BETA SAMPLES AVAILABLE

Preliminary product information
LinACE™ absolute shaft encoder
8th April 2016

LinACE™ absolute linear shaft encoder

LinACE™ is an extremely robust absolute linear cylindrical encoder system designed for direct integration into hydraulic, pneumatic, electromechanical actuators and linear motors as a feedback element for position or velocity.

The LinACE™ encoder system consists of a sliding encoder readhead and a solid steel shaft acting as a measuring standard.

By replacing the main shaft of the actuator or one of the guide shafts with LinACE™ hard chrome plated shaft the encoder becomes part of the actuator and provides measuring in the axis of movement. The readhead can replace the existing sliding bearing eliminating the need for an external encoder and thereby reducing space consumption.

The encoders come in asynchronous serial RS422, PWM, SSI, BiSS and CAN proprietary output variants and offer a range of selectable resolutions from 50 µm to 0.5 µm with speeds up to 5 m/s.

The LinACE™ encoder has a built-in advanced self-monitoring function, continually checking several internal parameters. Error reporting, warnings and other status signals are available on all digital interfaces and visualised with the on-board LED.

The encoder is insensitive to external magnetic fields, operates from –30 °C to +85 °C and is resistant to shock and vibration. The encoder position is retained even if the shaft rotates while moving backwards and forwards.

The LinACE™ encoder system is suitable for integration into electric, hydraulic and pneumatic actuators for motion control in industrial and medical applications. Custom design service for OEM integration is also available.

- **True absolute system**
- **Encoder for direct integration into an actuator**
- **No magnetically induced position hysteresis**
- **Resolutions up to 0.5 µm**
- **Lengths up to 500 mm (320 mm for shaft diameter 4 mm)**
- **Speeds up to 5 m/s**
- **Built-in self-monitoring**
- **Integrated status LED**
- **Asynchronous serial RS422 communication, PWM, SSI, BiSS and CAN proprietary interface**
- **Non-magnetised hard chrome plated shaft**
- **Shaft insensitive to stray magnetic fields**

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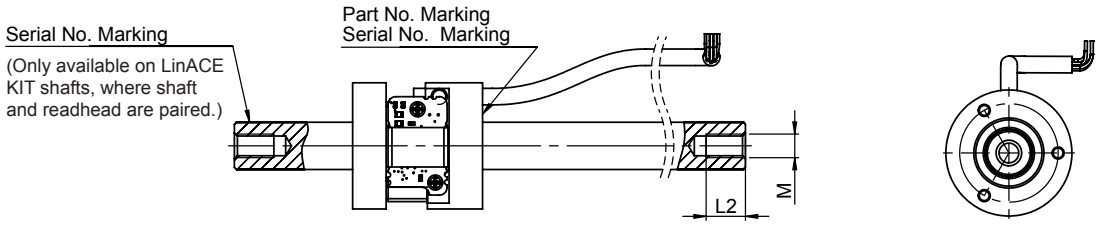
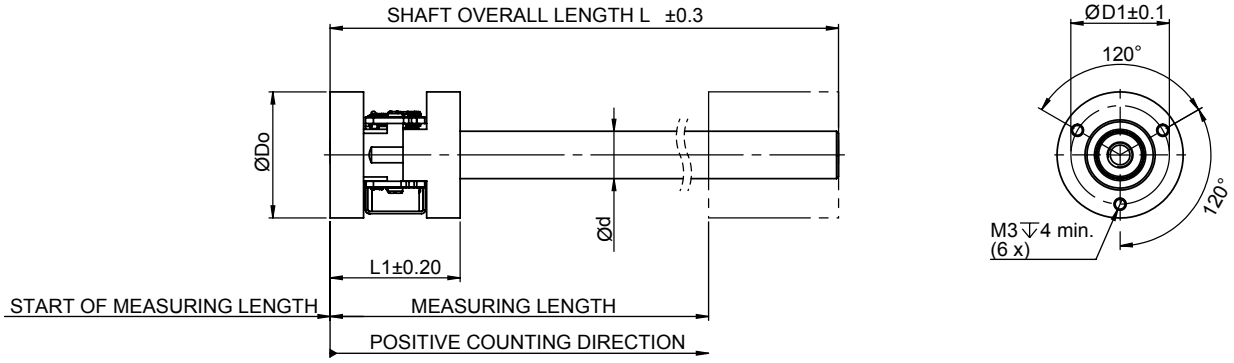
Dimensions

Dimensions and tolerances in mm.

Option with cable



Option with pads



Mechanical specifications			
Shaft diameter in mm (d)	4 h7	8 h7	12 h6
Shaft overall length in mm (L)	320 max.	500 max.	
Shaft threaded holes (M×L2)	None*	M4×6	M6×10
Readhead diameter in mm (Do)	30 f7	32 f7	
Readhead length in mm (L1)	25	29	33
Readhead threaded holes (D1)	20	22	25

* See Appendix 1 on page 15.

NOTES:
- Start of measuring length may be any number bigger than zero.
- Shaft must be inserted with orientation as on the drawing.
- Shaft/readhead module fit: F7/h7 or F7/h6 (see shaft diameter in the table above).
- Encoder shaft may be rotated independently of the linear travel.
- Use installation kit if mounting surfaces are not perfectly parallel (see Appendix 3 on page 18).

Sliding bearing material	**Sint-A51 bronze Impregnated with oil**	**Sint-A51 bronze Impregnated with low temperature oil**
p × v	1.6 N/mm² × m/s	
p_{max}, continuous operation at ~0.17 m/s speed	10 N/mm²	
Maximum speed, continuous operation	5 m/s	
Thermal expansion coefficient	18 × 10^{-6} K^{-1}	
Operating temperature	–12 °C to +85 °C	–30 °C to +85 °C
Friction coefficient	0.05 to 0.10	

