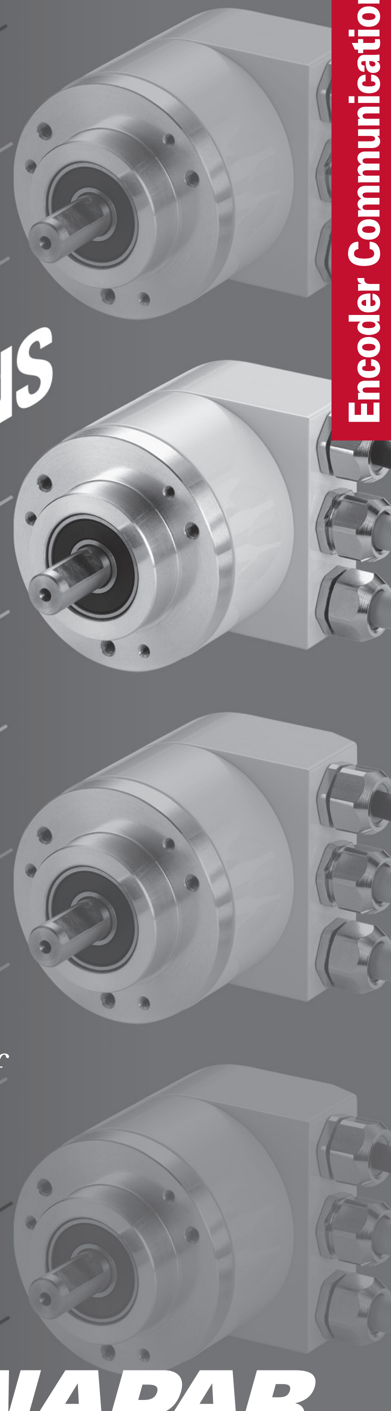
Encoder Communications

ENCODER COMMUNICATIONS HANDBOOK



A reference guide for understanding the basics of encoder communications

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Dynapar's characterizations of the Hiperface, Sine/Cos and EnDat protocols are based on the form of these products being offered commercially at the time of this publication. These products are subject to periodic revisions, so that interested parties should check the following web sites for additional and more current product information

Related Links:

www.feedbackdevices.com

www.danaherindustrialcontrols.com

Introduction

Modern factories are among the most wired places on earth, with multiple layers of computer networks handling a broad range of communications tasks. There are enterprise-level networks connecting different buildings and locations, plant-level networks within the facility, and multiple machine-level networks, which may be based on any of about a dozen network protocols.

The rising use of factory networks for automation has an impact on many devices, among them are rotary encoders. Encoders may use any one of a number of communication protocols. Other equipment may use still different protocols. Integrating the different encoder networks so that diagnostic and status information on individual encoders anywhere can be accessed by the plant-level network is a challenge.

Encoders

Encoders are sensors that generate digital signals in response to movement. Both shaft encoders, which respond to rotation, and linear encoders, which respond to motion in a line, are available. When used in conjunction with mechanical conversion devices such as rack-and-pinions, measuring wheels, or spindles, shaft encoders can also be used to measure linear movement, speed, and position.

In general, there are two main types of encoders: incremental and absolute. Incremental encoders generate a series of pulses in response to motion. These pulses can be used to measure speed or be fed to a counter to keep track of position. On the other hand, absolute encoders generate multi-bit digital words that indicate actual position directly. A major benefit of absolute encoders is that if the application loses power the encoder “remembers” its position prior to the power loss. An incremental encoder, on the other hand, does not have this inherent memory feature and so must be driven to home or a reference position in order to reset itself.

Incremental encoders are used mainly for position control and also for speed measurement where the lack of a zero point doesn’t effect performance. Absolute encoders can be used for both position and speed sensing and are useful where it is impractical or inconvenient to home the machinery each time the power is brought up.

Among encoders, there is a clear trend: the percentage of applications using absolute encoders has increased. There are several key reasons for this. Recently, the price gap compared to incremental encoders has shrunk. This price decrease has meant that absolute encoders are not just for critical applications anymore.

Other reasons are more industry wide and have to do with technological changes. One of these is the increased need for information as factories get more wired to factory software systems such as ERP (Enterprise Resource Planning) and SPC (Statistical Process Control). This increases the need for communication between machines as more devices and components are connected to fieldbuses in retrofits and equipment upgrades. Another is a desire and need for more diagnostic information from equipment to increase preventative maintenance and prevent unexpected failure and downtime.

