Data sheet
L-9517-9878-02-A

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TONiC™ Functional Safety incremental encoder system

Renishaw's TONiC Functional Safety (FS) is an open optical encoder system certified to the following international safety standards:

- **ISO 13849 Category 3 PLd**
- **IEC 61508 SIL2**
- **IEC 61800-5-2 SIL2**

TONiC FS offers all the benefits of the established TONiC linear and angle encoder systems giving exceptional metrology performance and ultimate reliability.

TONiC readheads incorporate Renishaw's market-proven third-generation filtering optics; this is further enhanced by dynamic signal processing including Auto Gain Control (AGC) and Auto Offset Control (AOC). The result is low sub-divisional error (SDE) and even lower noise (jitter) giving smoother velocity control for improved scanning performance and increased positional stability.

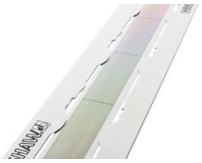
TONiC FS is also available for use in UHV environments. It has a clean residual gas analysis (RGA), low out-gassing and a bake-out temperature of 120 °C.

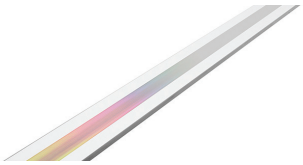
- **Functional Safety certified**
- **Ultra-high vacuum compatible variant**
- **Detachable analogue (Ti) or dual output (DOP) interface**
- **Compatible with a wide range of linear and rotary scales with customer-selectable *IN-TRAC* ™ auto-phase optical reference mark (datum)**
- **Optimised filtering optics for even lower noise**
- **Dynamic signal processing provides ultra-low SDE of typically ±30 nm**
- **Auto Gain Control ensures consistent signal strength for long-term reliability**
- **Integral set-up LED for ease of installation**
- **Maximum speed to 10 m/s (3.24 m/s at 0.1 µm resolution)**

www.renishaw.com/tonicdownloads

#renishaw

Compatible linear scales

	RTLC20-S	RTLC20 (with *FASTRACK*™ carrier)
	Self-adhesive mounted stainless steel tape scale	**Stainless steel tape scale and self-adhesive mounted carrier**
		
Form (height × width)	0.4 mm × 8 mm including adhesive	RTLC20 scale: 0.2 mm × 8 mm *FASTRACK* carrier: 0.4 mm × 18 mm including adhesive
Accuracy (includes slope and linearity)	±5 µm/m	±5 µm/m
Linearity (Figures achievable with two-point error correction)	±2.5 µm/m	±2.5 µm/m
Maximum length	10 m [1] (> 10 m available on request)	RTLC20 lengths up to 10 m (> 10 m available on request) *FASTRACK* carrier lengths up to 25 m
Coefficient of thermal expansion (at 20 °C)	10.1 ±0.2 µm/m/°C	10.1 ±0.2 µm/m/°C

	RELx20	RSLx20
	Self-adhesive mounted low-expansion ZeroMet™ spar scale [2]	**Self-adhesive mounted stainless steel spar scale [2]**
		
Form (height × width)	1.5 mm × 14.9 mm	1.6 mm × 14.9 mm
Accuracy (at 20 °C)	Up to 1 m : ±1 µm 1 m to 1.5 m : ±1 µm/m	Up to 1 m : ±1.5 µm 1 m to 2 m : ±2.25 µm 2 m to 3 m: ±3 µm 3 m to 5 m : ±4 µm
Maximum length [2]	1.5 m	5 m
Coefficient of thermal expansion (at 20 °C)	0.75 ±0.35 µm/m/°C	10.1 ±0.2 µm/m/°C

1 For RTLC20-S axis lengths > 2 m, the *FASTRACK* carrier with RTLC20 is recommended.

2 Clip and clamp mounting is not Functional Safety approved. RELx20 and RSLx20 spar scales **must** be mounted with the supplied self-adhesive backing tape to be Functional Safety approved.

For more information about the linear scales refer to the relevant incremental scale data sheet which can be downloaded from **www.renishaw.com/tonicdownloads**.

Compatible rotary scale

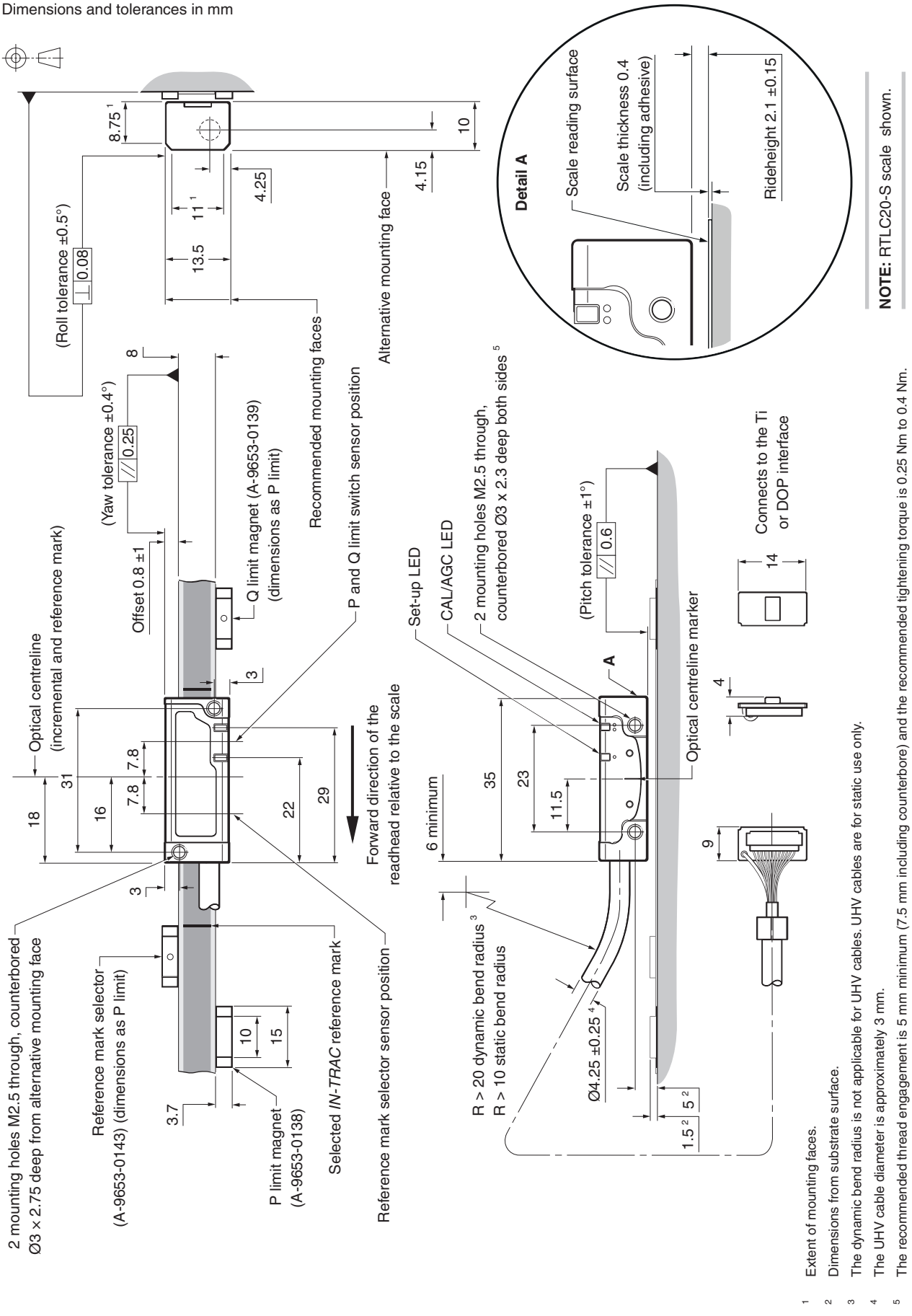
	RESM20 303/304 stainless steel ring
	
Accuracy (at 20 °C)	±1.9 arc second (Typical installed accuracy for a 550 mm diameter ring) [1]
Ring diameters	52 mm to 550 mm
Coefficient of thermal expansion (at 20 °C)	15.5 ±0.5 µm/m/°C

[1] 'Typical' installations are a result of graduation and installation errors combining and, to some magnitude, cancelling.

