Welcome to the “Using Power Analyzer Specifications to Determine Measurement Uncertainty” Webinar

THE PRESENTATION WILL BEGIN AT 10:00AM CT / 17:00 CET

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René Bastiaanssen

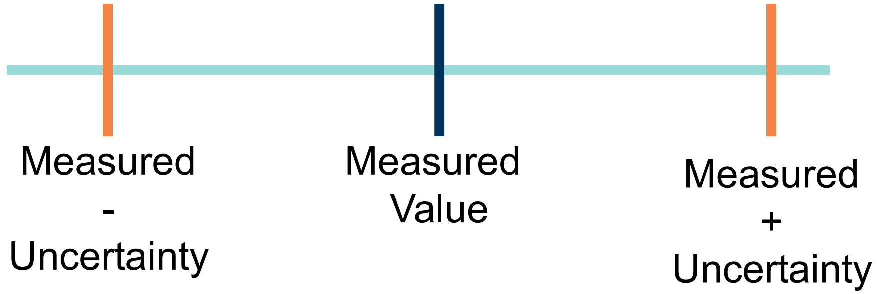
- René has a demonstrated history in Test & Measurement Instrumentation, Sales, and Engineering with an educational background in Electronics and Management.
- René has been with HBM/HBK since 2009, fulfilling various positions ranging from local sales to team lead for Power and Transient (mechanical and electrical) applications in the Northwest Europe region.
- Currently he is a member of the HBK Electrical Power Testing Business Development team and responsible for developing electrical power testing related applications within the EMEA region.

Agenda

1. Why care about Measurement Uncertainty?
   1. Knowing your measurement uncertainty
   2. Having a low measurement uncertainty
   3. Understanding measurement uncertainty
2. MU in Power Analyzers
3. Reading Power Analyzer datasheets
4. Quiz time!
5. HBK GN310B Power Analyzer board calculation example
6. Summary

1. Why care about measurement uncertainty

- Let us split this in 3 challenges, the benefits of:
  1. Knowing your measurement uncertainty
  2. Having a low measurement uncertainty
  3. Understanding measurement uncertainty



- Measurement uncertainty is the range around reading in which the true value will be
  - Involves probability
  - quality of a result
  - makes results comparable

- What does a result without a known measurement uncertainty mean? Some might struggle with point A:
  - Not calculating MU but taking values like "Accuracy class" as absolute truth
  - Considering MU as one single value for all cases

> *GUM, Chapter 3.1.2*
> *(Basic Concepts)*
>
> *"In general, the result of a measurement is only an approximation or estimate of the value of the measurand and thus is complete only when accompanied by a statement of the uncertainty of that estimate."*

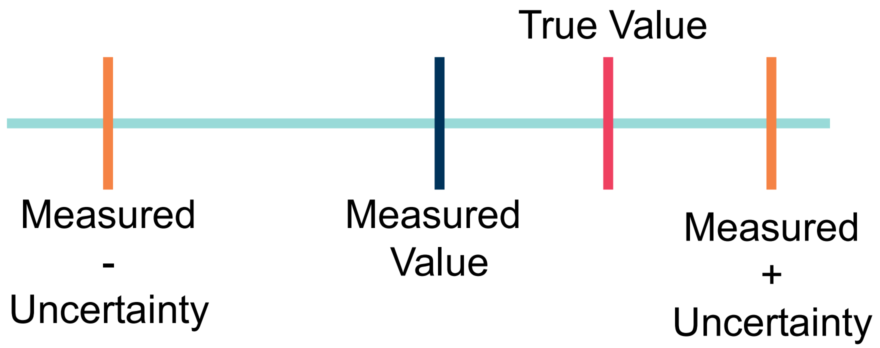
Point A. Knowing your MU

- MU ≠ Accuracy
  - MU is a property of the measured value
  - Accuracy is a property of the instrument

- MU cannot be considered as a single value
  - There is always a static part (Offset)
  - Consider the following thought experiment:
    - We take an actual Power Analyzer “banner spec” e.g. 0.03% measurement error
    - 0.03% of what?
    - Let us say we measure 0.1 W in a range in which we can measure 20 kW
    - Will your MU be 0.00003 W?
    - Therefore, read datasheets carefully, there is likely some more info in there.

