Industrial Sensor Networking Technology for Improvement of Manufacturing Equipment Efficiency

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To improve overall manufacturing equipment precision and efficiency, Azbil has developed its K1G-C04M high-precision position sensor controller, which is compatible with the MECHATROLINK-III open field network. In this product, a problem involving previous analog output position sensor controller models was solved, and sensor instrumentation was optimized to measure at a rate of up to 250 μs and a resolution of 0.1 μm. At the same time, the constant periodicity, high speed, and communication monitoring of MECHATROLINK-III made the controller compatible with manufacturing equipment with higher demands for reliability.

1. Introduction

The K1G high-precision position sensor can measure changes in the position of object edges with a high level of accuracy using a combination of sensor heads and a sensor controller.

Figure 1. K1G High-precision Position Sensor

The position of the edge of an object that is located between the emitter sensor head, which has a built-in laser diode, and the photosensitive receiver sensor head, which has a built-in linear image sensor, can be measured to a high degree of accuracy.

The analog output models, which were developed first, output the results of measurement in analog values such as voltage. Because there are many error factors during analog/digital conversion, however, more reliable digital sensors were required. Also, the controllers used to control large-scale devices need to operate many sensors and actuators simultaneously, but there were problems of inaccurate measurement time associated with analog output devices.

In order to solve these problems and to help ensure that all equipment has highly accurate and powerful functions, we developed the K1G-C04M sensor controller, which is compatible with the MECHATROLINK-III open field network, which provides superior real-time processing.

2. What is a high-precision position sensor?

2.1. Measurement performance

The K1G high-precision position sensor emits parallel laser light beams from the emitter sensor head toward an object. Fresnel diffraction occurring along the edge is observed by the linear image sensor of the receiver, and the edge position is determined by Fresnel diffraction approximation correction.

Fresnel diffraction approximation correction is the measurement principle that was established for older PB-series edge sensors. Even a linear image sensor that has low pixel density can determine the edge position in high resolution. In addition, this approximation correction requires a small number of arithmetic operations. The figure below illustrates Fresnel diffraction.

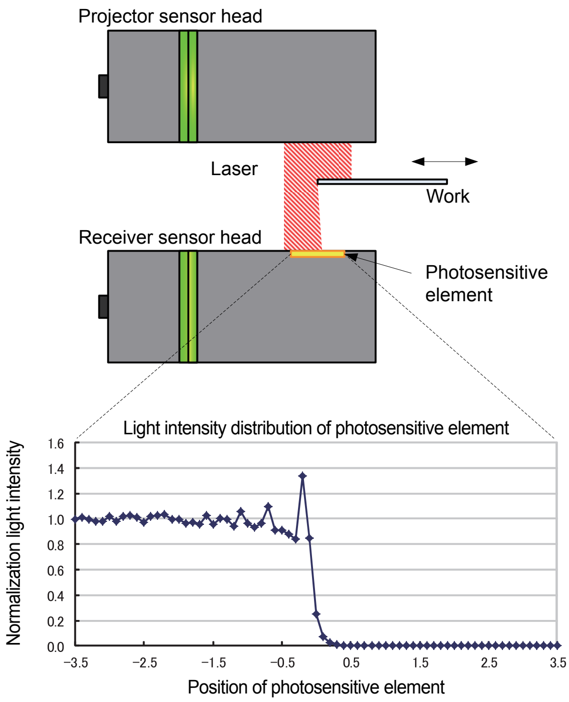

Figure 2. Light Intensity Distribution during Fresnel Diffraction

In Fresnel diffraction approximation correction, the light intensity when there is no workpiece present serves as a standard and the edge position is determined from the normalized light intensity. The edge position is determined by the approximation of the Fresnel diffraction pattern by the hyperbolic secant, and by the reverse conversion of the light intensity data of two points straddling the threshold value (see Reference publication 1).

Thanks to upgrading of the linear image sensor, enhanced accuracy of the internal arithmetic operations, and parallel processing by a dedicated engine, the K1G achieves the following:

- 0.1 μm measurement resolution, which is 10 times better than that of older models.
- 250 μs measurement period, which is twice as fast as that of older models.
- Processing of four pairs of sensor heads, which is double the number that can be connected to older models.