For more information about the RESM20 ring, refer to *RESM rotary scale* data sheet (Renishaw part no. L-9517-9154) which can be downloaded from www.renishaw.com/tonicdownloads.

TONiC FS T3xxx readhead installation drawing

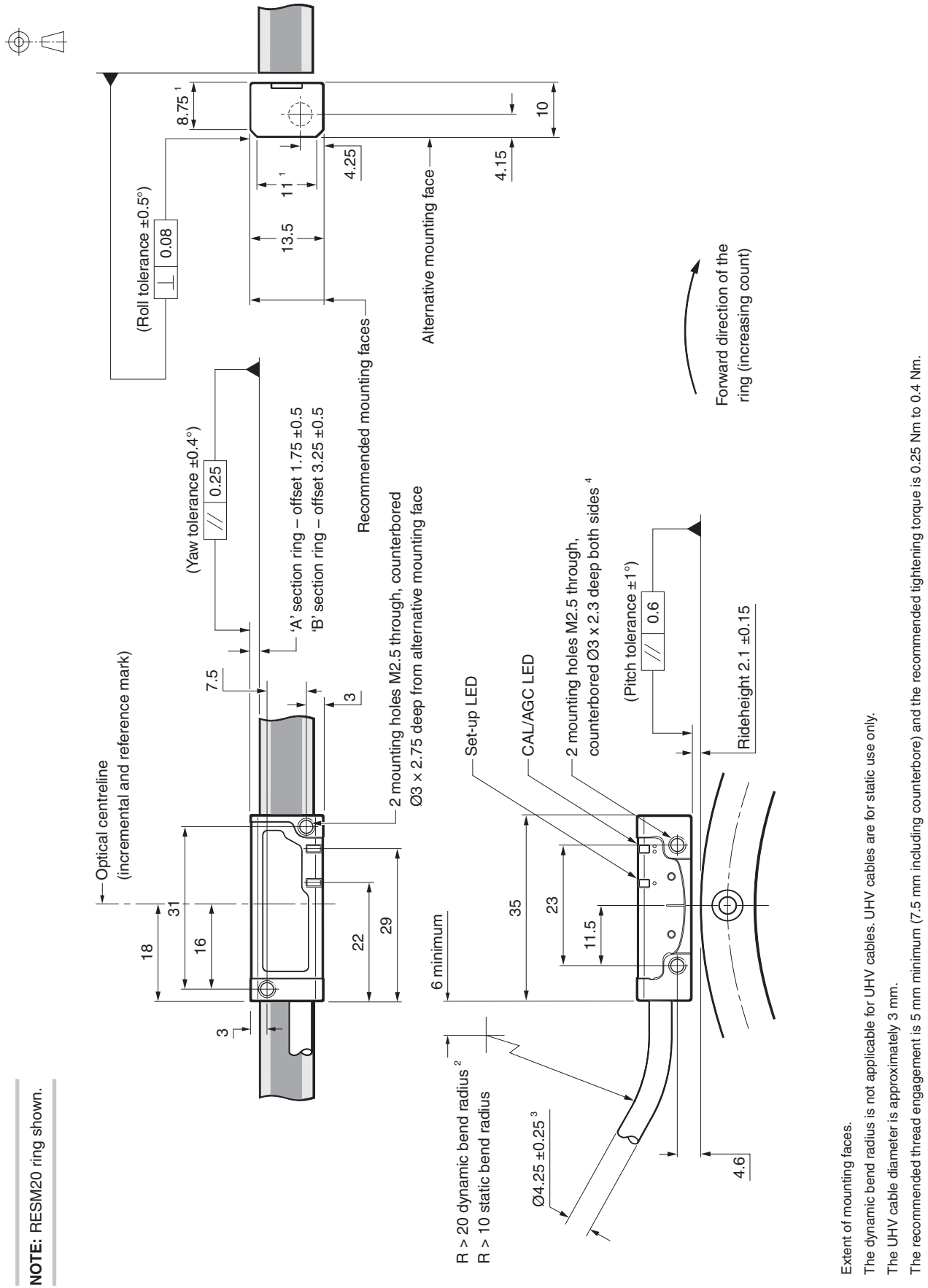
Dimensions and tolerances in mm



1 Extent of mounting faces.
2 Dimensions from substrate surface.
3 The dynamic bend radius is not applicable for UHV cables. UHV cables are for static use only.
4 The UHV cable diameter is approximately 3 mm.
5 The recommended thread engagement is 5 mm minimum (7.5 mm including counterbore) and the recommended tightening torque is 0.25 Nm to 0.4 Nm.

TONiC FS T4xxx readhead installation drawing

Dimensions and tolerances in mm



NOTE: RESM20 ring shown.