Many absolute encoders have the ability to change parameters (including the zero point) without opening the case, and have internal diagnostics that monitor and report the condition of the unit and help anticipate or prevent breakdowns.

For more detailed information on encoder basics, see the Encoder Application Handbook from Dynapar available at **www.dynapar.com.**

Encoder Communications

The output of an encoder can be transmitted in either parallel or serial form.

Parallel Output

Parallel output makes all output bits available simultaneously. It may be provided as straight binary or transformed into gray code. Gray code produces only a single-bit change at each step, which can reduce errors.

Some parallel-output encoders also can accept inputs from the outside – output latching commands, for example, and direction sense setting.

The advantage of parallel output is that it's fast: all the data is available in real time, all the time. Disadvantages include bulky and expensive cables and limited cable

Decimal	Gray Code	Binary
0	0000	0000
1	0001	0001
2	0011	0010
3	0010	0011
4	0110	0100
5	0111	0101
6	0101	0110
7	0100	0111
8	1100	1000
9	1101	1001
10	1111	1010
11	1110	1011
12	1010	1100
13	1011	1101
14	1001	1110
15	1000	1111

length. Most encoders come with cables a meter or two long. Open-collector (sinking or sourcing) outputs can go roughly a third that far. However, using a push-pull output configuration, cable lengths can reach 100m.

Serial Output

The alternative to parallel communication is serial. There are several dedicated serial buses available, as well as standard industrial buses. Tradeoffs among these include bandwidth, update rate, hardware requirements, wire count, proprietary vs. nonproprietary nature, and availability.

SSI

SSI (or Synchronous Serial Interface) is an all-digital point-to-point interface popular in Europe. It provides unidirectional communication at speeds up to 1.5MHz and uses two twisted pair wires plus two wires for power.

Some encoders also provide a 1V p-to-p sin/cos output for real-time control, since the on-demand absolute encoder data can come in too slowly for many control loops.

SSI extended can also provide parity or an alarm that can represent any condition.

Encoders may also be supplied with additional incremental outputs for speed feedback. For serial communications, one pair of wires is for a differential clock signal and the other pair is for data feedback from the sensor.

Data rate depends on both resolution and cable length. Clock frequencies can be as high as 1.5MHz. However, as clock frequency increases, the maximum cable run decreases, a limitation common to all protocols.

Cable Length vs. Data Rate for SSI

Cable Length	Data Rate
50 m	400 kHz
100 m	300 kHz
200 m	200 kHz
400 m	100 kHz

The data frame length depends on the device and its resolution. In an SSI interface, there is one slave per master, referred to as a point-to-point connection. The clock remains high until the master needs information from the sensor. It then sends a stream of clock pulses equivalent to the number of bits of information from the sensor. Samples of each bit are usually taken on the falling edge of the clock pulse. This insures that the propagation and process delays are accounted for. Sensor manufacturers are free to insert alarm bits if required, but the requirement must be provided before the product is shipped, and a single alarm bit may have several meanings.

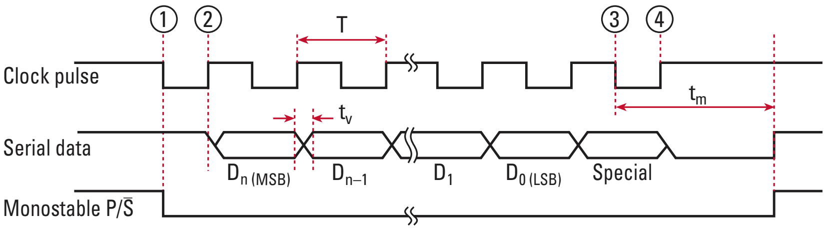


Figure 1 SSI Communication Format

EnDat

EnDat (Encoder Data) is a proprietary protocol developed by Heidenhain of Germany. Like SSI, it is synchronous and features a point-to-point connection, with clock signals fed to the encoder by the controller with speeds to 4MHz. EnDat can carry more information than SSI because it provides for internal memory in the encoder that can be read and written to by the controller. This data can include encoder diagnostics, identification, and alarm status. It can also contain information about the motor in which it was mounted to such as model and serial numbers.

Varying clock pulse stream lengths are also required from the varying data that may be received or sent to the device. Also, using a function called a Datum Shift, an encoder can easily be reset to a new zero or reference point. The Datum Shift is a value that is added to the physical position of an encoder. SSI provides a direct reading of the physical position, so it requires the end user to rotate the shaft to the zero position.