Point B. Having a low MU

- Value of having low MU is relevant for all
- Result depends on application
  - Producer of EV's for example
    - Increases efficiency -> increases range
    - Increases driver's confidence in product



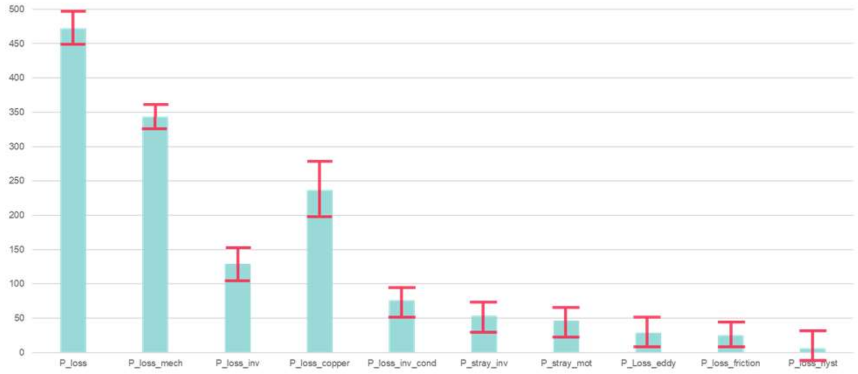
True Value

Measured
-
Uncertainty

Measured
Value

Measured
+
Uncertainty

  - Where producer of components might be more interested in losses
    - Can we trust our loss numbers that are in the single watts?
      - For machines with many KW power levels of output?
    - Design considerations (Heat? Cooling?)
      - Reduce costs
      - Simplify integration
      - Improve overall efficiency



  - Test service providers like to quantify their results

Point C. Understand your MU

- Helps to optimize test benches
  - Sensor/transducer choice
  - Amplifier selection

- Helps to optimize measuring process
  - Reduce offset related errors
  - Setpoint load vs. continuous ramp load?
    - (auto) range

2. MU in Power Analyzers

- Any analog amplifier error source follows the = ax + b curve

- Where:
  - A % of reading error
    - Represents the linear increasing error due to the increase of the input voltage
    - Often referred to as gain error
  - B % of range error
    - Represents the error when measuring 0 V
    - Often referred to as offset error
  - Both have a dependency to the conditions the amplifier is used in

- For measurement uncertainty these errors can be considered independent error sources.
  - Important! → rules for applying MU calculations → Geometric addition
  - Basic MU knowledge needed

3. Reading Power Analyzer datasheets

- Tolerances given as percentages; how should they be applied?
  - Range or reading?
  - What is their uncertainty?
    - It depends how a tolerance is mentioned on the datasheet
      - Pass/Fail?
      - Typical?
      - Min/max?
      - Guaranteed?

- Distribution factors
  - Tells us something on how the tolerance is defined
  - What about a tolerance without further details?

- What does this mean to your uncertainty calculations?

Reading Power Analyzer datasheets

- “Single number” specification? → Look for more detail
- Meaning of “fine print” details in datasheets
  - The “fine print” Beyond the details, can have a significant impact on the accuracy or the use case.
    - Example: Listed is a DC accuracy of 0.03% reading + 0.03% range. Reading all “fine print”, a note for the DC accuracy: Add 0.02% of reading with filters OFF

- Questions to ask yourself when looking on an “accuracy number”:
  - Is this accuracy the power accuracy or just voltage OR current?
  - Is it for DC only or also for AC?
  - If for AC, for what frequency? And what power factor?
  - At what sample rate, with which filter setting and what averaging period is it established?
  - What is the distribution type of this tolerance