1 Extent of mounting faces.

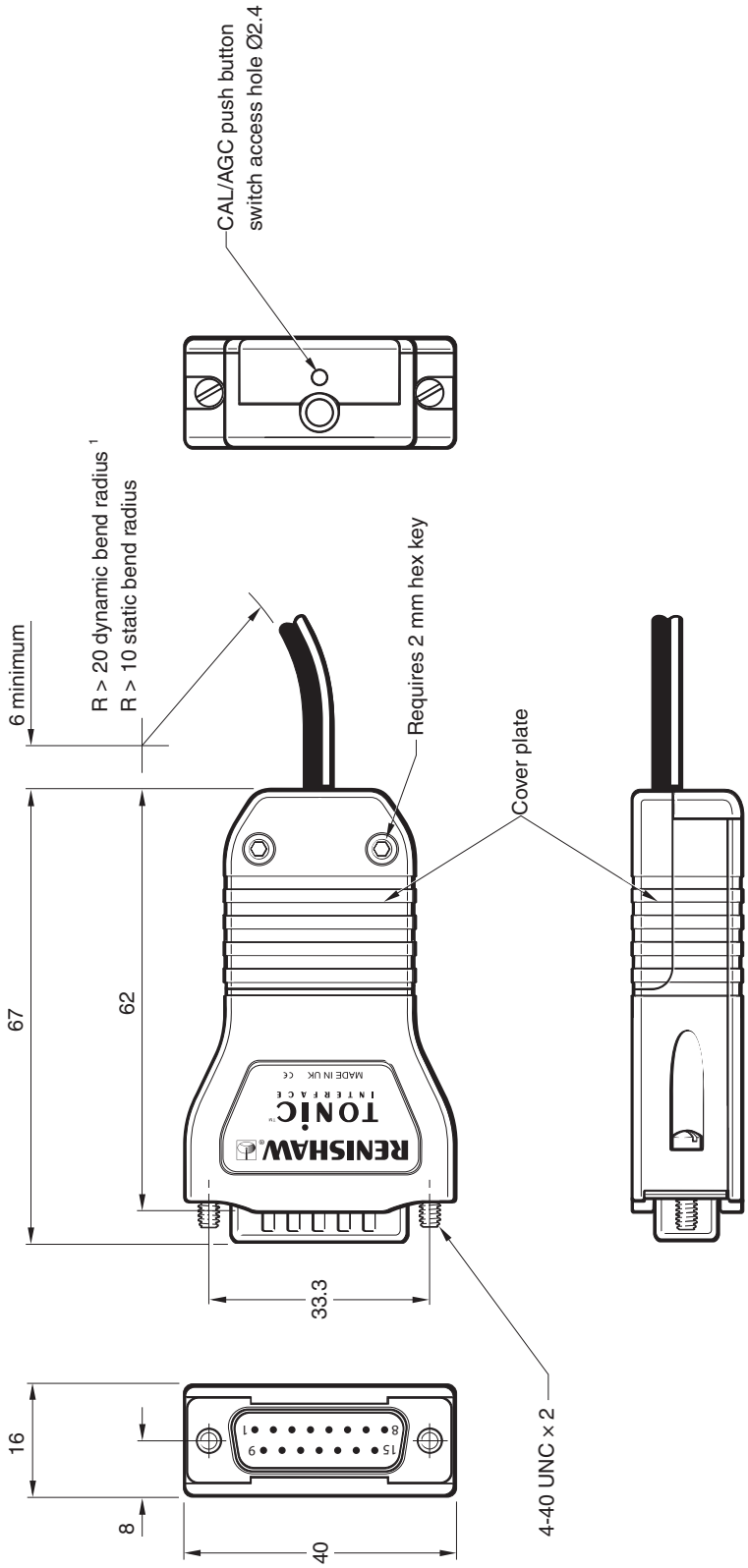
2 The dynamic bend radius is not applicable for UHV cables. UHV cables are for static use only.

3 The UHV cable diameter is approximately 3 mm.

4 The recommended thread engagement is 5 mm minimum (7.5 mm including counterbore) and the recommended tightening torque is 0.25 Nm to 0.4 Nm.

Ti interface installation drawing

Dimensions and tolerances in mm

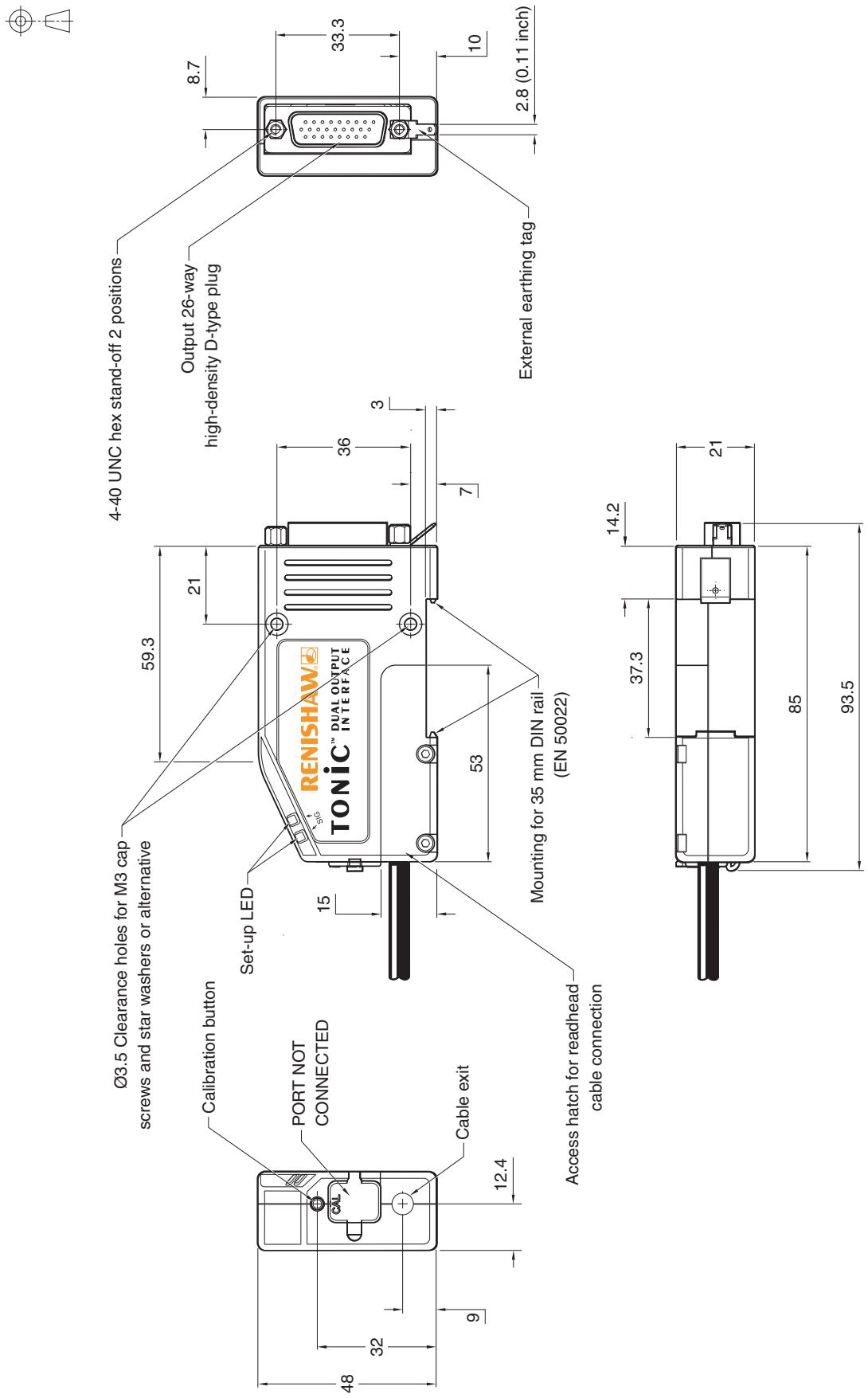


NOTE: The Ti interface is not suitable for mounting in a UHV environment.

[1] The dynamic bend radius is not applicable for UHV cables. UHV cables are for static use only.

DOP interface installation drawing

Dimensions and tolerances in mm



NOTE: The DOP interface is not suitable for mounting in a UHV environment.