Technical specifications

System data		
Maximum shaft overall length	500 mm (320 mm for shaft diameter 4 mm)	
Shaft diameter	4 mm, 8 mm and 12 mm	
Shaft linear expansion coefficient	~11 × 10^{-6}/K	
Maximum speed	5 m/s	
System accuracy	±5 µm – for shaft overall lengths up to 125 mm ±10 µm, ±20 µm, ±50 µm – for shaft overall lengths up to 500 mm (in both cases readhead and shaft are not exchangeable) ±100 µm – readhead and shaft are exchangeable (start of measuring length can be any value bigger than zero)	
Hysteresis	Less than unit of resolution	
Repeatability	Better than unit of resolution	
Electrical data		
Supply voltage	4 V to 6 V – voltage on readhead. Consider voltage drop over cable (see page 4).	
Set-up time	5 ms (after switch-on)	
Power consumption	Typ. 115 mA, max. 150 mA	
Mechanical data		
Material type	Shaft	EN 1.1203 / AISI 1055 or EN 1.0601 / AISI 1060 30 µm to 40 µm Hard chrome coating 800 HV to 1100 HV
	Readhead	CuZn37Mn3Al2PbS, not coated
	Sliding bearing	Sint-A51 bronze impregnated with standard oil Sint-A51 bronze impregnated with low temperature oil
Environmental data		
Temperature	Operating	–12 °C to +85 °C for bearings impregnated with standard oil –30 °C to +85 °C for bearings impregnated with low temperature oil
	Storage	–40 °C to +90 °C
Humidity	90 % (non-condensing)	

Status indicator LED

LED	Status
Green	Normal operation; position data is valid
Orange	Warning; position data is valid; one parameter is near limits
Red	Error; position data is not valid
No light	No power supply

WARNING!

ESD protection
Readhead is ESD sensitive - handle with care. Do not touch wires or sensor area without proper ESD protection or outside of ESD controlled environment.

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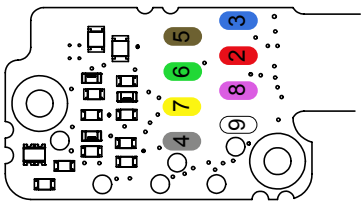
Electrical connections

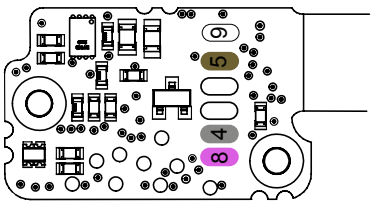
Pin / Pad	Wire Colour	Asynchronous serial RS422	PWM	SSI	BiSS	CAN bus
Housing	Outer shield	Encoder / machine case (Earth connection)	Encoder / machine case (Earth connection)	Encoder / machine case (Earth connection)	Encoder/machine case (Earth connection)	Encoder / machine case (Earth connection)
1	Inner shield	0 V (GND)	0 V (GND)	0 V (GND)	0 V (GND)	0 V (GND)
2	Red	RX data in+	-	Clock+	MA+	-
3	Blue	RX data in–	-	Clock–	MA–	-
4	Grey	-	Status	-	-	CANL
5	Brown	5 V supply	5 V supply	5 V supply	5 V supply	5 V supply
6	Green	TX data out+	-	Data+	SLO+	-
7	Yellow	TX data out–	-	Data–	SLO–	-
8	Pink	-	PWM Out	-	-	CANH
9	White	0 V (GND)	0 V (GND)	0 V (GND)	0 V (GND)	0 V (GND)

Voltage difference between Ground (white wire and inner shield) and encoder housing (outer shield) should not exceed 10 V_{pp}.

For output types: Serial, SSI, BiSS, PWM

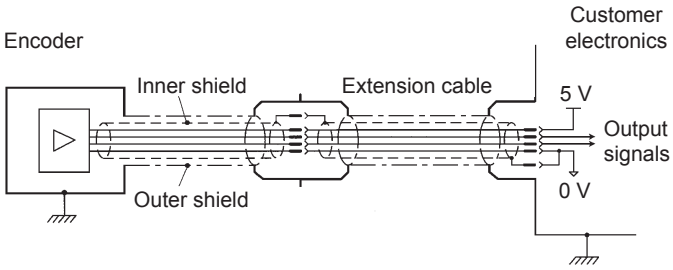


For output type: CAN bus

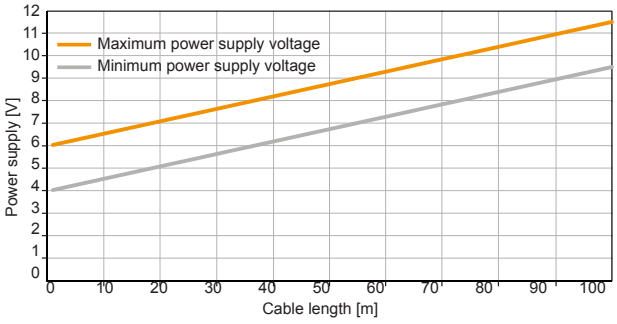


Cable specifications

Outer diameter	4.2 ±0.2 mm
Jacket material	Extruded polyurethane (PUR)
White wire	0.9 ±0.07 mm diameter, 26 AWG (19 strands REF 6), 0.13 Ω/m
Other wires	0.6 ±0.07 mm diameter, 30 AWG (7 strands REF 6), 0.35 Ω/m
Power supply lines resistance	0.48 Ω/m at 20 °C
Durability	20 million cycles at 20 mm bend radius
Bend radius	Dynamic 25 mm, static 10 mm (internal radius)
Weight	34 g/m nominal



Voltage drop over cable



For cables longer than 5 meters input voltage on the cable must be adjusted so the voltage drop is taken into account.
Voltage drop over cable ~55 mV/m – without load.