- Answer to the questions above are to be fed into your MU calculation

Reading Power Analyzer datasheets: Basics on MU

- All tolerances first need to be “normalized” to the standard deviation
  - Some tolerances are already given as such
    - Represented by a Gauss (normal) shaped distribution, often indicated by descriptions like typical
  - Other values might be given with a higher level of confidence
    - Today we discuss a rectangular distribution, descriptions like Pass/Fail limits, min/max, guaranteed
    - These we need to multiply by the factor 0.58 to allow calculation with and comparison to Gauss or normal shaped distributions.
  - This enables us to calculate individual errors and make them comparable

- Now we want to calculate MU, how to add these values?
  - independent error sources can be combined using geometric addition
  - Error sources which are not independent should be added arithmetically
  - Result is 1σ (sigma) based, level of confidence can be expanded (K factor)

- MU trainings are available!

4. Quiz time!

Question 1

- What is the advantage of a specification given as pass/fail limits?

  - A:
    - it allows for easy comparison to other values
  - B:
    - it has a higher level of confidence therefore allows for a lower MU

Answer A is not correct. having the distribution mentioned enables comparison yes, it is only easy if all in fact have the same distribution

Answer B is correct, as units outside this specification do not leave production it offers a high level of confidence with a rectangular probability distribution

Question 2

- We are comparing specifications from two different suppliers to determine MU performance in our application.
  supplier A specifies an error of reading for the area we are measuring in as 0.04%
  Supplier B specifies an error of reading for the area we are measuring in as 0.055% (pass/fail limit)
  How should we compare the two tolerances?

  - A:
    - just compare them, they are numbers
  - [✓ B:]
    - multiply supplier B specification by factor 0.58
  - C:
    - multiply supplier A specification by factor 0.58

Answer A is not correct, we can only compare specifications with the same probability distribution. if the distribution is different, we need to calculate back everything to the same normal distribution

Answer B is correct, this spec is given as pass/fail and is therefore rectangular distributed. Supplier A does not specify a distribution therefore we need to assume a typical spec, Gauss shape and apply factor 1

Answer C is not correct, Supplier A does not specify a distribution therefore we need to assume a typical spec, gauss shape and apply factor 1

Question 3

- We are measuring DC power. which specification gives a more favorable MU? You may assume all analyzers are in the same measurement range and our measured value is at the full scale of the input.
  - specification A: 0.02% of reading + 0.05% of range given as guaranteed spec
  - specification B: 0.015% of reading + 0.020% of range given as pass/fail spec
  - specification C: 0.03% of reading + 0.03% of range

The smallest resulting MU value is most favorable.
What is the right order for the smallest to the biggest MU?

- A:
  - A smallest, B mid, C biggest
- B:
  - B smallest, C mid, A biggest
- [✓ C:]
  - B smallest, A mid, C biggest

As range and reading are equal, we can take an arbitrary input value let us say 1.
Now we calculate the result MU by geometric addition and apply the correct distribution factor which is 0,58 for spec a and B but 1 for spec C as we have to assume Gauss shape here (typical value)

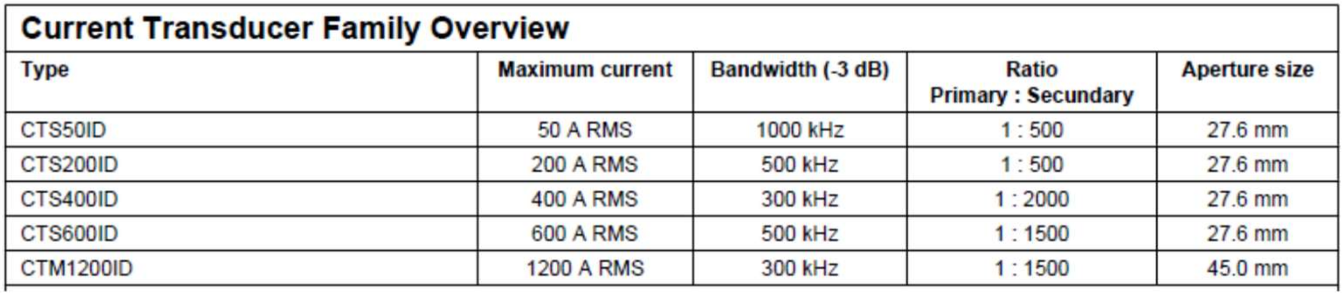
Spec A: SQRT((0.58*0.02)^2+(0.58*0.05)^2)=0.031
Spec B: SQRT((0.58*0.015)^2+(0.58*0.020)^2)=0.015
Spec C: SQRT((0.03)^2+(0.03)^2)=0.042