General specifications

Power supply	5 V ±10%	Readhead only: < 100 mA T3xxx/T4xxx with Ti0000 < 100 mA T3xxx/T4xxx with DOP < 275 mA Current consumption figures refer to unterminated systems. For digital outputs, a further 25 mA per channel pair (eg A+, A–) will be drawn when terminated with 120 R. For analogue outputs, a further 20 mA in total will be drawn when terminated with 120 R. Power from a 5 Vdc supply complying with the requirements for PELV of standard IEC 60950.
	Ripple	200 mVpp maximum @ frequency up to 500 kHz maximum
Temperature	Storage	–20 °C to 70 °C
	Operating	0 °C to +70 °C
	Bakeout (UHV readhead)	+120 °C
Humidity	System	95% relative humidity (non-condensing) to IEC 60068-2-78
Sealing	Standard readhead	IP40
	UHV readhead	IP20
	Ti interface	IP20
	DOP interface	IP30
Acceleration	Operating (readhead)	500 m/s^2, 3 axes
Shock	Operating (system)	500 m/s^2, 11 ms, ½ sine, 3 axes
Vibration	Operating (system)	Sinusoidal 100 m/s^2, 55 Hz to 2000 Hz, 3 axes
Shock	Non-operating	1000 m/s^2, 6 ms, ½ sine, 3 axes
Mass	Readhead	10 g
	Ti interface	100 g
	DOP interface	205 g
	Standard cable	26 g/m
	UHV cable	14 g/m
EMC compliance		IEC 61800-5-2 Annex E
Readhead cable	Standard	Double-shielded, outside diameter 4.25 ±0.25 mm Flex life > 20 × 10^6 cycles at 20 mm bend radius UL recognised component
	UHV	Tin coated braided single screen, FEP core insulation
Maximum cable length	Readhead to interface	10 m
	Interface to controller	25 m (with 40 MHz to 50 MHz clocked output interface) 50 m (with < 40 MHz clocked output interface) 50 m (with analogue interface)
Typical sub-divisional error (SDE)		±30 nm
Functional Safety certification [1]		ISO 13849 Category 3 PLd IEC 61508 SIL2 IEC 61800-5-2 SIL2

[1] The system must be installed and operated in accordance with the instructions defined in the relevant TONiC FS installation guide. Failure to follow the correct use instructions and failure to heed the limitations may result in SIL2 and/or PLd not being achieved and will invalidate the Functional Safety certification.

The TONiC FS installation guides can be downloaded from our website at **www.renishaw.com/fsencoders**.

Safety sub-functions

The TONiC Functional Safety (FS) encoder system provides safe position data that supports the following safety sub-functions defined by IEC 61800-5-2:2016:

- Safe stop 1 (SS1) and Safe stop 2 (SS2)
- Safe operating stop (SOS)
- Safe limited acceleration (SLA) ≤ 500 m/s^2
- Safe acceleration range (SAR) ≤ 500 m/s^2
- Safe limited speed (SLS) ≤ 10 m/s
- Safe speed range (SSR) ≤ 10 m/s
- Safely limited position (SLP)
- Safely limited increment (SLI)
- Safe direction (SDI)
- Safe speed monitor (SSM) ≤ 10 m/s

The system must be installed and operated in accordance with the instructions defined by the installation guide. Failure to follow the correct use instructions and failure to heed the limitations may result in PLd and / or SIL2 not being achieved and will invalidate the functional safety certification.

Functional Safety data declaration

Product identification	TONiC™ Functional Safety (FS) encoder system

IEC 61508 safety data

	TONiC FS readhead	TONiC FS readhead and Ti interface	TONiC FS readhead and DOP interface
Safety Integrity Level	2		
Random Hardware Failures (per hour)	$\lambda_S = 1.77 \times 10^{-7}$ $\lambda_D = 8.41 \times 10^{-8}$ $\lambda_{DD} = 7.57 \times 10^{-8}$ $\lambda_{DU} = 8.41 \times 10^{-9}$	$\lambda_S = 1.77 \times 10^{-7}$ $\lambda_D = 1.38 \times 10^{-7}$ $\lambda_{DD} = 1.25 \times 10^{-7}$ $\lambda_{DU} = 1.38 \times 10^{-8}$	$\lambda_S = 1.77 \times 10^{-7}$ $\lambda_D = 4.14 \times 10^{-7}$ $\lambda_{DD} = 3.73 \times 10^{-7}$ $\lambda_{DU} = 4.14 \times 10^{-7}$
PFD_{avg}	Not available as this system does not support low demand mode		
PFH (per hour)	$\lambda_{DU} = 8.41 \times 10^{-9}$	$\lambda_{DU} = 1.38 \times 10^{-8}$	$\lambda_{DU} = 4.14 \times 10^{-7}$
Architectural Constraints	Type B HFT = 0 SFF = 96%		
Hardware safety integrity compliance	Route 1H		
Systematic safety integrity compliance	Route 1S		
Systematic capability	SC2		
Demand mode	Continuous		

ISO 13849 safety data

	TONiC FS readhead	TONiC FS readhead and Ti interface	TONiC FS readhead and DOP interface
$MTTF_D$ (years)	1300	800	270
Diagnostic coverage	Medium (90%)		
Category	3		
Performance level	d		
Lifetime/Replacement limits	20 years		

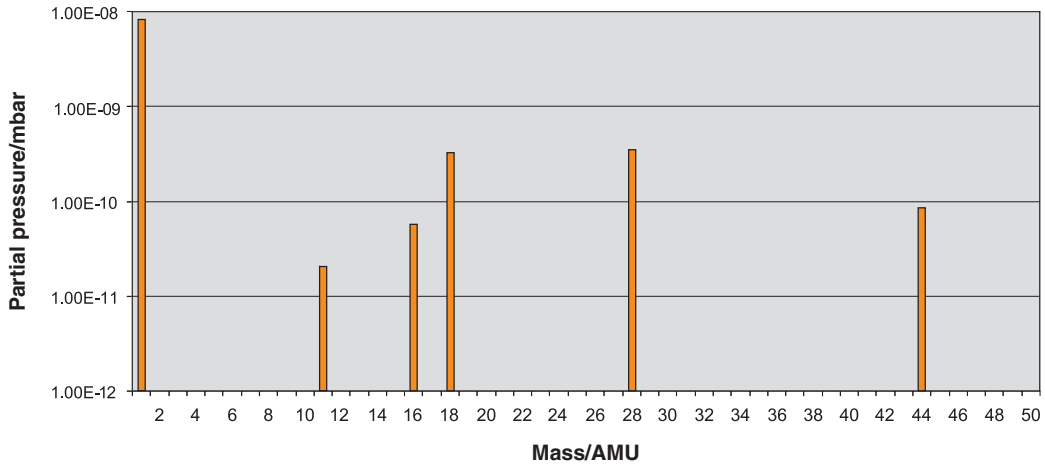
RGA results

Test schedule

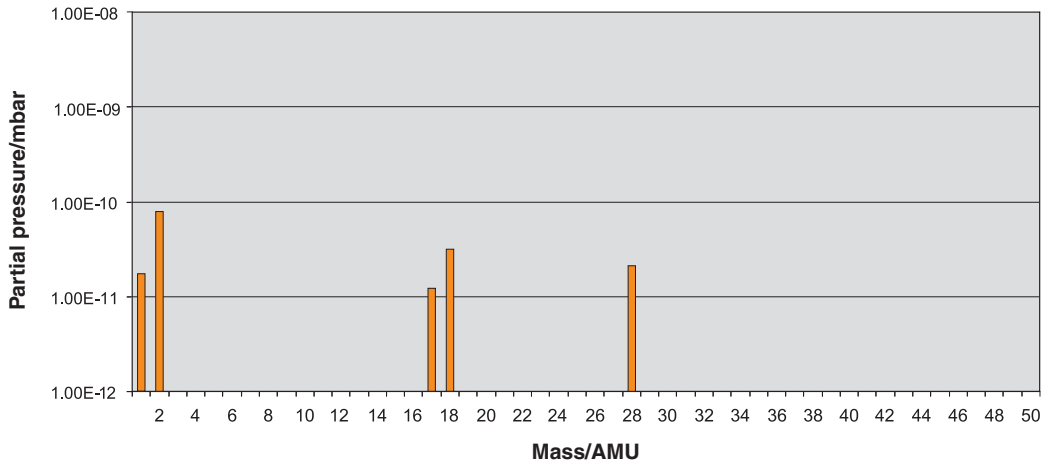
A quadrupole mass spectrometer (AccuQuad 200 RGA), set to 200AMU scan range, was used to collect RGA (residual gas analysis) data and to measure total chamber pressure. After initial conditioning of the system, a background spectrum was recorded together with the total pressure in the test chamber.