As a result of the above, higher speed and higher accuracy have been realized.

2.2. Applications of the K1G

With its small sensor heads and ability to measure the amount of edge position movement with a high level of accuracy for both transparent and opaque materials, the K1G is used for measuring the amount of meander, especially for edge position control (EPC) and center position control (CPC) during the roll-to-roll process. Figure 3 shows control of meander.

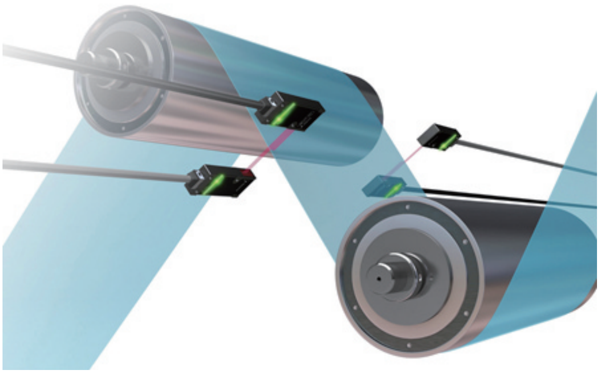

Figure 3. Meander Measurement

In the thin film production process for products such as lithium ion batteries, multiple workpieces are controlled for meander and then are overlapped. For that reason, a large number of axes need to be controlled, and the synchronous operation performance between each axis affects the product quality. Therefore, compatibility with a real-time field network is required so that the synchronization of the edge positions can be maintained between different sensor controllers.

2.3. Output performance challenges

The K1G series includes an analog output model that was developed earlier, called the K1G-C04 sensor controller. The following is an I/O block diagram for the K1G-C04.

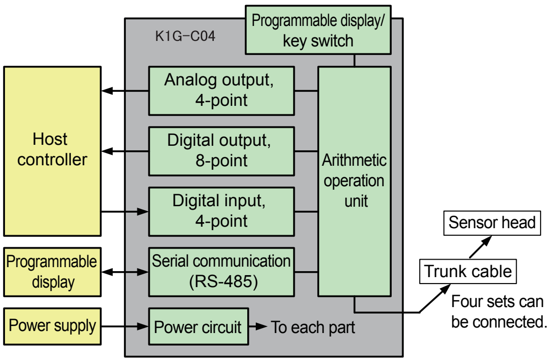

Figure 4. K1G-C04 Input/Output Block Diagram

This model has four analog outputs (1 to 5 V or 4 to 20 mA), eight digital outputs, four digital inputs, a serial communication interface (RS-485), a sensor head connection interface, and a power supply.

Analog output (voltage or current) is in accordance with the edge position. The digital output is used for event occurrence, to tell whether or not the edge position is within the preset range, etc. The digital inputs are used for device control, such as starting laser emission. The serial communication interface is used to monitor the measurement situation and to change the settings. These interface ports are connected to a host controller (such as a programmable logic controller) and indicators, and are built into equipment.

Taking the edge position and analog outputs into account, the sensor controller assigns the measuring width of the connected sensor head to the analog output range. If the edge position measurement from a 15 mm sensor head (K1G-S15) is assigned to 1 to 5 V, the voltage that is equivalent to a 0.1 μm measurement resolution is approximately 0.027 mV.

When we consider that there is error due to analog/digital conversion accuracy, wiring, etc., this small voltage is not easy to handle. If we focus on the resolution, we can obtain the edge position through serial communication, but we cannot maintain real-time processing. Consequently, we cannot take advantage of the superior measurement performance of this product.

For this reason, we have developed a sensor controller that is compatible with MECHATROLINK-III, which allows high-speed synchronous operation and powerful motion control.

3. MECHATROLINK-III

MECHATROLINK-III is an open field network developed by Yasukawa Electric Corporation and managed by the MECHATROLINK Members Association.