5. HBK GN310B Power Analyzer board calculation example

- Practical considerations:
  - We focus on the electrical inputs Power Analyzer here, any transducers not included
  - As our measurement involves square wave (PWM) signals, best practice is to measure in wideband
    - Wideband is also the way GN310B specifications are given
    - Specifications with filters enabled would give more favorable results in calibrations, but do not represent real life
    - All specifications in the GN310B datasheet are given as pass/fail limits

Calculation example with GN310B: the case

- What are we measuring?
  - AC Power measurement: 24 kW (600V RMS, 40A RMS) at 500 Hz and Power Factor is 0.8
  - Current is measured with HBM CT type CTS50ID
    - As announced today we focus on the PA calculation, but we need data on the CT to determine the secondary current output and shunt to be used for calculation of the PA MU
  - From the CTS50ID datasheet:



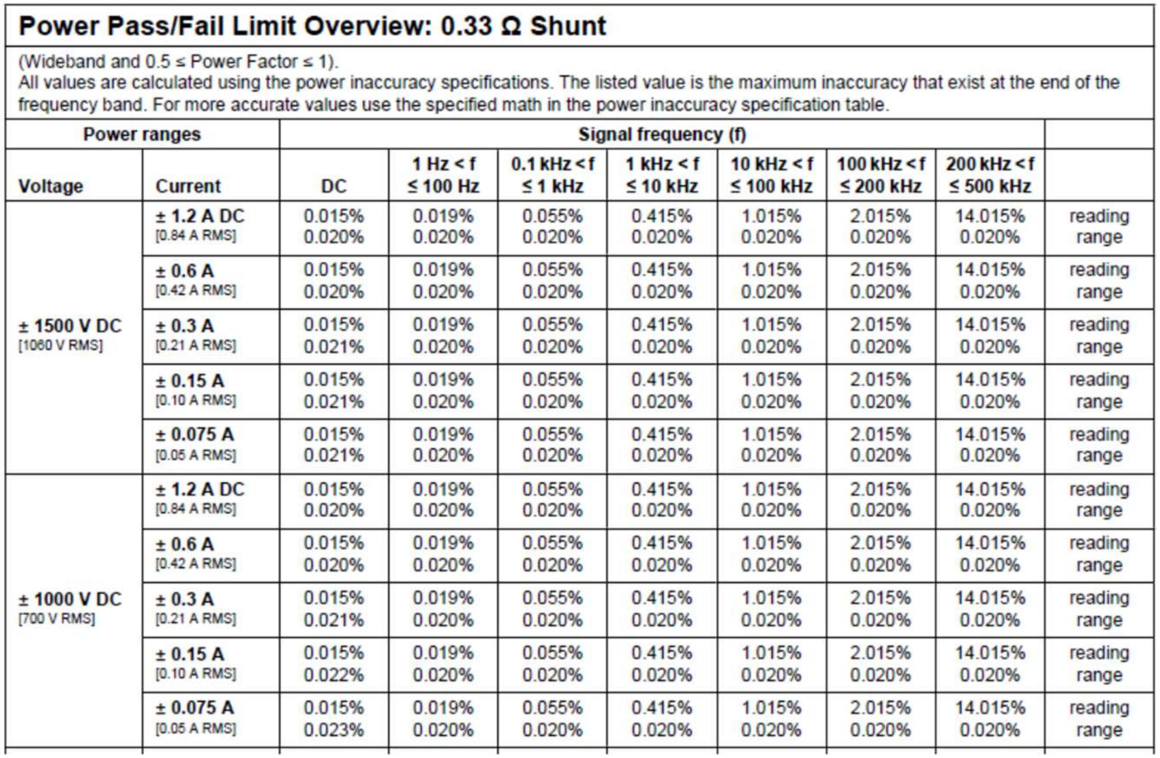
Current Transducer Family Overview

Type	Maximum current	Bandwidth (-3 dB)	Ratio Primary : Secundary	Aperture size
CTS50ID	50 A RMS	1000 kHz	1 : 500	27.6 mm
CTS200ID	200 A RMS	500 kHz	1 : 500	27.6 mm
CTS400ID	400 A RMS	300 kHz	1 : 2000	27.6 mm
CTS600ID	600 A RMS	500 kHz	1 : 1500	27.6 mm
CTM1200ID	1200 A RMS	300 kHz	1 : 1500	45.0 mm

  - So secondary current in our use case is 40/500 = 0.08A RMS

Calculation example with GN310B: reading the datasheet

- The coarse and easy approach
  - Lookup table on page 6 gives us all info needed for the calculation
  - We find the values determined earlier
    - Power Factor
    - Voltage measured directly 600V RMS
    - Current measured with CT secondary current 0.08A RMS
    - Frequency 500 Hz



Power Pass/Fail Limit Overview: 0.33 Ω Shunt

(Wideband and 0.5 ≤ Power Factor ≤ 1).