As with SSI, EnDat encoders transmit absolute position data on demand. Depending on the version, EnDat can include an analog 1-V p-to-p sin/cos output that electronics in the controller interpolate to derive incremental data for real-time control.

The hardware level minimally requires six wires for communications with distances up to 150m. Depending on the version of EnDat, there may be an additional wire that carries an analog incremental output for faster speed sampling. This is useful for speed-controlling drives that can be more demanding than the rate at which serial feedback is normally provided.

For more information on the EnDat protocol refer to the Heidenhain website at www.heidenhain.com.

HIPERFACE

HIPERFACE is a proprietary protocol developed by Max Stegmann GmbH. It uses an eight-wire cable (two for the RS-485 communications, two for power and four for 1V p-to-p incremental sin/cos). Absolute position data is transmitted via the RS-485 link at power up, and the system uses the incremental signal after that. This solves the problem of not knowing position at startup, but it does not self-correct for momentary data dropouts during operation. With only incremental data coming into the controller, a glitch can cause the controller

Dedicated Serial Interfaces

	HIPERFACE®	SSI + Sine/ Cos	EnDat®	BiSS
Open Protocol	No	No (License available)	No	Yes
Connection	RS-485: Bus or Point-to-Point Analog: Point-to-Point	Point-to-Point	Point-to-Point	Bus or Point-to-Point
Analog Signals Required	Yes	Yes	No	No
Transmission Mode (Digital)	Bidirectional, asynchronous	Unidirectional, synchronous	Bidirectional, synchronous	Bidirectional, synchronous
Digital Data Transmission Rate	38.4 kBaud	1.5 MHz	8 MHz*	10 MHz
Cable Length Compensation	No	No	Yes	Yes
Protocol Length Adjustable	No	No	Yes	Yes
No. of Wires	8	6–8	6 to 12	6
Hardware Compatible				
Alarm/Warning Bit	No	Definable	Yes	Definable

* Heidenhain® cables recommended for transmission rates above 2MHz.

to lose track of position. Unlike SSI, EnDat and BiSS, the HIPERFACE digital data channel is asynchronous – there are no clock signals from the controller. HIPERFACE can be connected point-to-point, and can also use a bus connection, which can save on wiring.

The data comes at a relatively slower rate of 38.4kBaud, but contains much more information than provided in SSI communications. Because all position data after startup is carried by the analog sin/cos channel, the frequency on the cable is low, and a 1,024 pulse-per-revolution encoder generates only a 204.8kHz signal at 12,000 rpm, although absolute position data cannot be sent reliably beyond about half that speed.

HIPERFACE can be point-to-point like SSI and EnDat, but it can also use bus connections in which several encoders can be wired together and addressed by a single master. HIPERFACE is the only one of the four major serial protocols that is asynchronous.

Like EnDat, it has internal memory that can hold motor information such as voltage, current, and other parameters. Using a licensed master, you can also de ne an absolute zero position. HIPERFACE can access the encoder's memory area for manufacturer's data, status, alarm information, and so on. In addition, the controller can write to certain memory areas.

At the hardware level, eight wires are required. The proprietary SinCos® output requires four wires for each differential pair, with two wires required for data communication and two for power.

For more information on HIPERFACE, refer to the Stegmann website at www.sick-stegmann.de.

BiSS

BiSS is the latest protocol designed and developed by IC-Haus, Germany. It was created to be an open non-proprietary protocol alternative to EnDat® and HIPERFACE® but designed with the capabilities of the proprietary protocols in mind. Combined features such as alarms, warnings, diagnostics, and the ability to store motor information to the encoder are part of the BiSS protocol.

BiSS sends full absolute position data whenever the controller polls the encoder, rather than just at startup. It allows easy recovery from momentary data dropouts during operation. Since it is an all-digital system, it eliminates the cost of A/D converters needed in drive systems that connect to encoders using some proprietary protocols. It is also hardware compatible with SSI and EnDat, requiring only software changes.

BiSS uses four data lines, one pair carrying data from the encoder and one carrying clock data to it, plus two power conductors. It also uses a variable clock rate of up to 10MHz.

BiSS can address internal registers in the encoder that can be read by and written to by the master with data about the encoder itself (identification, device data, resolution, etc.) It can also carry other digital data (temperature, etc.) and transmit it to the master on demand, without interfering with real-time operation.