Communication interfaces

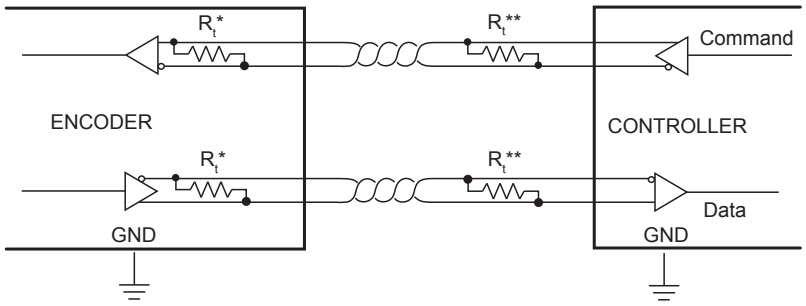
Asynchronous serial RS422		
	Baud rate	115.2 kbps, 128 kbps, 230.4 kbps, 256 kbps, 500 kbps, 1 Mbps
	Data format	8 bits, no parity, 1 stop bit
	Update rate	On demand or continuous
	Resolution	0.5 µm, 1 µm, 2 µm, 5 µm, 10 µm
	Latency	250 µs
PWM		
	Base frequency	122.07 Hz, 274.66 Hz, 366.21 Hz, 549.32 Hz, 1098.6 Hz
	Update rate	Same as base frequency
	Output resolution	16 bits
	Resolution	1 µm/step at up to 50 mm stroke 2 µm/step at up to 100 mm stroke 5 µm/step at up to 250 mm stroke 10 µm/step at up to 500 mm stroke
	Latency	250 µs
SSI *		
	Data format	Binary
	Clock frequency	50 kHz to 500 kHz (2.5 MHz**)
	Update rate	4 kHz
	Resolution	0.5 µm, 1 µm, 2 µm, 5 µm, 10 µm
	Latency	250 µs to 500 µs
	Timeout (monoflop time)	20 µs
BiSS		
	Maximum clock frequency	5 MHz
	Maximum request rate	30 kHz
	Bandwidth	2 kHz max.
	Resolution	0.5 µm, 1 µm, 2 µm, 5 µm, 10 µm
	Latency	<10 µs
	Timeout (monoflop time)	20 µs
CAN bus		
	Standard	Proprietary
	Update rate	Up to 4 kHz
	Resolution	0.5 µm, 1 µm, 2 µm, 5 µm, 10 µm
	Latency	250 µs

* Slave type interfaces might not be suitable for high-speed closed control loops because of the variable latency time.
** With *Delay First Clock* function on the controller.

Asynchronous serial communication interface over RS422

Encoder identification and position data is available over the request-response type of communication through the asynchronous serial link. There are two unidirectional communication channels, forming a full-duplex bidirectional data link. Every channel consists of a two wire differential twisted-pair connection conforming to the RS422 signalling standard.

Electrical connection



* The Command and Data signals are 5 V RS422 compatible differential pairs with RC termination inside the readhead.
** Termination at the controller is required, if total cable length is longer than 5 m. The nominal impedance of the cable is 120 Ω.

Output protection

Excessive output current and power dissipation caused by faults or by bus contention are prevented by two mechanisms. A foldback current limit on the output stage provides immediate protection against short circuits. In addition, a thermal shutdown circuit forces the driver outputs into a high-impedance state, if the chip temperature becomes too high.

Communication parameters

Link speed	115.2 kbps, 128 kbps, 230.4 kbps, 256 kbps, 500 kbps or 1 Mbps
Character length	8 bits
Parity	None
Stop bits	1
Repetition rate	4 kHz max.
Position latency	Fixed at 250 µs between the position acquisition and first start bit sent out.

Command set

Command "v" (small character "v")	
Response - version info and serial number 8 bytes ASCII Serial number 1 byte binary Firmware version (42) 1 byte binary ASIC revision (31) 1 byte binary Resolution (factor 0.1 µm) 6 bytes ASCII code description	
Command "1" (ASCII one)	
Response - position and status, transmitted once 1 byte constant header 0xEA 4 bytes binary absolute position, big-endian, right aligned 2 bytes encoder status – see table on next page 1 byte constant footer 0xEF	
The next request should not be sent sooner than 250 µs after the end of the previous response from the readhead to allow refreshing of the position data. If request is sent sooner, data will arrive on the end of the refresh cycle.	
Command "2" (ASCII two)	
Response - position and status, transmitted continuously every cycle (250 µs + time of transmission depandant on baud rate) 1 byte constant header 0xEA 4 bytes binary absolute position, big-endian, right aligned 2 bytes encoder status – see table on next page 1 byte constant footer 0xEF	
Command "0" (ASCII zero)	
Stop continuous transmission	

Structure of data packet

Encoder status (two bytes):	
b15:b10	Reserved; always zero
General status	
b9	Error. If bit is set, position is not valid.
b8	Warning. If bit is set, encoder is near operational limits. Position is valid. Resolution and/or accuracy might be lower than specified.
Error and Warning bits can be set at the same time; in this case Error bit has priority. The colour of the LED on the readhead housing indicates the value of the General status bits: Red = Error, Orange = Warning, Green = Normal operation, No light = No power supply. The general warning or error status is more closely defined by the Detailed status bits.	
Detailed status	
b7	Warning - Signal amplitude too high. The readhead is too close to the shaft.
b6	Warning - Signal amplitude low. The distance between the readhead and the shaft is too large.
b5	Error - Signal lost. The readhead is too far away from the shaft.
b4	Warning - Temperature. The readhead temperature is out of specified range.
b3	Error - Power supply error. The readhead power supply voltage out of specified range.
b2	Error - System error. Malfunction inside the circuitry or inconsistent calibration data is detected. To reset the System error bit try to cycle the power supply while the rise time is shorter than 20 ms.
b1	Error - Wrong code. Shaft might be inserted in the wrong direction.
b0	Error - Acceleration error. The position data changed too fast. Shaft might be inserted in the wrong direction.

PWM - Pulse width modulation interface

The PWM communication interface consists of two digital signals: the Status signal and the PWM Out signal. It is 3.3 V TTL compatible.

Electrical connection
The Status and PWM Out signals are 3.3 V TTL compatible. These signal outputs have weak ESD protection, therefore the readhead must be handled with additional care in ESD controlled environment and with ESD protection.
Maximum current sourced from or sunk into signal lines should not exceed 20 mA.

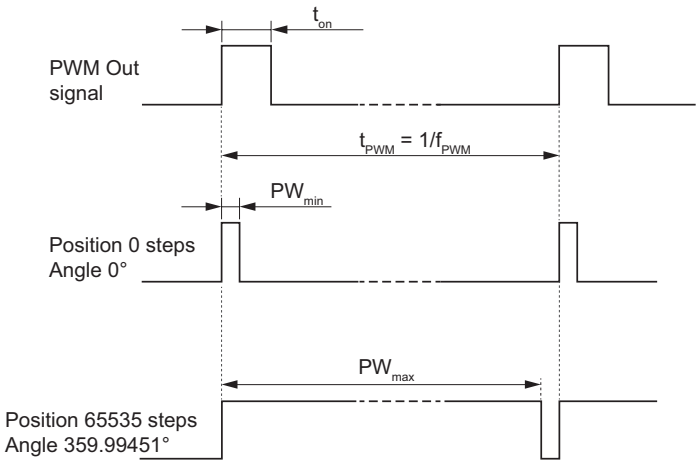
Status signal
The Status signal indicates the current status of the encoder. The Status signal is high for faultless operation and valid position information. The low state of the Status signal indicates an error state of the encoder which can be caused by:

- Operation outside installation tolerances
- Invalid or damaged magnetisation of ring
- Sensor malfunction
- System error
- No power supply

When the Status signal is low, the PWM Out signal is low and no pulses are output.
PWM signal duty cycle is updated with current encoder position at every PWM signal rising edge. The Status signal should also be checked at the rising edge of the PWM Out signal. If the Status signal changes during the PWM period, it does not affect the currently transmitted position information.