The component was placed in the vacuum chamber (0.015 m^3) and the system was then pumped using an KJL Lion 802 (800/s) diode ion pump and a Divac diaphragm pump at ambient temperature for 24 hours, after which a background scan and the total pressure in the test chamber were recorded again. If the system pressure was better than 5×10^{-9} mbar, the test specimen was baked at 120 °C for 48 hours. The system was then allowed to cool to ambient temperature before a final mass spectrum and the total pressure in the test chamber were recorded. These final RGA scans are shown below.

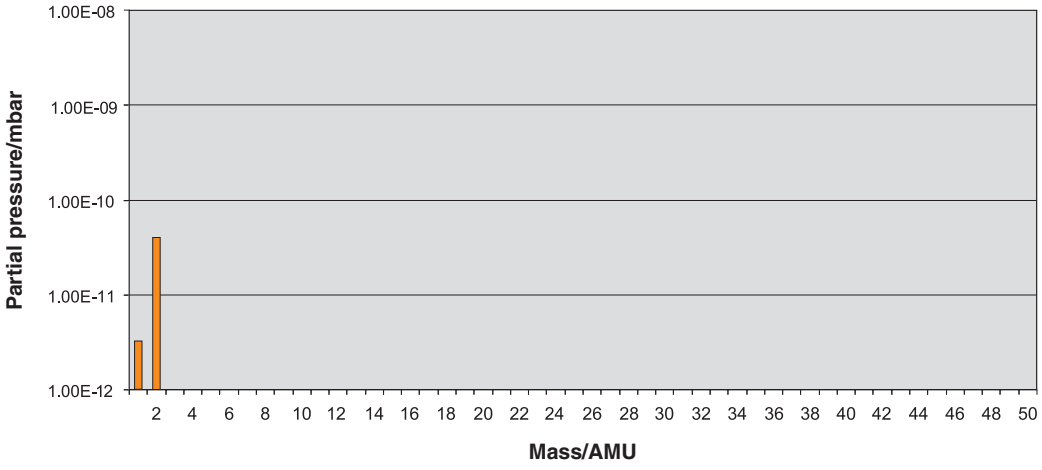
TONiC readhead with 1.0 m cable after bake-out (total pressure = 9.0×10^{-10} mbar)



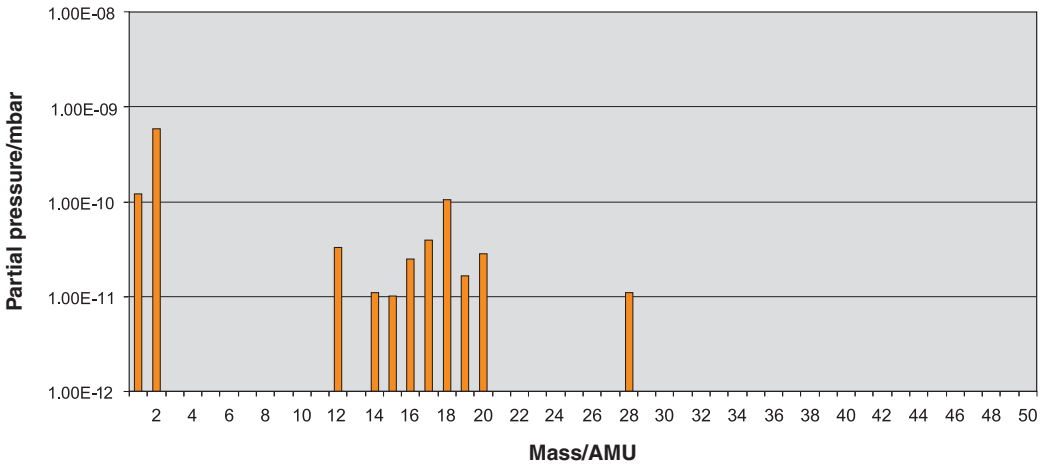
RTLC20-S self-adhesive stainless steel linear tape scale after bake-out (total pressure = 2.8×10^{-10} mbar)



RELx self-adhesive mounted linear spar scale after bake-out (total pressure = 3.0 × 10^{-10} mbar)



RESM20 ring (Ø115 mm) after bake-out (total pressure = 7.76 × 10^{-10} mbar)



Speed

Digital speeds

Clocked output option (MHz)	Maximum speed (m/s)					
	DOP0004 5 µm	DOP0020 1 µm	DOP0040 0.5 µm	DOP0100 0.2 µm	DOP0200 0.1 µm	DOP0400 50 nm
50	10	10	10	6.48	3.24	1.62
40	10	10	10	5.40	2.70	1.35
25	10	10	8.10	3.24	1.62	0.810
20	10	10	6.75	2.70	1.35	0.675
12	10	9	4.50	1.80	0.900	0.450
10	10	8.10	4.05	1.62	0.810	0.405
08	10	6.48	3.24	1.29	0.648	0.324
06	10	4.50	2.25	0.90	0.450	0.225
04	10	3.37	1.68	0.67	0.338	0.169
01	4.2	0.84	0.42	0.16	0.084	0.042

Clocked output option (MHz)	Maximum speed (m/s)				
	DOP1000 20 nm	DOP2000 10 nm	DOP4000 5 nm	DOP10KD 2 nm	DOP20KD 1 nm
50	0.648	0.324	0.162	0.0654	0.032
40	0.540	0.270	0.135	0.054	0.027
25	0.324	0.162	0.081	0.032	0.016
20	0.270	0.135	0.068	0.027	0.013
12	0.180	0.090	0.045	0.018	0.009
10	0.162	0.081	0.041	0.016	0.0081
08	0.130	0.065	0.032	0.013	0.0065
06	0.090	0.045	0.023	0.009	0.0045
04	0.068	0.034	0.017	0.0068	0.0034
01	0.017	0.008	0.004	0.0017	0.0008

Analogue speeds

Analogue output (Ti0000 and DOP interfaces)

10 m/s (–3dB)

Angular speed

Linear to angular speed conversion.

Angular speed depends on ring diameter. Use the following equation to convert to rev/min:

$$\text{Angular speed (rev/min)} = \frac{V \times 1000 \times 60}{\pi D}$$

Where V = maximum linear speed (m/s) and D = external diameter of RESM20 ring (mm).

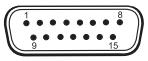
Output signals

NOTE: Only analogue sine and cosine outputs are functionally safe.