BiSS, like the other serial protocols, can be connected either point-to-point or via a bus.

BiSS has two modes; sensor mode and register mode. In sensor mode, the sensor or encoder communicates in a manner similar to SSI. The master begins to send a stream of clock pulses. Eventually the data line level will drop low and data sampling will begin. The data can be received and clocked at 10MHz. Due to the transmission speed, many drives may not require additional analog incremental outputs to control motor speed. Since SSI has a slower max transfer rate of 1.5MHz, the propagation and calculation delay is less than a full pulse width. This is how BiSS is capable of hardware compatibility with SSI. Only the data length and framework need to be changed in the software. **Figure 2** shows the communication format and a data frame map.

In register mode, the protocol modulates the clock pulse width to address specific slaves and parameters. This mode is unlike any other protocol. If in the sensor mode a warning or alarm bit is set high by the sensor or encoder, the end-user may access the register mode and find specifics on the alarm or warning. This might be an over-temperature warning or, in the case of an encoder, a disk pollution alarm. Dynapar Group has developed the ability to provide single step alarms in case improper position is being provided in sequence.

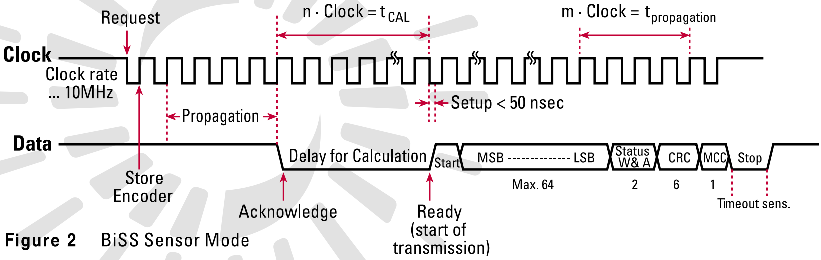


Figure 2 BiSS Sensor Mode

Other information such as acceleration, temperature, and identification can be retrieved from an encoder with BiSS. Also, as mentioned before, register mode allows for sending and storing data to the encoder.

On a hardware level, the same cable used in SSI and EnDat can be used with BiSS applications.

For more information on IC-Haus and the BiSS protocol, refer to the BiSS Website at www.biss-interface.com.

CC-Link

CC-Link (or Control and Communication Link) is a fieldbus for control with baud rates up to 10Mbps. Traditionally, it has been strongest and most popular in Japan and is heavily supported by Mitsubishi, although it is gaining popularity in China and Korea.

For more information on CC-Link , refer to the CC-Link Website at www.cc-link.org.

Open vs. Closed Communications Protocols

An important distinction between protocols is whether they are open or closed. *Closed communication protocols* are proprietary, meaning that the protocol use is controlled by the originators of the protocol. Slave device manufacturers are limited to those that are given permission by the originator, and can often be single source. In some cases detailed specifications of a proprietary protocol are restricted as well: they are available to license holders and not the general public.

Open communication protocols, on the other hand, are non-proprietary and non-restrictive. The protocol developers freely share specifications regarding data format and electrical design. Designers of products that use serial communications, such as sensors and encoders, can create their own interfaces without paying a licensing fee. This means that – when you are shopping for a replacement serial communication device – you'll find many more encoders available on the market. The most popular open communications protocol is SSI. SSI is a well accepted and time-tested protocol. More recently, the BiSS interface open serial protocol has come into the market. Using SSI as a basis, it represents an alternative to bi-directional communication protocols such as EnDat® and HIPERFACE®.

Closed Communications Protocol

There is one good reason to use a closed proprietary protocol; simplicity. For instance, the communication protocols slave configuration software is usually pre-designed, saving time and development costs. Another reason may be that a user prefers a particular vendor's product and agrees to pay the licensing fee in exchange for the ability to completely rely on that manufacturer for all levels of required support for the encoder or sensor. The drawback to this approach is that the user limits his/her options in the future, when a replacement device is needed.

Open Communications Protocol

There are several key benefits to using an open communication protocol. These include availability. Encoder buyers have more selection options and alternative manufacturers to choose from.

Another is cost. Manufacturers of products using closed communication protocols can charge any fee that the market will bear for a replacement encoder, since there is virtually no competition from other manufacturers. On the other hand, competition among suppliers of open-communication-based products promotes price and product alternatives.

Closed protocol developers limit the amount of information that is published and available to buyers. However, if the need exists, an educated user can check the compliance of an open protocol from a specific manufacturer. Information regarding that protocol is freely posted on the Internet.