PWM Out signal
The PWM Out is a pulse width modulated output with 16-bit resolution whose duty cycle is proportional to the measured position. The change of the pulse width by PW_{min} corresponds to a change in position by one unit of the selected encoder resolution (in µm).

PWM Out signal timing diagram



Communication parameters
Communication interface variant in the part number defines the PWM frequency and all other dependent parameters.

		Communication interface variant						
Parameter	**Symbol**	**A**	**B**	**C**	**D**	**E**	**Unit**	**Note**
PWM frequency	f_{PWM}	122.07	244.14	325.52	488.28	976.56	Hz	
Signal period	t_{PWM}	8,192.00	4,096.00	3,072.00	2,048.00	1,024.00	µs	
Minimum pulse width	PW_{min}	0.1250	0.0625	0.0469	0.0313	0.0156	µs	Position 0
Maximum pulse width	PW_{max}	8,191.88	4,095.94	3,071.95	2,047.97	1,023.98	µs	Positions 65534 and 65535 *
Minimum counter frequency	f_{CNTR}	8	16	21	32	64	MHz	Receiving counter frequency

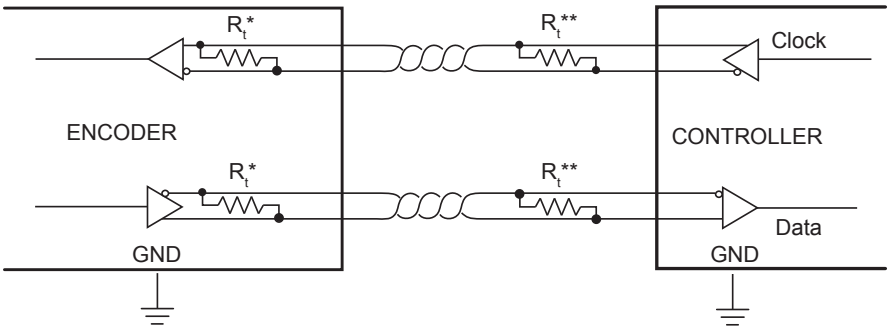
* Note that positions 65534 and 65535 result in the same pulse width PW_{max}.

$$\text{Position [µm]} = \left(\frac{t_{on} \times 65536}{T_{PWM}} - 1 \right) \times \text{Resolution}$$

SSI - Synchronous serial interface

The encoder position, in 21 bit natural binary code, and the encoder status are available through the SSI protocol. The position data is right aligned. LSB represents selected encoder resolution. After the position data there are two general status bits followed by the detailed status information.

Electrical connection

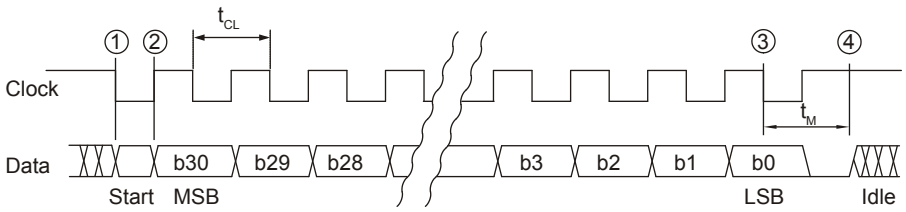


* The Clock and Data signals are 5 V RS422 compatible differential pairs with RC termination inside the readhead.
** Termination at the controller is required, if total cable length is longer than 5 m. The nominal impedance of the cable is 120 Ω.

Output protection

Excessive output current and power dissipation caused by faults or by bus contention are prevented by two mechanisms. A foldback current limit on the output stage provides immediate protection against short circuits. In addition, a thermal shutdown circuit forces the driver outputs into a high-impedance state, if the chip temperature becomes too high.

SSI timing diagram

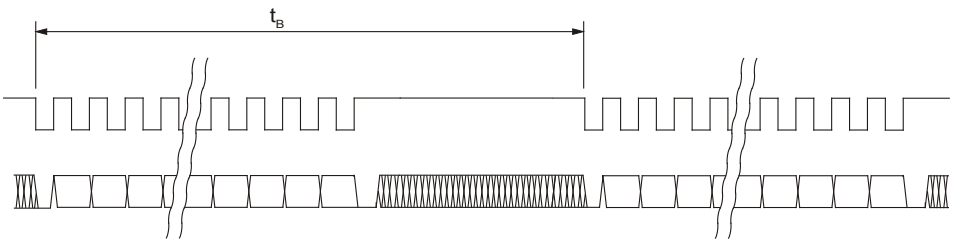


The controller interrogates the readhead for its position and status data by sending a pulse train to the Clock input. The Clock signal always starts from high. The first falling edge ① latches the current position data and on the first rising edge ② the most significant bit (MSB) of the position is transmitted to the Data output. The Data output should then be latched on the following falling edge. On subsequent rising edges of the Clock signal the next bits are transmitted.

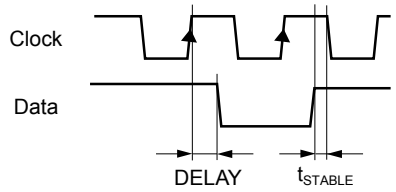
After the transmission of the last bit ③ the Data output goes to low. When the t_M time expires, the Data output is undefined ④. The Clock signal must remain high for at least t_M before the next reading can take place.

While reading the data, the period t_{CL} must always be less than t_M. However, reading of the encoder position can be terminated at any time by setting the Clock signal to high for the duration of t_M.

To allow updating of the position data at least t_B should pass between two subsequent readings. If the reading request arrives earlier than t_B after the previous reading, the encoder position will not be updated.