TONIC FS readhead output

Function	Output type		Signal		Colour
Power	-		5 V Power		Brown
			0 V Power		White
Incremental signals	Analogue	Cosine	V_1	+	Red
				–	Blue
		Sine	V_2	+	Yellow
				–	Green
Reference mark	Analogue		V_0	+	Violet
				–	Grey
Limits	Open collector		V_p		Pink
			V_q		Black
Set-up	-		V_X		Clear
Calibrate	-		CAL		Orange
Shield	-		Inner shield [1]		Green/Yellow
	-		Outer shield		Outer screen

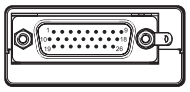
Ti0000 interface output

Function	Output type		Signal		Pin
Power	-		5 V Power		4
			5 V Sense		5
			0 V Power		12
			0 V Sense		13
Incremental signals	Analogue	Cosine	V_1	+	9
				–	1
		Sine	V_2	+	10
				–	2
Reference mark	Analogue		V_0	+	3
				–	11
Limits	Open collector		V_p		7
			V_q		8
Set-up	-		V_X		6
Calibrate	-		CAL		14
Shield	-		Inner shield		Not connected
	-		Outer shield		Case
					 15-way D-type plug

[1] Standard cable: The inner shield is connected to 0 V inside the Ti interface.
UHV cable: There is no inner shield on UHV cables.

DOP interface output

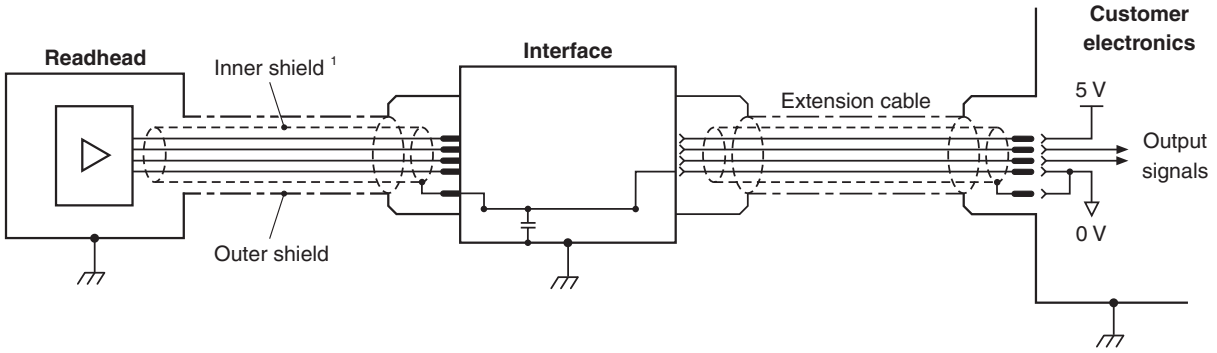
Function	Output type		Signal		Pin
Power	-		5 V Power		26
			5 V Sense		18
			0 V Power		9
			0 V Sense		8
Incremental signals	RS422A digital		A	+	24
				–	6
			B	+	7
				–	16
	Analogue	Cosine	V_1	+	1
				–	19
		Sine	V_2	+	2
				–	11
Reference mark	RS422A digital		Z	+	15
				–	23
	Analogue		V_0	+	12
				–	20
Alarm	RS422A digital		E	+	25
				–	17
Limits	Open collector		P		4
			Q		13
Readhead set-up	-		X		10
Shield	-		Inner shield		Not connected
	-		Outer shield		Case



26-way high-density D-type plug

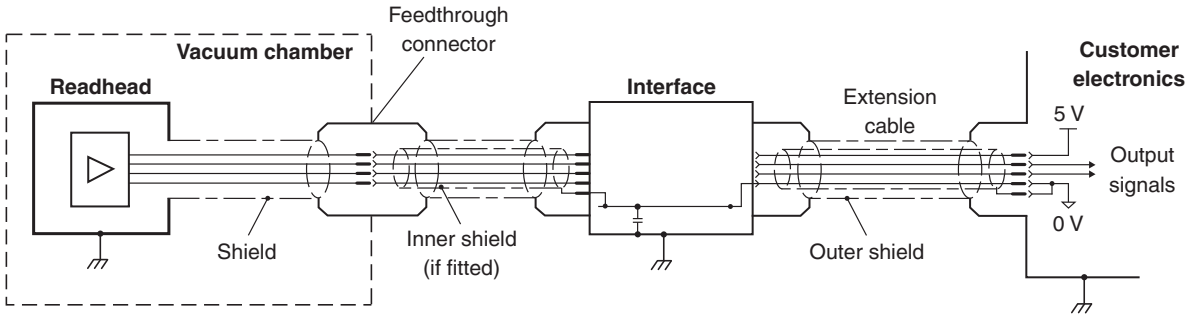
Electrical connections

Grounding and shielding - standard TONiC FS system



IMPORTANT: The outer shield must be connected to the machine earth (Field Ground). The inner shield must be connected to 0 V at receiving electronics only. Care should be taken to ensure that the inner and outer shields are insulated from each other. If the inner and outer shields are connected together, this will cause a short between 0 V and earth, which could cause electrical noise issues.

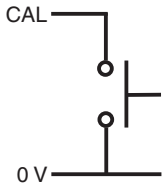
Grounding and shielding - Ultra-high vacuum (UHV) TONiC FS system



IMPORTANT: The outer shield should be connected to the machine earth (Field Ground). The inner shield should be connected to 0 V at receiving electronics only. Care should be taken to ensure that the inner and outer shields are insulated from each other. If the inner and outer shields are connected together, this will cause a short between 0 V and earth, which could cause electrical noise issues.

NOTE: For DOP interfaces the external earthing tag on the interface must be used when mounting the interface on a DIN rail.

Remote CAL operation



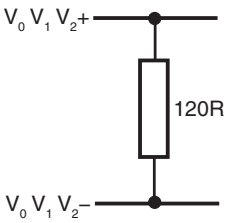
The Ti and DOP interfaces include a push-button switch to enable CAL/AGC features.

Remote operation of the CAL/AGC is possible via pin 14 of Ti0000 interfaces.

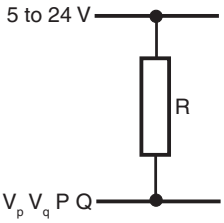
For applications where no interface is used, remote operation of CAL/AGC is essential.

Recommended signal terminations [1]

Analogue outputs

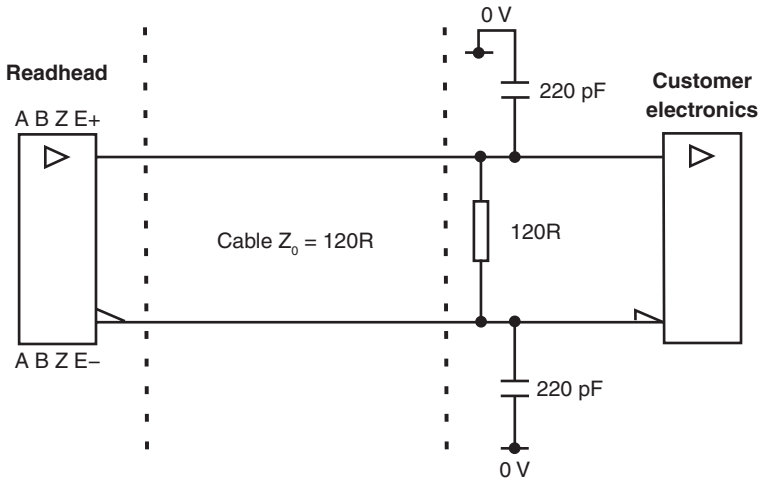


Limit outputs



NOTE: Select the resistor R so that the maximum current does not exceed 20 mA. Alternatively use a suitable relay or opto-isolator.

