performance to be dependent on the number of axis connected to it.

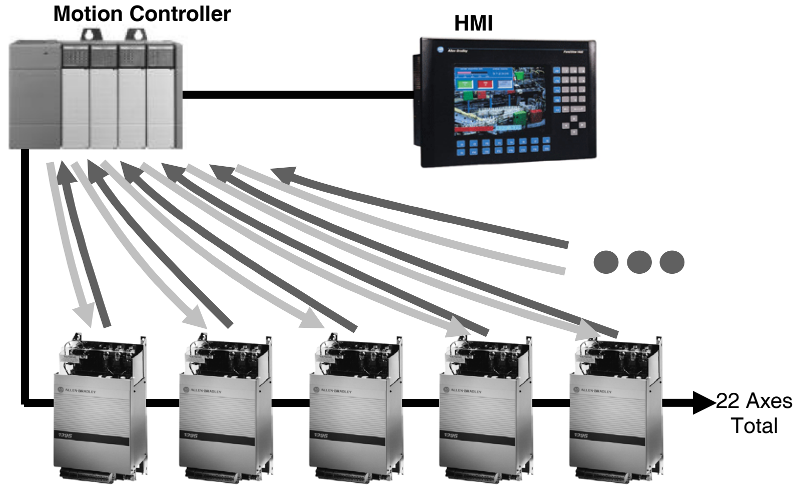

Figure 2. Centralized Motion Control.

BENEFITS OF DECENTRALIZED MOTION CONTROL

By splitting up the single coordinating task of a centralized motion controller into small, fast decentralized tasks in the drive, the motion control system's performance improves due to reduced network and CPU load. Instead of having to communicate a new speed control set point to every drive and a feedback value from each drive in the Eaglematic machine each 100 µs, the network only needs to broadcast a master position once every 400 µs. A broadcast can be received simultaneously by all nodes on the network, so that the maximum number of axes inside a machine no longer depends on the CPU performance and the communication bandwidth of the centralized motion controller. It is only determined by the maximum allowed number of nodes and the bandwidth of a network. Today's available time and cost efficient drive processors provide ample processing power to realize all control loops and additional decentralized motion controller functionalities inside the drive.

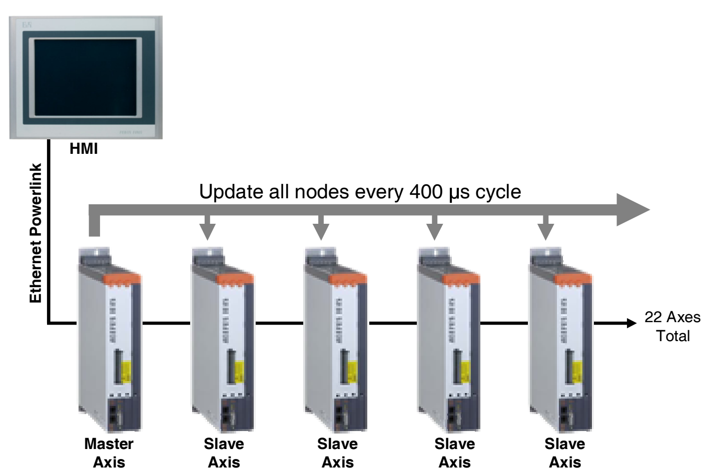

Figure 3. Decentralized Motion Control.

II.III DETERMINISTIC REAL-TIME COMMUNICATION

II.III.I ETHERNET IN MOTION CONTROL APPLICATIONS

With its peer to peer communication capabilities and high communication bandwidth of 100 Mbaud, Ethernet is the perfect media to transfer vast amounts of information within a minimum amount of time. There is a common familiarity with Ethernet and standard hardware is available at a minimum cost. However, Ethernet has one limitation, which makes it unsuitable in its standard form: this is due to latency caused by collisions. If a collision is detected on the bus, each sender resends the information after a randomly determined delay. This has prevented Ethernet from being used in motion control applications. Developments in the recent years have been successful in providing Ethernet with a high determinism (jitter less than 1 μs) by introducing time slicing mechanisms into the Ethernet protocol. This makes Ethernet capable of real-time communication and suitable for use in motion control applications. The open standard Ethernet Powerlink, developed by B&R and now distributed by the Ethernet Powerlink Standardization Group (EPSG), headed by the University of Zürich in Winterthur (ZHW), turned out to be the ideal real-time Ethernet solution for the Eagle 22 axis application.

II.III.II ETHERNET POWERLINK COMMUNICATION CONCEPT

Ethernet Powerlink transfers data in two ways: an asynchronous channel and a synchronous channel. In the asynchronous channel, non-realtime critical information like Internet Protocol (IP) based data (e.g. a video stream) can be transferred. The asynchronous channel is also used to upload and download information to and from the drive (e.g. drive firmware to the drive or motion traces from the drive). The synchronous channel consists of time slices, which can be assigned to nodes on the network. For the cut-to-length machine, 22 nodes (one drive per node) were linked via Ethernet Powerlink. This would have resulted in a network cycle time of 800 μs. Within the 800 μs cycle time, each drive, represented by one time slice, receives the right to broadcast information to all the other nodes, while all the other nodes listen. The network communication manager, represented by the Power Panel, regulates the traffic on the network and initiates each broadcast by a poll to the respective node. In order to decrease the network cycle time even further, multiple Powerlink nodes were assigned to a single time slot, providing a prescale factor to less important nodes while preserving single use time slots for nodes that broadcast cycle time critical, master positions. Each cycle time another prescaled node per time slot is polled by the network communication master, while broadcasted information is received by all nodes on the network. This communication and decentralized motion control concept allows the communication of multiple master positions to up to 240 drives within one Ethernet Powerlink cycle of 400 μs.