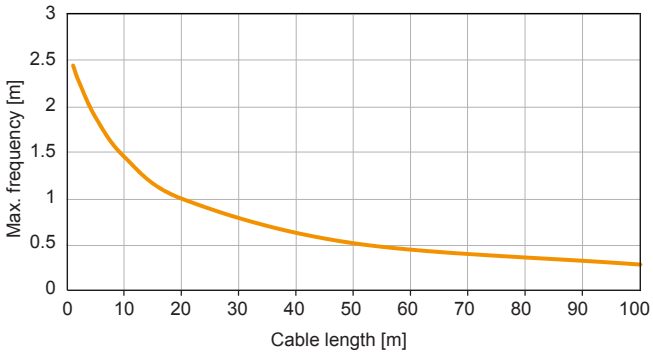


Maximum frequency



The readhead needs 170 ns to respond to incoming clocks (t_{RESP}). Change on Data signal is delayed for 170 ns after the rising edge on Clock line. Additional delay is caused by the time the signal needs to propagate through cable to the readhead and back (t_{PROP}). This delay is typically 14 ns per 1 meter of cable. Data signal must be stable for at least 10 % of the clock period length before the value is latched.
The clock frequency must be reduced with a longer cable. Total cable length must be taken into account, from the encoder to the receiver.
$t_{DELAY} = t_{RESP} + t_{PROP} \times$ cable length

Frequency derating versus cable length:



Communication parameters

Parameter	Symbol	Min	Typ	Max
Clock period	t_{CL}	2 µs		20 µs
Clock frequency	f_{CL}	50 kHz		500 kHz (2.5 MHz *)
Monoflop time	t_M		20 µs	
Update time	t_B	250 µs		
Readhead response delay	t_{RESP}		170 ns	
Cable propagation delay	t_{PROP}		14 ns/m	

* With *Delay First Clock* function on the controller.

Start bit and idle line value are defined by the *Communication interface variant*.

Communication interface variant	Line state selection	Usage
A	Start bit = 0; idle line = 0	Not recommended for new design
B	Start bit = 1; idle line = 1	Standard

Structure of data packet

Bit	b30 : b10	b9 : b8	b7 : b0
Data length	21 bits	2 bits	8 bits
Meaning	Encoder position	General status	Detailed status

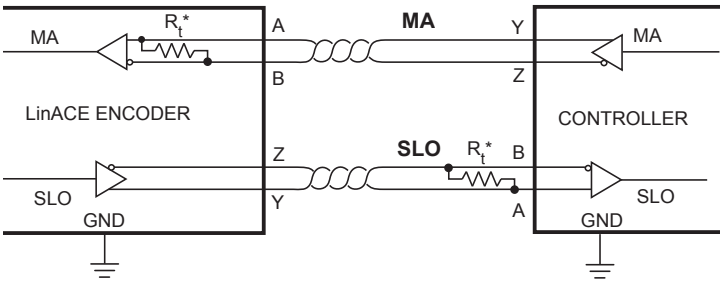
Encoder position		
	b30 : b10	Encoder position – Right aligned, MSB
General status		
	b9	Error bit. If set, the position is not valid.
	b8	Warning bit. If set, the encoder operational is close to its limits. The position is still valid, but the resolution and/or accuracy might be out of specification.
	The Error and Warning bits can be set at the same time, in this case the Error bit has priority. The colour of the LED on the readhead housing indicates the value of the General status bits: Red = Error, Orange = Warning, Green = Normal operation, No light = No power supply. The general warning or error status is more closely defined by the Detailed status bits.	
Detailed status		
	b7	Warning - Signal amplitude too high. The readhead is too close to the shaft.
	b6	Warning - Signal amplitude low. The distance between the readhead and the shaft is too large.
	b5	Error - Signal lost. The readhead is too far away from the shaft.
	b4	Warning - Temperature. The readhead temperature is out of specified range.
	b3	Error - Power supply error. The readhead power supply voltage out of specified range.
	b2	Error - System error. Malfunction inside the circuitry or inconsistent calibration data is detected. To reset the System error bit try to cycle the power supply while the rise time is shorter than 20 ms.
	b1	Error - Wrong code. Shaft might be inserted in the wrong direction.
	b0	Error - Acceleration error. The position data changed too fast. Shaft might be inserted in the wrong direction.

BiSS-C interface

The encoder position, in 26 bit natural binary code, and the encoder status are available through the BiSS-C protocol. The position data is right aligned. After the position data there are two status bits (active low) followed by CRC (inverted).

BiSS is implemented for point-to-point operation; multiple slaves are not supported.
Communication is unidirectional, readhead is not user programmable, also custom parameters can not be stored into the readhead.

Electrical connection



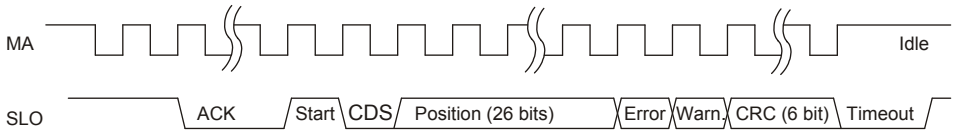
Signals	
MA	Master clock. Max. clock frequency is 5 MHz.
SLO	Slave out. Data is output on rising edge on SCK. Data is valid on the falling edge of SCK signal.

*The MA and SLO lines are 5 V RS422 compatible differential pairs. The termination resistor on the MA line is integrated inside the encoder. The termination on the end of the SLO line at the controller end is required, if the total cable length is longer than 5 m. The nominal impedance of the cable is 120 Ω.

Output protection

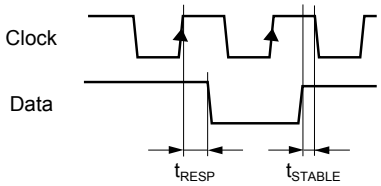
Excessive output current and power dissipation caused by faults or by bus contention are prevented by two mechanisms. A foldback current limit on the output stage provides immediate protection against short circuits. In addition, a thermal shutdown circuit forces the driver outputs into a high-impedance state, if the chip temperature becomes too high.

BiSS-C timing diagram



MA is idle high. Communication is initiated with first falling edge.
The encoder responds by setting SLO low on the second rising edge on MA.
When the encoder is ready for the next request cycle it indicates this to the master by setting SLO high.
The absolute position and CRC data is in binary format and sent MSB first.
Multicycle data is not implemented, therefore CDS bit is always zero.

Cable length compensation



The readhead needs 170 ns to respond to incoming clocks (t_{RESP}). Change on Data signal is delayed for 170 ns after the rising edge on Clock line. Additional delay is caused by the time the signal needs to propagate through cable to the readhead and back (t_{PROP}). This delay is typically 14 ns per 1 meter of cable. Total cable length must be taken into account, from the encoder to the receiver.