Digital outputs



Standard RS422A line receiver circuitry.

The capacitors are recommended for improved noise immunity.

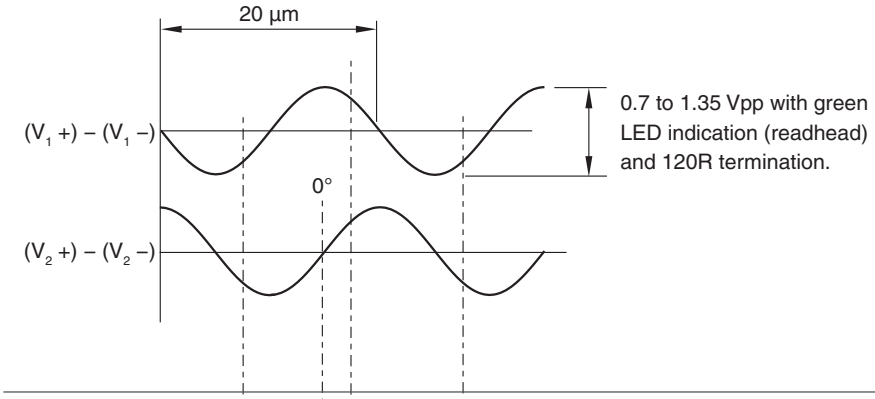
[1] Only the analogue sine and cosine outputs are functionally safe.

Output specifications

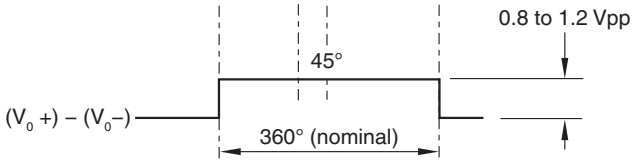
Analogue output signals [1]

Incremental

2 channels V_1 and V_2 differential sinusoids in quadrature (90° phase shifted)



Reference



The reference output is bi-directionally repeatable. [2]

The differential pulse V_0 is centred on 45°.

NOTE: The Ti0000 differential signals are centred on ~1.65 V and the DOP interface differential signals are centred on 2.5 V.

[1] Only the analogue sine and cosine outputs are functionally safe.

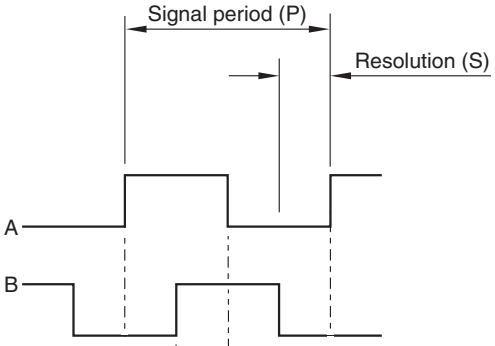
[2] Only the calibrated reference mark is bi-directionally repeatable.

Digital output signals (DOP interface only) [1]

Form – Square wave differential line driver to EIA RS422A (except limits P and Q)

Incremental [2]

2 channels A and B in quadrature (90° phase shifted)



Model	P (µm)	S (µm)
DOP0004	20	5
DOP0020	4	1
DOP0040	2	0.5
DOP0100	0.8	0.2
DOP0200	0.4	0.1
DOP0400	0.2	0.05
DOP1000	0.08	0.02
DOP2000	0.04	0.01
DOP4000	0.02	0.005
DOP10KD	0.008	0.002
DOP20KD	0.004	0.001

Reference [2]

Bi-directionally repeatable pulse Z, duration equal to the resolution

Wide reference [2]

Bi-directionally repeatable pulse Z, duration equal to the signal period

NOTE: Select 'standard' or 'wide' reference at time of ordering, to match the requirements of the controller being used. Wide reference mark not available on DOP0004

[1] Only the analogue sine and cosine outputs are functionally safe.

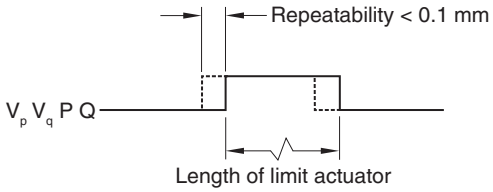
[2] For clarity, the inverse signals are not shown.

Limits

Open collector output, asynchronous pulse

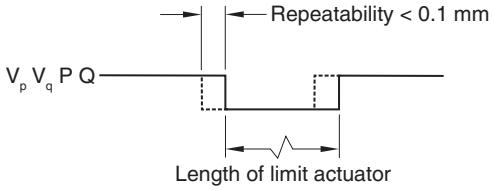
Active high

- Ti0000 interface
- DOP interface (dependent on reference mark option selected; see page 24)



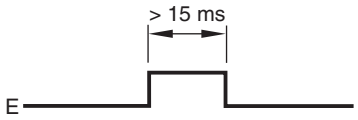
or active low

- TONiC FS readhead
- DOP interface (dependent on reference mark option selected; see page 24)



Alarm (DOP interface only)

Line driven [1] (asynchronous pulse)



The line driven alarm is asserted when:

- The signal amplitude is < 20% or > 135%
- The readhead speed is too high for reliable operation

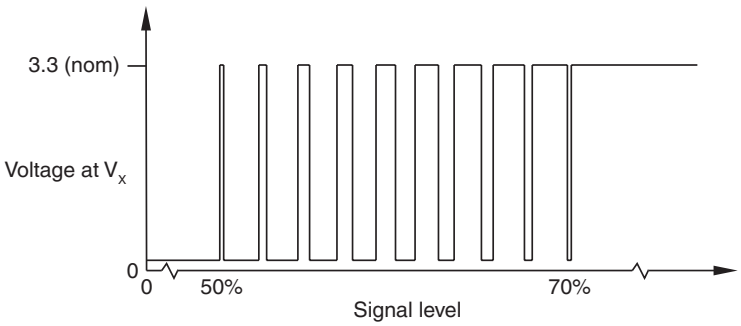
or 3-state alarm

Differentially transmitted signals are forced open circuit for > 15 ms when the alarm conditions are valid.

[1] For clarity, the inverse signals are not shown.

Set-up signal [1]

Ti0000 interface

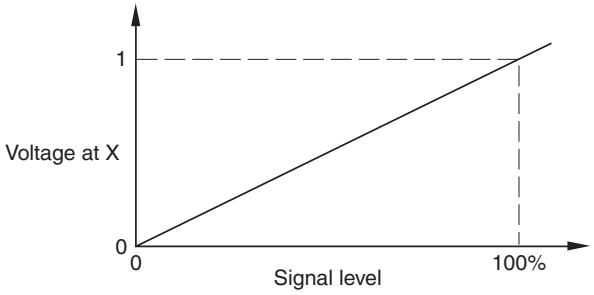


Between 50% and 70% the signal level V_X is a duty cycle.

Time spent at 3.3 V increases with incremental signal level.

At > 70% the signal level V_X is nominal 3.3 V.

DOP interface



The set-up signal voltage is proportional to the incremental signal amplitude.

[1] The set-up signals as shown are not present during the calibration routine.