The physical layer is an Ethernet network, and the high-speed cyclic communication and complete synchronous operation of up to 62 slave devices can be realized by an ASIC. In particular, the standard servo control profile and the standard stepping motor control profile are provided. Slave devices produced by different manufacturers can be used as long as they are the same type.

3.1 Features of MECHATROLINK-III

The following describes the features of MECHATROLINK-III.

Pursuit of high speed

Up to 31.25 μs cyclic communication is possible. With 8 slave station devices, 250 μs cyclic communication is possible.

High degree of synchronization

Jitter between slave devices can be held within 1 μs by correcting the delay time from the master unit.

Support for large-scale systems

Since the distance between nodes can be extended to a maximum of 100 m, this network can also be used for large-scale systems. In addition, topologies such as a cascade connection or star connection can be selected according to the system.

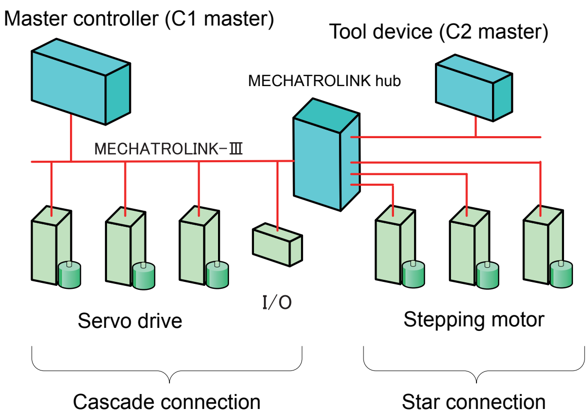

Figure 5. MECHATROLINK-III System Overview

Support for various slave devices

Not only cyclic communication, but also asynchronous communication (event-driven communication) functions are supported.

Also, the communication data size and communication cycle can be set for each slave device, and a highly efficient network can be constructed by combining high-speed and low-speed slaves or by combining large slave devices that have a large amount of data and small slave devicess that have a small amount of data.

Assured reliability

The controller has a function that retries communication within the same transmission cycle in instances when abnormal communication occurs. The highly reliable nature of the system supports applications that require synchronous performance between multiple slave devices such as multi-axis control applications and others. This retry processing is executed automatically by an ASIC.

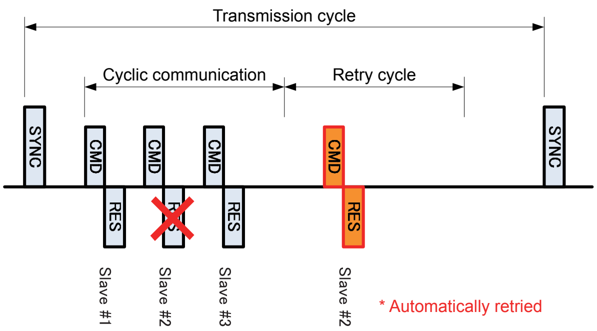

Figure 6. Retry Processing

Data transparency

Messaging and message relaying by the master unit are supported.

With this function, the master unit (C1 master) and tool unit (C2 master) can access the maintenance data for reading and writing the parameters of slave devices located under the MECHATROLINK-III network and for operation maintenance.

Also, a master unit (with a message relay function) can deliver messages that have been sent by devices outside the MECHATROLINK-III network to the appropriate slave devices within the slave network. This allows construction of a more flexible network.

Development support from the MECHATROLINK Members Association

The information required for system development is available from the MECHATROLINK Members Association web page. In addition, if a user has any technical questions during the product development phase, the Association can be contacted for further information.

Also, before products are released, a certification test can be carried out in order to ensure that the product(s) in question conform to the standard and to ensure connectivity with third-party products. Certification testing using a mass production prototype is available from the MECHATROLINK Members Association. Testing requires approximately 2 to 4 weeks. If the certification tests are passed, the certification logo below can be attached to the product.

MECHATROLINK

Figure 7. MECHATROLINK Certification Logo

4. Sensor controller compatible with MECHATROLINK-III

The following describes the K1G-C04M sensor controller, which is compatible with MECHATROLINK-III.