$t_{DELAY} = t_{RESP} + t_{PROP} \times$ cable length

The data signal must be stable before the value is latched. Therefore with a cable longer than 1 meter and a clock frequency higher than 2.5 MHz this delay must be compensated for in the receiver (controller) which the encoder is connected to.

Status bits

Type	Value 0	Value 1	Possible reason for failure
Error	Position data is invalid.	OK	Error bit is active low. If low, the position is not valid.
Warning	Position data is valid.	OK	Warning bit is active low. If low, the encoder operation is close to its limits. The position is still valid but the resolution and/or accuracy might be out of specification.

Communication parameters

Communication interface variant in the part number defines the functionality of the encoder.

Communication interface variant	Description	Parameter	Value
H	Long response high frequency	ACK length	12 bits
		MA frequency	Max. 5 MHz

Parameter	Symbol	Worst case
Latency		<10 µs
Bandwidth *		2 kHz
Maximum request rate		30 kHz
Timeout		20 µs
Readhead response delay	t_{RESP}	170 ns
Cable propagation delay	t_{PROP}	14 ns/m

* Bandwidth parameter is mechanical bandwidth. LinACE samples at 4 kHz therefore any mechanical changes that are appearing faster than 2 kHz are not detectable on the output (Nyquist theorem). If request for position comes faster than sampling frequency, LinACE encoder recalculates the position at the time of request based on current shaft velocity.

Data packet description

Data packet length is fixed to 34 bits. It consists of 26 bits of Position, 2 Status bits and 6 CRC bits (see table below).

Position	Status		CRC (inverted)
	Error	Warning	
26 bits	1 bit	1 bit	6 bits

Polynomial for CRC calculation of position, error and warning data is: $x^6 + x^1 + 1$. Represented also as 0x43.
It is inverted and transmitted MSB first.
Example of calculation routine for 6-bit CRC can be found in Appendix 2 of this document.

For more information regarding BiSS protocol see **www.biss-interface.com**.

CAN – Controller Area Network

Upon power-up the readhead starts sending messages at a frame rate of 1 kHz. Each message consists of an 11 bit identifier and six data bytes, including the encoder position, time stamp of the message and status of the readhead. The byte order of the position data is little-endian, i.e. the least significant byte is sent first. The automatic retransmission on the CAN bus is disabled.

Communication parameters

Protocol	Proprietary
Identifier length	11 bits
Identifier	0x127
Data length	6 bytes
Data rate	1000 Hz
Bit rate	250 kbit/s
Byte order	Little-endian
Bit alignment	MSB first

Electrical connection

The LinACE readhead has a 120 Ohm line terminating bias circuit (TBC) installed (supplying +2.5 V on the bus for the Recessive state). If using more than 1 encoder on the same CAN bus, contact local sales representative to obtain readheads without terminating resistors installed.

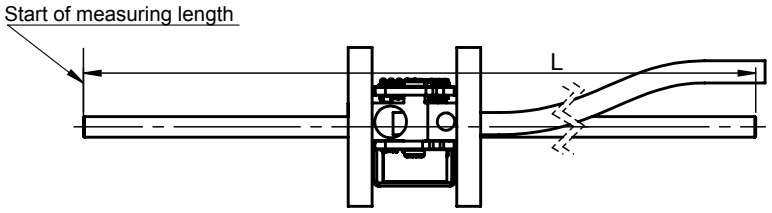
Structure of data packet

Byte	B1 : B3	B4	B5	B6
Data length	3 bytes	1 byte	1 byte	1 byte
Bit	b47 : b24	b23 : b16	b15 : b8	b7 : b0
Meaning	Encoder position	Time stamp	General status	Detailed status

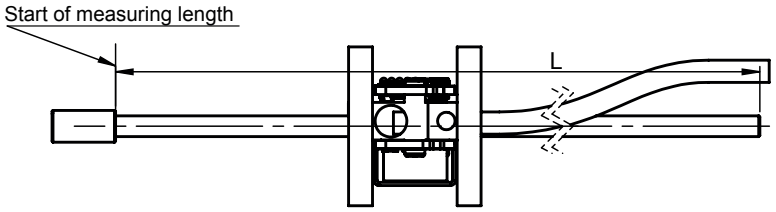
Encoder position		
		Encoder position in chosen resolution as 24 bit signed value – Least significant byte (B1) first, most significant byte (B3) last.
Time stamp		
		Time stamp of the message as 8 bit unsigned value in range from 1 ms to 200 ms. Time stamp is incremented every packet by 1.
General Status		
	b15 : b10	Reserved. Always zero.
	b9	Warning bit. If set, the encoder operational is close to its limits. The position is still valid, but the resolution and/or accuracy might be out of specification.
	b8	Error bit. If set, the position is not valid.
	The Error and Warning bits can be set at the same time, in this case the Error bit has priority. The colour of the LED on the readhead housing indicates the value of the General status bits: Red = Error, Orange = Warning, Green = Normal operation, No light = No power supply. The general warning or error status is more closely defined by the Detailed status bits.	
Detailed status		
	b7	Warning - Signal amplitude too high. The readhead is too close to the shaft.
	b6	Warning - Signal amplitude low. The distance between the readhead and the shaft is too large.
	b5	Error - Signal lost. The readhead is too far away from the shaft.
	b4	Warning - Temperature. The readhead temperature is out of specified range.
	b3	Error - Power supply error. The readhead power supply voltage is out of specified range.
	b2	Error - System error. Malfunction inside the circuitry or inconsistent calibration data is detected. To reset the System error bit try to cycle the power supply while the rise time is shorter than 20 ms.
	b1	Error - Wrong code. Shaft might be inserted in the wrong direction.
	b0	Error - Acceleration error. The position data changed too fast. The shaft might be inserted in the wrong direction.