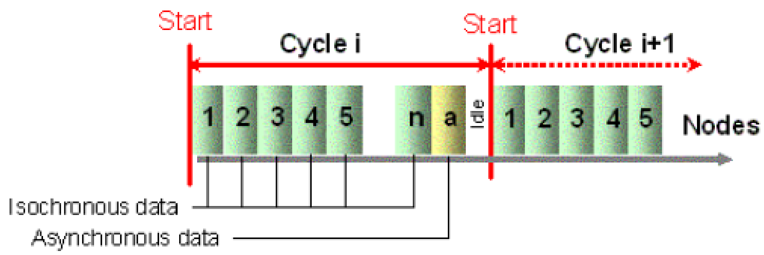

Figure 4. Basic Ethernet Powerlink Cycle.

Eaglematic Ethernet Powerlink Network Architecture:

Powerlink Network Nodes

Node Type	Prescale Factor	Time Slots	Broadcast Cycle
3 Master Drives	1	3	0.4 ms
19 Slave Drives	3	7	1.2 ms
22		**10**	
Ethernet Powerlink Cycle Time:		**0.4 ms**	

Powerlink Cycle Time 0.4 ms

Time Slot	1	2	3	4	5	6	7	8	9	10	Async. Channel
Type	Master Drives			Slave Drives							
1	1	2	3	4	7	10	13	16	19	22	
2				5	8	11	14	17	20		
3				6	9	12	15	18	21		
Broadcast Cycle	**0.4 ms**			**0.4 ms x 3 nodes = 1.2 ms**							

Table 2. Ethernet Powerlink Cycle Time.

II.IV INTEGRATED HARDWARE ARCHITECTURE

The Eaglematic machine features a unique and cost efficient automation hardware architecture. Commonly available automation solutions exhibit a clear separation of human machine interface panel, PLC, motion controller, and communication into separate units. Each part of the system requires its own housing, its own processor, its own communications ports, and its own programming software. For this application, an HMI solution was chosen which combines all of these separate components into a single housing with one processor and programming software. This single processor hardware solution becomes feasible because all of the highly processing power dependent motion tasks, which had previously been done in the motion controller, are now being performed inside the drives. Logic control and HMI related tasks can be performed at a much lower speed (for example, the logic control tasks can use a 4 ms cycle and HMI can be handled during idle time). The integrated hardware structure of this HMI panel also eliminates up to 6 communication ports between the HMI, PLC, and motion controller in addition to saving precious installation space and time.

II.V MULTITASKING REAL-TIME OPERATING SYSTEM

Another means, which helps to optimize the required processing power inside the panel, is a multitasking operating system, in which tasks are executed in deterministic cycle classes. HMI or other low priority tasks can be run in slower cycles, which leave processing power to run high speed tasks with the shortest possible cycle time. In this way, deterministic, high-speed functions can be realized while saving precious CPU power compared to a single task operating system.

II.VI SYNCHRONIZATION OF MOTION, PLC TASKS, AND COMMUNICATION

The use of a deterministic, real-time operating system also makes it possible to synchronize the drive, communication, and control tasks. This allows the precise time (down to the microsecond) that it takes for a value to be picked up by the communication network, transferred to another device, and processed by the new task to be determined. As a consequence, the different cycle classes inside a system need to be scaled as multiples of the lowest cycle time. In the case of the cut-to-length machine, this is the 400 μs cycle time of the position control loop of the drive. The real-time operating system then synchronizes the different cycle times to each other by using the start of a position control loop drive cycle as the clock signal. This method guarantees optimum motion precision, since information gets picked up without latency and arriving information is processed without wait time.

II.VII INTEGRATED SOFTWARE ARCHITECTURE

The operating system architecture that was chosen for this project also integrates visualization, logic control, motion control, and communication into one single programming tool. One transparent variable database is used throughout the complete system. This enables the application programmer to use every single drive parameter (e.g. temperature of the IGBT inside the drive) inside the logic control task, thus enabling the machine to perform new functions, previously not feasible. For example, the drive firmware is stored inside the centralized HMI panel memory on the machine. If a drive needs to be exchanged, the only thing the field service must do is physically exchange the drive. Regardless of which firmware version is installed on the exchanged drive, the CPU will check the compatibility of the new drive firmware and, if required, download the appropriate firmware into the drive. This eliminates software compatibility conflicts and ensures an easy and fast drive exchange.

III. CONCLUSIONS

By utilizing the combined benefits of Ethernet Powerlink and decentralized motion control, Eagle Manufacturing was able to design a machine, which delivers unprecedented process accuracy despite the large number of geared axes in one system. Substantial savings were realized by eliminating the need for one or several centralized motion controllers. Further cost savings were achieved by the integrated design of the B&R Power Panel, which integrated the functionality of visualization, motion control, logic control, and communication into one single processor. The integrated software programming environment of B&R Automation Studio, which provides a single programming tool for all tasks including visualization, motion control, logic control, and communication, was the decisive factor to cut the time from the start of application programming to the delivery of the machine by weeks. By using the integrated hardware, software, and communication concept of B&R, the machine builder was able to cut 30% of the previously budgeted cost for automation against a conventional system consisting of an HMI Panel, PLC, and motion controller. The new machine design enables the automotive end user to produce higher quality parts and simultaneously cut operating cost by reducing waste, set-up, and down time, while increasing the overall flexibility of the production line.

IV. REFERENCES

[1] Dieplinger, C., Ed., “Eagle Manufacturing – Automotive components cut to perfection,” Automotion, December 2004, pp. 20-21.

[2] “Ethernet Powerlink: Real-Time Industrial Ethernet is Reality,” Ethernet Powerlink Standardization Group, Zurich University of Applied Sciences.