4.1. Appearance and structure

The following shows the appearance of the K1G-C04M sensor controller.

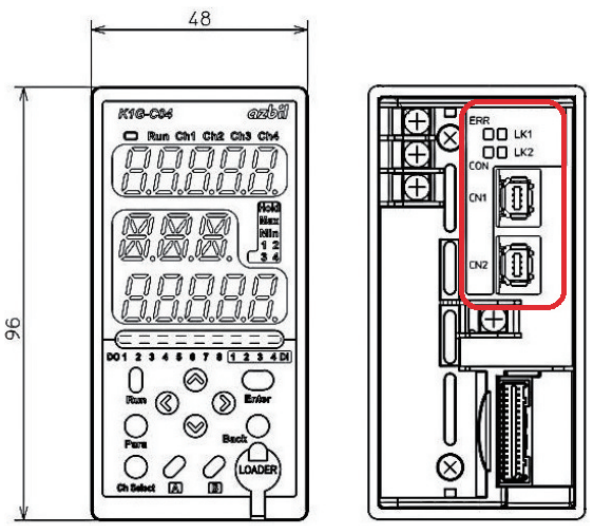

Figure 8. K1G-C04M External View

The controller has four LEDs and two connectors on its rear panel. There are two link LEDs (LK1 and LK2), which indicate the status of physical connections, a connection LED (CON), which indicates a connection to the MECHATROLINK-III master unit, and an error LED (ERR), which lights up if a communication error occurs.

Industrial mini-I/O connectors, which are the standard for MECHATROLINK-III devices, have been adopted for this controller.

No rotary switches are used for slave station address setting. The device address can be set via the man-machine interface on the front panel, or through the use of software.

4.2. Communication specifications

The communication specifications are as follows.

Communication protocol:	MECHATROLINK-III
Type:	Slave
Station address:	03 to EF (hexadecimal numeral; selectable by software)
Transmission byte count:	32/48 bytes (Selectable by software)
Supported transmission cycle:	0.25, 0.5, 1 to 64 ms (in 0.5 ms increments)
Synchronous mode:	Synchronous or asynchronous
Supported profile:	Standard I/O profile
Supported commands:	See Table 1.
Messaging:	Supported

Table 1 Command List

Cyclic communication	
	NOP, ID_RD, CONFIG, SYNC_SET, ALM_RD, ALM_CLR, CONNECT, DISCONNECT, DATA_RWA, DATA_RWS
Event-driven communication	
	NOP, ID_RD, CONNECT, DISCONNECT

Here, the DATA_RWA (Asynchronous Data Read/Write) and DATA_RWS (Synchronous Data Read/Write) commands are required for the standard I/O profile. All commands other than these two commands are common to all profiles, and they are used for connection to the master unit and for acquisition of device information.

The data handled by the DATA_RWA and DATA_RWS commands are identical.

The following shows the DATA_RWA and DATA_RWS commands and their response for 32-byte transmissions.

Command

Byte	Command
0	DATA_RWS/DATA_RWA
1	WDT
2 to 3	CMD_CTRL
4	Digital input
5 to 31	Reserved

Response

Byte	Response
0	DATA_RWS/DATA_RWA
1	RWDT
2 to 3	CMD_STAT
4 to 7	PV1
8 to 11	PV2
12 to 15	PV3
16 to 19	PV4
20 to 21	Channel 1 event occurrence status
22 to 23	Channel 2 event occurrence status
24 to 25	Channel 3 event occurrence status
26 to 27	Channel 4 event occurrence status
28 to 29	Controller status
30 to 31	Error status bits

Bytes 0 to 3 bytes are common to the command and response messages, and these bytes conform to the communication specifications. The 4th byte of the command is the digital input data. Similar to its function with analog output models, it can be used to control laser emission.

The response messages may contain the edge position (PV values 1 to 4), event occurrence state (for channels 1 to 4), and the controller state (controller error status, error status bits). Here, the error status bit may contain information such as whether the sensor head is disconnected. Due to this fact, the master unit can easily carry out the processing required to recover from an abnormality, although doing so is normally difficult for instrumentation that uses an analog output model.