Appendix 1 - End tips for installation of LinACE with 4 mm shaft diameter

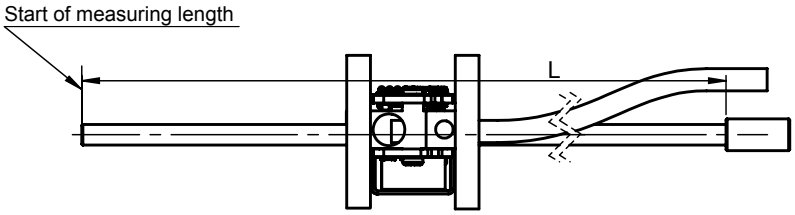
Option 00: no End Tips



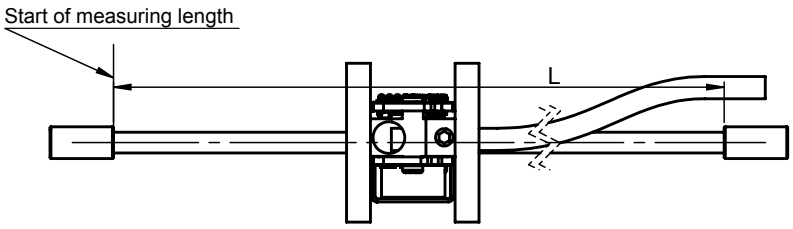
End Tip option A0: 4-A & no End Tip or D0: 4-D & no End Tip



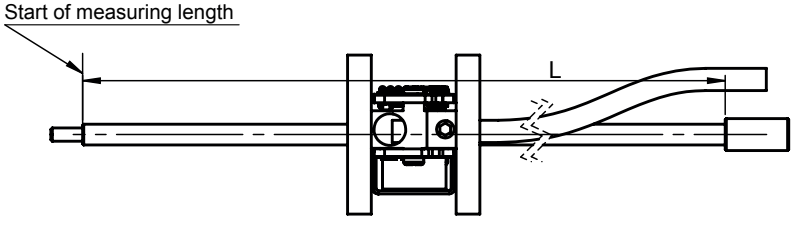
End Tip option 0A: no End Tip & 4-A or 0D: no End Tip & 4-D



End Tip option AA*: 4-A & 4-A or DD*: 4-D & 4-D

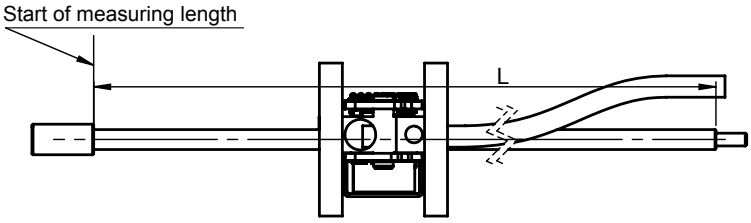


End Tip option CA: 4-C & 4-A or CD: 4-C & 4-D

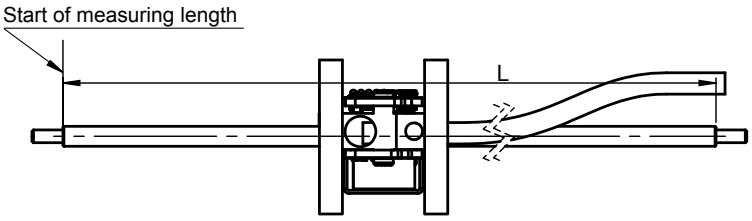


* End Tip options AA or DD do not allow readhead replacement (readhead can not be removed from the shaft).

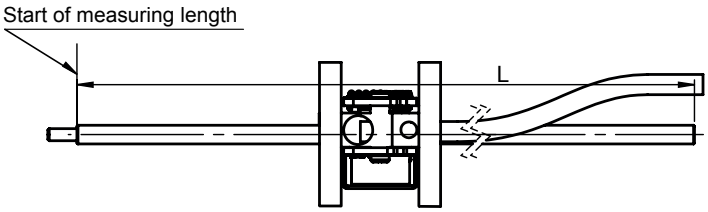
End Tip option AC: 4-A & 4-C or DC: 4-D & 4-C



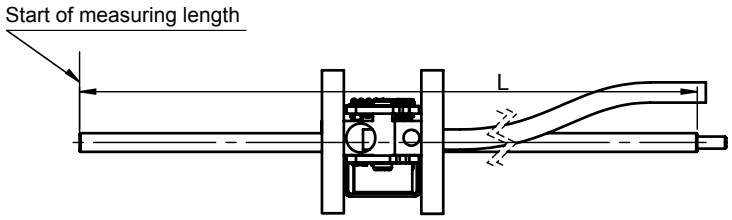
End Tip option CC: 4-C & 4-C

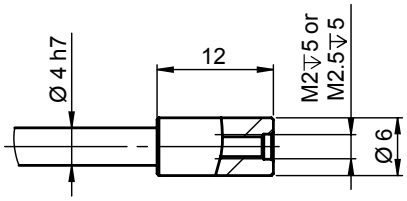


End Tip option C0: 4-C & no End Tip

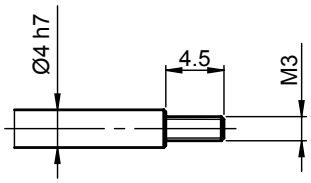


End Tip option 0C: no End Tip & 4-C





End Tip: 4-A (M2.5) or 4-D (M2)



End Tip: 4-C

L - shaft length defined in the product code

Appendix 2 - 6-bit CRC calculation with 0x43 polynome for BiSS

BiSS communication offers a CRC value to check the correctness of the data read from the encoder. This chapter gives an example of the CRC calculation on the receiver side. The CRC calculation must always be done over the complete set of data. The polynomial for the CRC calculation is $P(x) = x^6 + x^1 + 1$, also represented as 0x43.
Following code example must be modified to fit actual data length. Position data, error and warning bits must all be included into calculation in the same order as in the BiSS data packet.