All values are calculated using the power inaccuracy specifications. The listed value is the maximum inaccuracy that exist at the end of the frequency band. For more accurate values use the specified math in the power inaccuracy specification table.

Power ranges		Signal frequency (f)							
Voltage	**Current**	**DC**	**1 Hz < f ≤ 100 Hz**	**0.1 kHz < f ≤ 1 kHz**	**1 kHz < f ≤ 10 kHz**	**10 kHz < f ≤ 100 kHz**	**100 kHz < f ≤ 200 kHz**	**200 kHz < f ≤ 500 kHz**	
± 1500 V DC [1060 V RMS]	**± 1.2 A DC** [0.84 A RMS]	0.015% 0.020%	0.019% 0.020%	0.055% 0.020%	0.415% 0.020%	1.015% 0.020%	2.015% 0.020%	14.015% 0.020%	reading range
	± 0.6 A [0.42 A RMS]	0.015% 0.020%	0.019% 0.020%	0.055% 0.020%	0.415% 0.020%	1.015% 0.020%	2.015% 0.020%	14.015% 0.020%	reading range
	± 0.3 A [0.21 A RMS]	0.015% 0.021%	0.019% 0.020%	0.055% 0.020%	0.415% 0.020%	1.015% 0.020%	2.015% 0.020%	14.015% 0.020%	reading range
	± 0.15 A [0.10 A RMS]	0.015% 0.021%	0.019% 0.020%	0.055% 0.020%	0.415% 0.020%	1.015% 0.020%	2.015% 0.020%	14.015% 0.020%	reading range
	± 0.075 A [0.05 A RMS]	0.015% 0.021%	0.019% 0.020%	0.055% 0.020%	0.415% 0.020%	1.015% 0.020%	2.015% 0.020%	14.015% 0.020%	reading range
± 1000 V DC [700 V RMS]	**± 1.2 A DC** [0.84 A RMS]	0.015% 0.020%	0.019% 0.020%	0.055% 0.020%	0.415% 0.020%	1.015% 0.020%	2.015% 0.020%	14.015% 0.020%	reading range
	± 0.6 A [0.42 A RMS]	0.015% 0.020%	0.019% 0.020%	0.055% 0.020%	0.415% 0.020%	1.015% 0.020%	2.015% 0.020%	14.015% 0.020%	reading range
	± 0.3 A [0.21 A RMS]	0.015% 0.021%	0.019% 0.020%	0.055% 0.020%	0.415% 0.020%	1.015% 0.020%	2.015% 0.020%	14.015% 0.020%	reading range
	± 0.15 A [0.10 A RMS]	0.015% 0.022%	0.019% 0.020%	0.055% 0.020%	0.415% 0.020%	1.015% 0.020%	2.015% 0.020%	14.015% 0.020%	reading range
	± 0.075 A [0.05 A RMS]	0.015% 0.023%	0.019% 0.020%	0.055% 0.020%	0.415% 0.020%	1.015% 0.020%	2.015% 0.020%	14.015% 0.020%	reading range