T3xxx linear readhead part numbers

Compatible with RTLC20-S, RTLC20/*FASTRACK*, RSLx20, or RELx20 scale

T3 0 3 0 - 15 A

Series

T3 = TONiC FS linear readhead

Readhead type

0 = Standard (select 'cable termination' A)

6 = Ultra-high vacuum (select 'cable termination' M)

Scale type compatibility

1 = RSLx20 / RELx20

3 = RTLC20-S / RTLC20

Reference mark

0 = Customer selectable reference mark

1 = All reference marks are output [1]

Cable length

02 = 0.2 metres (standard 'readhead type' only)

05 = 0.5 metres (standard 'readhead type' only)

10 = 1.0 metres

15 = 1.5 metres

20 = 2.0 metres (standard 'readhead type' only)

30 = 3.0 metres

50 = 5.0 metres

60 = 6.0 metres

99 = 10.0 metres

Cable termination

A = Standard mini connector to mate with Ti or DOP interfaces

M = Vacuum cable with mini connector to mate with Ti or DOP interfaces

Valid system configurations can be checked at **www.renishaw.com/epc**.

[1] Only the calibrated reference mark is bi-directionally repeatable.

T4xxx rotary readhead part numbers

Compatible with RESM20 rings

T4 0 0 1 - 15 A

Series

T4 = TONiC FS rotary readhead

Readhead type

0 = Standard (select 'cable termination' A)

6 = Ultra-high vacuum (select 'cable termination' M)

Ring diameter

0 = RESM20 > Ø135 mm

1 = RESM20 Ø60 mm to Ø135 mm

2 = RESM20 < Ø60 mm

Reference mark

1 = All reference marks are output

Cable length

02 = 0.2 metres (standard 'readhead type' only)

05 = 0.5 metres (standard 'readhead type' only)

10 = 1.0 metres

15 = 1.5 metres

20 = 2.0 metres (standard 'readhead type' only)

30 = 3.0 metres

50 = 5.0 metres

60 = 6.0 metres

99 = 10.0 metres

Cable termination

A = Standard mini connector to mate with Ti or DOP interfaces

M = Vacuum cable with mini connector to mate with Ti or DOP interfaces

Valid system configurations can be checked at www.renishaw.com/epc.

Ti interface part number

Compatible with all TONiC FS readheads

Ti0000A00A

DOP interface part numbers

Compatible with all TONiC FS readheads

DOP 0200 A 20 A

Series

DOP = TONiC dual output interface

Interpolation factor / resolution [1]

0004 = 5 µm	0200 = 0.1 µm	4000 = 5 nm
0020 = 1 µm	0400 = 50 nm	10KD = 2 nm
0040 = 0.5 µm	1000 = 20 nm	20KD = 1 nm
0100 = 0.2 µm	2000 = 10 nm	

Alarm format and conditions

A = Line driven E output; all alarms

B = Line driven E output; low signal and high signal alarms only

E = 3 state; all alarms

F = 3 state; low signal and high signal alarms only

Clock frequency

50 = 50 MHz	12 = 12 MHz	04 = 4 MHz
40 = 40 MHz	10 = 10 MHz	01 = 1 MHz
25 = 25 MHz	08 = 8 MHz	
20 = 20 MHz	06 = 6 MHz	

Reference mark

A = P / Q limits - ‘Active high’, standard reference mark

B = P / Q limits - ‘Active low’, standard reference mark

C = P / Q limits - ‘Active high’, wide reference mark [2]

D = P / Q limits - ‘Active low’, wide reference mark [2]

NOTE: For TONiC FS UHV systems, only the readhead is UHV compatible. The Ti and DOP interfaces must be kept outside of the vacuum chamber.

Valid system configurations can be checked at www.renishaw.com/epc.

1 Contact Renishaw for other interpolation factors.

2 A wide reference mark is not available with DOP0004 (5 µm) interfaces.

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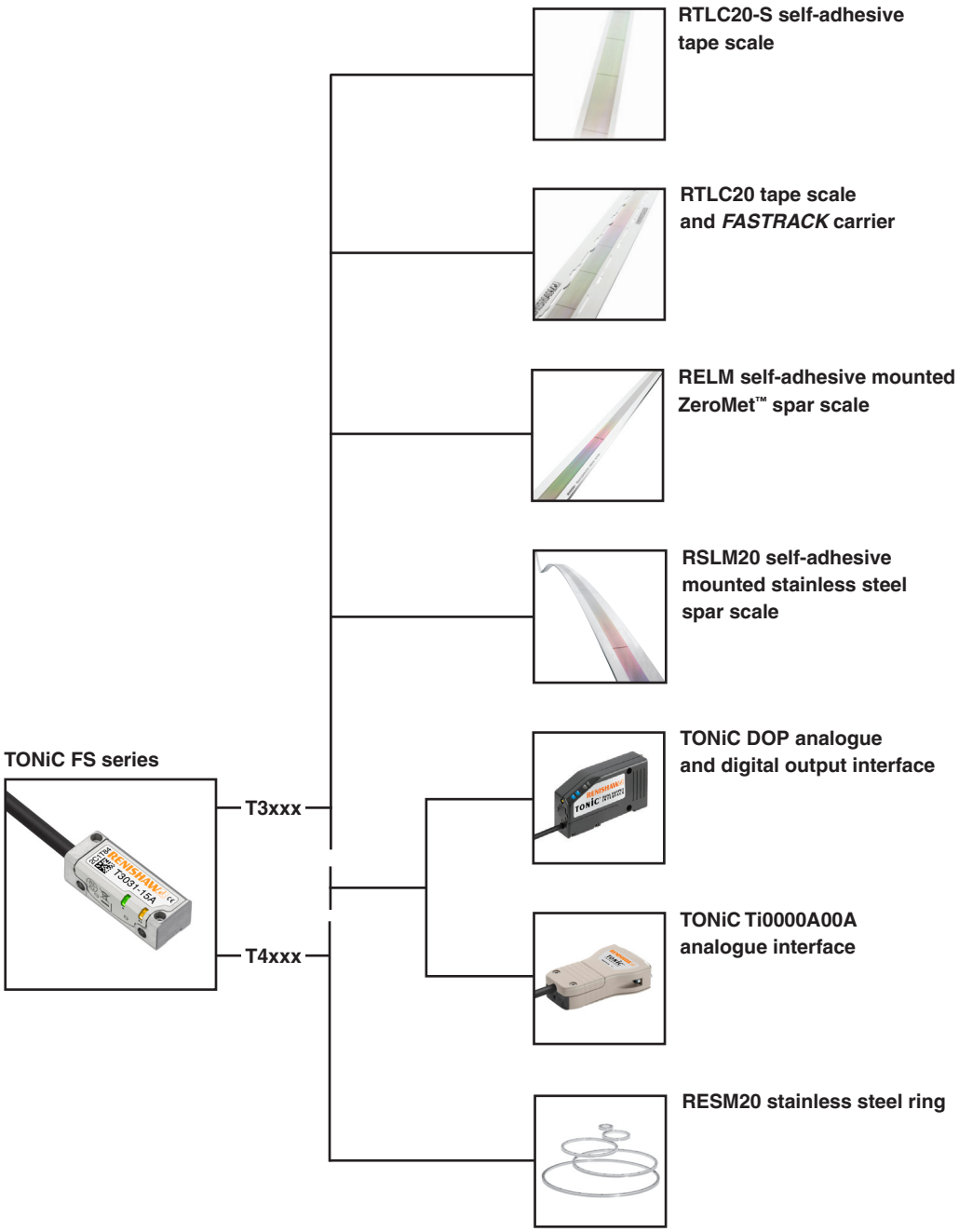
TONiC FS compatible products



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