4.3. Messaging

The available functions for message communication have been defined by function codes. In this product, in addition to the related information acquisition function (memory reading) of MECHATROLINK, we have defined a unique protocol that packages the message format (MODBUS RTU) to be used for serial communication by K1G-C04, which is an analog output model. This protocol allows setting changes to be made by devices outside the MECHATROLINK-III network, as well as the monitoring of measurement status.

4.4. I/O block diagram

The following shows an input/output block diagram for the K1G-C04M controller.

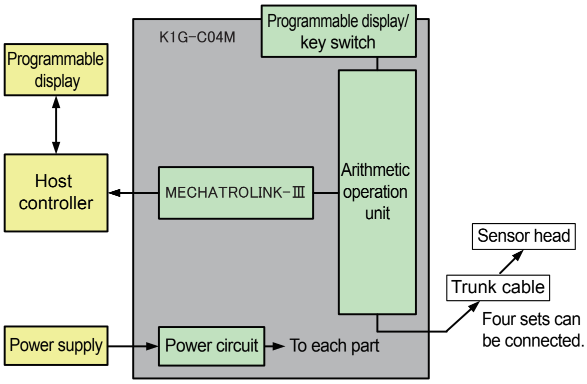

Figure 9. K1G-C04M Input/Output Block Diagram

It shows that the multiple system interfaces such as analog outputs have been integrated into MECHATROLINK-III. By using a host controller that supports message relaying, messages can be exchanged with an indicator or other device located outside the MECHATROLINK-III network.

4.5. K1G-C04M instrumentation examples

With the cooperation of Digital Electronics Corporation, a manufacturer of programmable displays, the dedicated software (Cockpit Parts) used to set and adjust the K1G-C04M has been developed. This software can be installed in programmable displays produced by Digital Electronics Corporation, and can be used for communication with the K1G via the motion controller (MECHATROLINK-III master) produced by Yasukawa Electric Corporation. The following shows the assumed device connection.

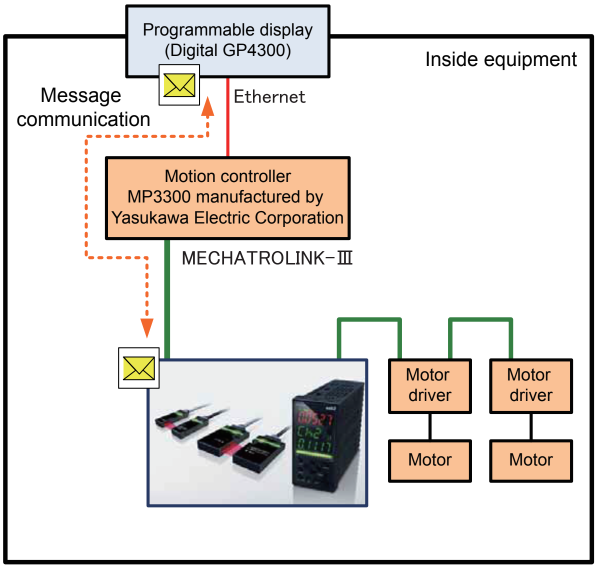

Figure 10. Message Communication Chart

This instrumentation makes it possible to change the settings of a K1G-C04M that is built into equipment, and to monitor the operation status.

5. Conclusion

This paper describes the newly developed K1G-C04M sensor controller with MECHATROLINK-III support. This sensor controller makes possible instrumentation that maximizes sensor performance (such as high speed and high accuracy operation). Also, the message communication capability enables transmission of sensor information outside of the MECHATROLINK-III network. The controller can be connected to the plant infrastructure network. For this reason, we feel that the functions required for Industry 4.0, etc., have been realized.

The number of network-related requirements is expected to increase in the future. We intend to develop and provide products that meet these requirements and that contribute to enhancing the value of the existing equipment.

Acknowledgments:

I would like to thank Digital Electronics Corporation, Yasukawa Electric Corporation, and the MECHATROLINK Members Association for the great support they have provided for product development and the production of this paper.

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