Code example:

```
u8 tableCRC6[64] =  {
                      0x00, 0x03, 0x06, 0x05, 0x0C, 0x0F, 0x0A, 0x09,
                      0x18, 0x1B, 0x1E, 0x1D, 0x14, 0x17, 0x12, 0x11,
                      0x30, 0x33, 0x36, 0x35, 0x3C, 0x3F, 0x3A, 0x39,
                      0x28, 0x2B, 0x2E, 0x2D, 0x24, 0x27, 0x22, 0x21,
                      0x23, 0x20, 0x25, 0x26, 0x2F, 0x2C, 0x29, 0x2A,
                      0x3B, 0x38, 0x3D, 0x3E, 0x37, 0x34, 0x31, 0x32,
                      0x13, 0x10, 0x15, 0x16, 0x1F, 0x1C, 0x19, 0x1A,
                      0x0B, 0x08, 0x0D, 0x0E, 0x07, 0x04, 0x01, 0x02};

u8 crcBiSS(u32 bb)
 {
 u8 crc;
 u32 t;
 t = (bb >> 30) & 0x00000003;
 crc = ((bb >> 24) & 0x0000003F);
 t = crc ^ tableCRC6[t];
 crc = ((bb >> 18) & 0x0000003F);
 t = crc ^ tableCRC6[t];
 crc = ((bb >> 12) & 0x0000003F);
 t = crc ^ tableCRC6[t];
 crc = ((bb >> 6) & 0x0000003F);
 t = crc ^ tableCRC6[t];
 crc = (bb & 0x0000003F);
 t = crc ^ tableCRC6[t];
 crc = tableCRC6[t];
 return crc;
 }
```

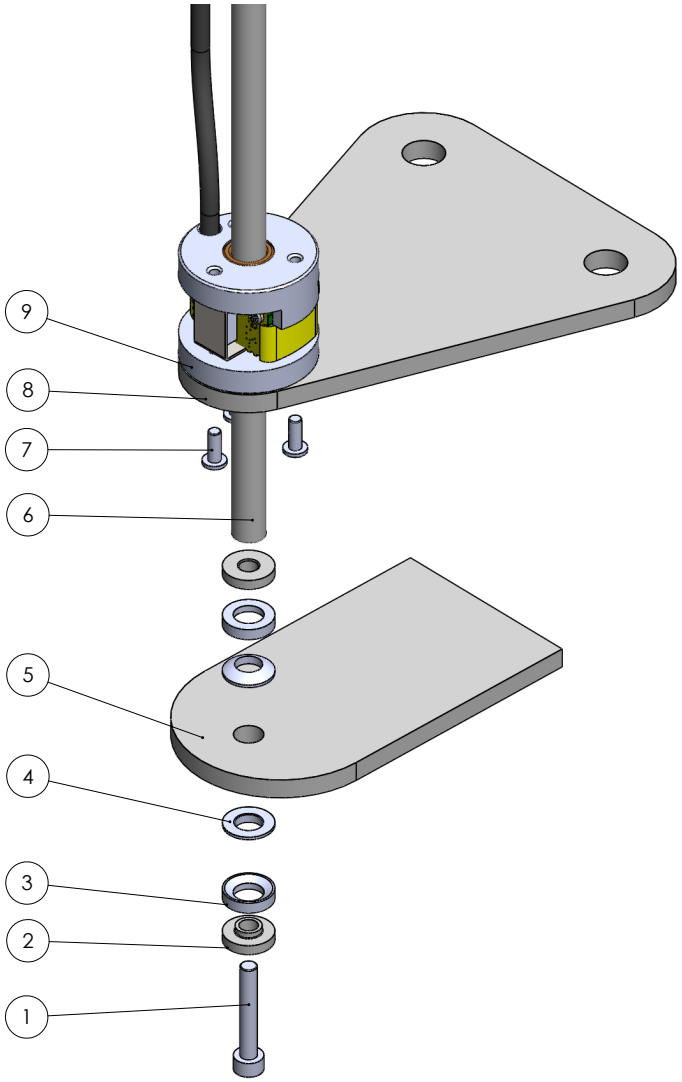
Recommended literature:

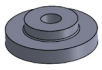
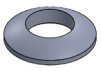
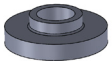
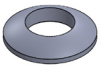
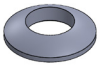
- Painless guide to CRC error detection algorithm; Ross N. Williams.
- Cyclic Redundancy Code (CRC) Polynomial Selection For Embedded Networks; P. Koopman, T. Chakravarty

Appendix 3 - Installation kit for LinACE

Installation kit should be applied if mounting surfaces parallelism can not be ensured.

Exploded view:



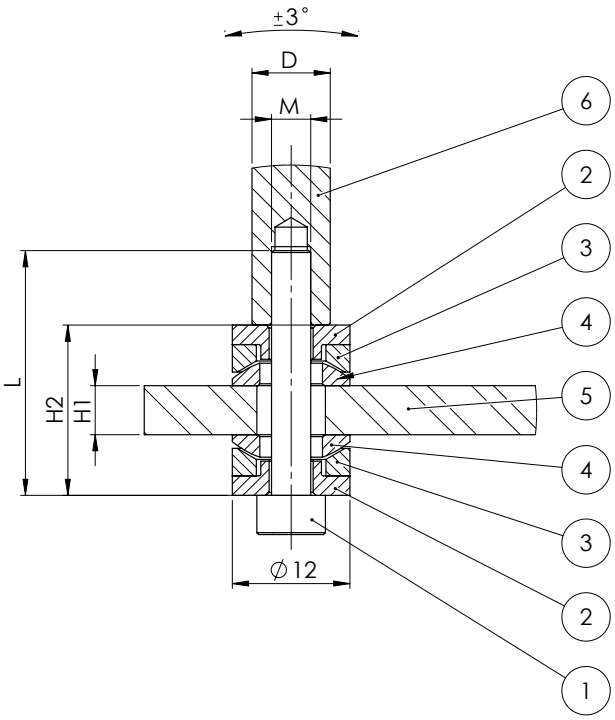
Shaft size	No. 2	No. 3	No. 4	Mounting kit No.
D4 *	2× 	2× 	2× 	CAACC002
D8	2× 	2× 	2× 	CAACC001
D12	0	2× 	2× 	CAACC003

* End Tip A required.

NOTE: Fasteners (No. 1 and No. 7) are not included in mounting kit.

Installation instructions:

1. Attach LinACE readhead (No. 9) onto the beam (No. 8) using 3 fasteners M3 (No. 7) with torque 1 Nm.
2. Insert LinACE shaft (No. 6) through LinACE readhead (No. 9).
3. On the lower beam (No. 5) assemble the joint according to picture.



D	H2	M	L	T
[mm]	[mm]	[mm]	[mm]	[Nm]
4	H1 +12.4	M2.5	H1 +16	0.5
8	H1 +12.4	M4	H1 +17	2
12	DH1 +8.4	M6	H1 +16	6

4. Gently attach the LinACE shaft (No. 6) to the joint with fastener (No. 1) so that the joint assembly can be easily moved by hand.
5. Move the upper part (LinACE readhead on beam) as close as possible to the joint.
6. Tighten fastener (No. 1) with specified torque.

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