Calculation example with GN310B: reading the datasheet

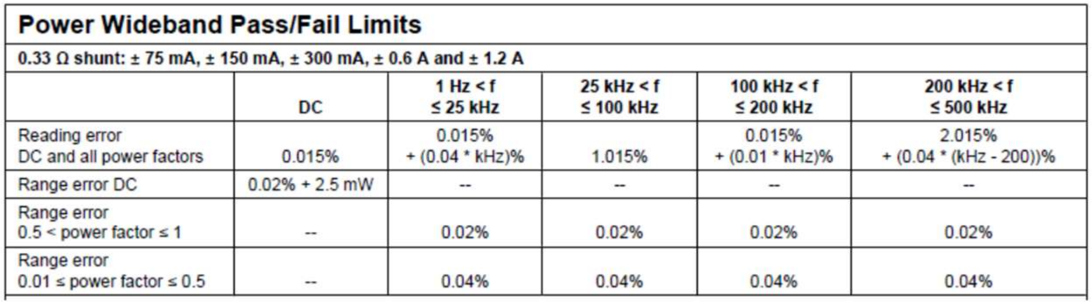
- Calculate MU with values determined:
  - Tolerances found 0.055% of reading and 0.020% of range
  - Measured value (reading) 600V * 40A = 24 kW
  - Measuring range 600V * 50A = 30 kW

  - Reading error: 0.58*(0.055% of 24 kW) = 7.66 W
  - Range error: 0.58*(0.020% of 30 kW) = 3.48 W

  - Total error $\sqrt{}(7.66^2 + 3.48^2)$ = 8.41 W for K=1
  - As % of reading this is **0.035% (for K=1)**

Calculation example with GN310B: reading the datasheet

- The most accurate approach
  - Table on page 5 gives us all info needed for the calculation:
  - We feed the values we found earlier into the equation as indicated



Power Wideband Pass/Fail Limits

0.33 Ω shunt: ± 75 mA, ± 150 mA, ± 300 mA, ± 0.6 A and ± 1.2 A

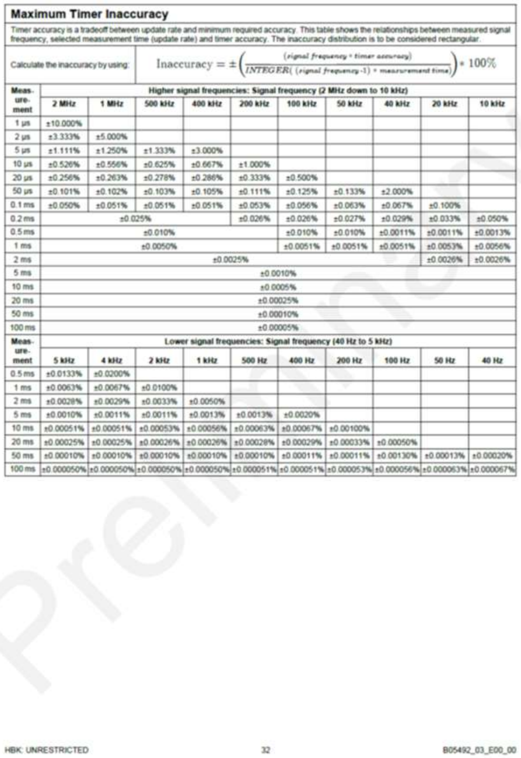
	DC	**1 Hz < f ≤ 25 kHz**	**25 kHz < f ≤ 100 kHz**	**100 kHz < f ≤ 200 kHz**	**200 kHz < f ≤ 500 kHz**
Reading error DC and all power factors	0.015%	0.015% + (0.04 * kHz)%	1.015%	0.015% + (0.01 * kHz)%	2.015% + (0.04 * (kHz - 200))%
Range error DC	0.02% + 2.5 mW	--	--	--	--
Range error 0.5 < power factor ≤ 1	--	0.02%	0.02%	0.02%	0.02%
Range error 0.01 ≤ power factor ≤ 0.5	--	0.04%	0.04%	0.04%	0.04%