Understanding the operating capabilities and functional limitations of each of the available feedback control protocols helps in selecting the right encoder protocol for a given application.

Bus Network Comparison			
	DeviceNet	**Profibus**	**Interbus**
Topology	Linear (trunkline/dropline)	Linear (trunkline/dropline)	Closed Loop
Communication System	Master/Slave	Multimaster (Producer/Consumer)	Master/Slave
Data Exchange	Polled, Change of State, Cyclic	Polled	Polled
Max. Length	500 m	1200 m (w/repeaters)	13 km
Max. Nodes	64	126	512
Data Packet	0–8 bytes	244 bytes	Flexible
Transmission Speed	125 Kbps @ 500 m 250 Kbps @ 250 m 500 Kbps @ 100 m	9.6 Kbps to 12 Mbps	500 Kbps
Transmission Media	2-wire twisted pair with 2-wire bus power cable w/drain wire	2-wire twisted pair w/shield	Local: 3-pair twisted w/drain Remote: 5-pair twisted w/drain

Industrial Buses

Industrial buses have proliferated in recent years, with many kinds of proprietary and non-proprietary buses on the market. For feedback applications, there are three general-purpose industrial buses that are most commonly used with encoders.

DeviceNet

DeviceNet Cable vs. Baud Rate		
Baud Rate	**Max. Trunk Line Length (thick cable)**	**Max. Cumm. Drop Length**
125 kbps	1640 ft	512 ft.
250 kbps	820 ft.	256 ft.
500 kbps	328 ft	128 ft.

Based on the Controller Area Network, or CAN bus, which was developed by Bosch for use in automobiles and commercialized for industrial use by Allen-Bradley/Rockwell Automation, this bus is now administered by the Open DeviceNet Vendor Association (ODVA).

The system's basic trunkline-dropline topology provides separate twisted-pair wires for both signal and power distribution, enabling 24 VDC devices to be powered directly from the bus. End-to-end network distance varies with data rate and cable size. The 0 to 8 byte data packet is ideal for low-end devices with small amounts of I/O that must be exchanged frequently.

Device Net supports baud rates to 500kbps maximum at a maximum trunk line length of 328 ft or a maximum cumulative drop length of 128 ft. Encoders with DeviceNet have programmable scale, direction, and preset with position data.

Profibus

This open communication standard developed by the European Community (European Common Standard EC50170) comes in two variations: FMS, which is used for upper level cell-to-cell communication, and Profibus DP, which is optimized for data transfer with local field devices like valves, drives, and encoders. There are specific device profiles defined, including one for encoders. DP is good for applications that require high-speed transmission of fairly large amounts of information (512 bits of input data and 512 bits of output data over 32 nodes in 1msec).

Profibus Cable vs. Baud Rate

Baud Rate	Max. Segment Length	Max Expansion (with repeaters)
500kbps	1311 ft.	13,114 ft.
1.5Mbps	655 ft.	6,557 ft.
12Mbps	327 ft.	3278 ft.

Initially developed by Siemens, Profibus boasts baud rates to 12Mbps with a maximum segment length of 327 ft and features programmable resolution, preset, and direction. Profibus encoders can communicate speed, direction, and on-time diagnostics.

Interbus

Designed by Phoenix Contact in the mid 1980s, Interbus is the longest-standing open industrial network. A true token-ring topology, Interbus is actually divided into two buses. The remote bus is an RS-485 transmission medium with length capabilities up to 13km. The local or peripheral bus enables connection of up to eight devices within a 10m range.

CAN

The CAN network (Controller Area Network) was first used in the automotive industry in the 1980s. The current CAN L2 and CANOpen protocols feature baud rates up to 1Mbps. CANOpen has programmable preset and resolution with L2 having programmable direction and limit values. Both protocols offer speed, acceleration, position, and limit data.

CAN is closely related to DeviceNet with virtually identical hardware and wiring configurations, differing only in the message formatting.

For many of these protocols, the encoder transmits the absolute position only when interrogated. In others, the encoder sends incremental data as it turns, and provides absolute data either on startup or when interrogated. These methods cut down on bus traffic, but also mean that the control system must know enough to demand an absolute position update whenever there's a momentary glitch. The update may take only a few milliseconds, but it's a factor to keep in mind when designing a control system. Some encoders also provide a 1V p-p sin/cos output for real-time control, since the on-demand absolute encoder data can come in too slowly for many control loops.

General Wiring and Installation Guidelines

The most frequent problems encountered in transmitting an encoder's signals to receiving electronics are signal distortion and electrical noise. Either can result in gain or loss of encoder counts. Many problems can be avoided with good wiring and installation practices.

For starters, take reasonable care when connecting and routing power and signal wiring on a machine or system. Radiated noise from nearby relays, transformers, and electronic drives may be induced into the signal lines causing undesired signal pulses. Likewise, the encoder may induce noise into sensitive equipment lines adjacent to it.

Route machine power and signal lines separately. Signal lines should be shielded, twisted and routed in separate conduits or harnesses spaced at least 12 inches from power leads. Power leads are defined here as transformer primary and secondary leads, motor armature leads, and any 120VAC or above control wiring for relays, fans, and thermal protection.

Maintain continuity of wires and shields from the encoder through to the controller avoiding the use of terminals in a junction box. This helps minimize radiated and induced noise and ground loops.

In addition, transients in the encoder power supply can adversely influence operation. Typically, encoder power should be regulated to within ±5%, and it should be free of induced transients.

The encoder case must also be grounded to insure proper and reliable operation. Some encoders have provisions for a case ground connection through the connector/cable if a ground cannot be secured through the mounting bracket or machine ground. Use high quality shielded wire and connect the shield only at the instrument end.

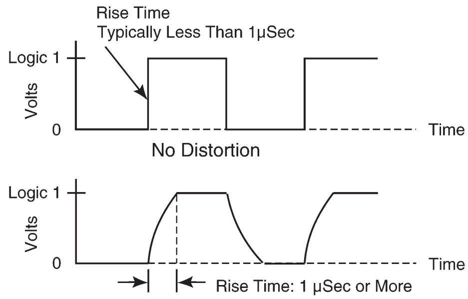
Signal distortion can be eliminated with complementary encoder signals (line drivers), used with differential receivers (line receivers or comparators) at the instrument end. Also, an encoder using twisted-pair shielded cable ensures that wire-induced currents will self-cancel.

In industrial environments, high current fluxes are created by motors, remote control switches, and magnetic fields. This can result in varying electrical potentials at different ground points. To avoid problems, ground the shield, together with all other parts of the system requiring grounding, from a single point at the instrument end.

Grounding requirements, conventions, and definitions are contained in the National Electric Code. Local codes will usually dictate the particular rules and regulations for system safety grounds.

Signal Distortion

The majority of signal transmission problems involve electrical noise, with the severity of the problem increasing with greater transmission distance. Good shielding practices help reduce noise.



Typical Signal Distortion

The primary cause of signal distortion is cable length, or more specifically, cable capacitance. The longer the cable, the greater the potential for signal distortion. Generally, the receiving electronics will respond to an input signal that is either a logical 0 or 1. The region between 0 and 1 is undefined, and the transition though this region must be less than about 1 microsecond. As the leading edge of the waveform is distorted, the transition time increases. At some point, the receiver becomes unstable and encoder counts may be gained or lost.

To minimize distortion, use low capacitance cable, typically less than 40 picofarads per foot. Squarewave distortion is not usually significant for cable lengths less than 50 feet (capacitance up to about 1,000 picofarads). Encoders supplied with differential line drivers are recommended for applications with cable length requirements of hundreds of feet.

About Dynapar

Dynapar™ is a world-leading manufacturer of optical and magnetic encoders and resolvers with more than 50 years of experience in engineering and manufacturing rotary feedback devices. Dynapar was founded in Gurnee, Illinois in 1955 and has been expanded through the acquisitions to include Hengstler™, Acuro™, NorthStar™, and Harowe™ product lines. Dynapar is now uniquely a provider of technologies spanning optical, magnetic, and resolver based feedback.

Pioneering the first true vector-duty hollow-shaft encoder launched Dynapar's strong presence in several industries, including steel, paper, elevator, oil and gas, wind energy, medical, material handling, and industrial servo manufacturers. From small kit encoders to large mill-duty tachometers, Dynapar has the industry covered.

Dynapar customers rely on expertise and support provided from the U.S. sales and manufacturing location in Gurnee, Illinois: Phone +1 800.873.8731 or +1 847.662.2666; FAX +1 847.662.6633; Website: www.dynapar.com. In addition, Dynapar supports global customers with local sales and production locations in Germany, Japan, China, West Indies, and Brazil.

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