- Reading error: 0.58*(0.015 + (0.04*0.5)% of 24 kW) = 4.87 W
- Range error: 0.58*(0.020% of 30 kW) = 3.48 W

- Total error $\sqrt{(4.87^2 + 3.48^2)}$ = 5.99 W for K=1
- As % of reading this is **0.024% (for K=1)**

Calculation example with GN310B: reading the datasheet

- For the motor analyzer users out there, ever considered the inputs used for your torque measurement? And what about speed inputs?



Maximum Timer Inaccuracy

Timer accuracy is a tradeoff between update rate and minimum required accuracy. This table shows the relationships between measured signal frequency, selected measurement time (update rate) and timer accuracy. The inaccuracy distribution is to be considered rectangular.

Calculate the inaccuracy by using:

$$\text{Inaccuracy} = \pm\left(\frac{(\text{signal frequency} * \text{timer accuracy})}{INTEGER(\,(\text{signal frequency}^{-1}) * \text{measurement time})}\right) * 100\%$$

Meas-ure-ment	Higher signal frequencies: Signal frequency (2 MHz down to 10 kHz)									
	2 MHz	1 MHz	500 kHz	400 kHz	200 kHz	100 kHz	50 kHz	40 kHz	20 kHz	10 kHz
1 µs	±10.000%									
2 µs	±3.333%	±5.000%								
5 µs	±1.111%	±1.250%	±1.333%	±3.000%						
10 µs	±0.526%	±0.556%	±0.625%	±0.667%	±1.000%					
20 µs	±0.256%	±0.263%	±0.278%	±0.286%	±0.333%	±0.500%				
50 µs	±0.101%	±0.102%	±0.103%	±0.105%	±0.111%	±0.125%	±0.133%	±2.000%		
0.1 ms	±0.050%	±0.051%	±0.051%	±0.051%	±0.053%	±0.056%	±0.063%	±0.067%	±0.100%	
0.2 ms	±0.025%				±0.026%	±0.026%	±0.027%	±0.029%	±0.033%	±0.050%
0.5 ms	±0.010%					±0.010%	±0.010%	±0.0011%	±0.0011%	±0.0013%
1 ms	±0.0050%					±0.0051%	±0.0051%	±0.0051%	±0.0053%	±0.0056%
2 ms	±0.0025%								±0.0026%	±0.0026%
5 ms	±0.0010%									
10 ms	±0.0005%									
20 ms	±0.00025%									
50 ms	±0.00010%									
100 ms	±0.00005%									

Meas-ure-ment	Lower signal frequencies: Signal frequency (40 Hz to 5 kHz)									
	5 kHz	4 kHz	2 kHz	1 kHz	500 Hz	400 Hz	200 Hz	100 Hz	50 Hz	40 Hz
0.5 ms	±0.0133%	±0.0200%								
1 ms	±0.0063%	±0.0067%	±0.0100%							
2 ms	±0.0028%	±0.0029%	±0.0033%	±0.0050%						
5 ms	±0.0010%	±0.0011%	±0.0011%	±0.0013%	±0.0013%	±0.0020%				
10 ms	±0.00051%	±0.00051%	±0.00053%	±0.00056%	±0.00063%	±0.00067%	±0.00100%			
20 ms	±0.00025%	±0.00025%	±0.00026%	±0.00026%	±0.00028%	±0.00029%	±0.00033%	±0.00050%		
50 ms	±0.00010%	±0.00010%	±0.00010%	±0.00010%	±0.00010%	±0.00011%	±0.00011%	±0.00130%	±0.00013%	±0.00020%
100 ms	±0.000050%	±0.000050%	±0.000050%	±0.000050%	±0.000051%	±0.000051%	±0.000053%	±0.000056%	±0.000063%	±0.000067%

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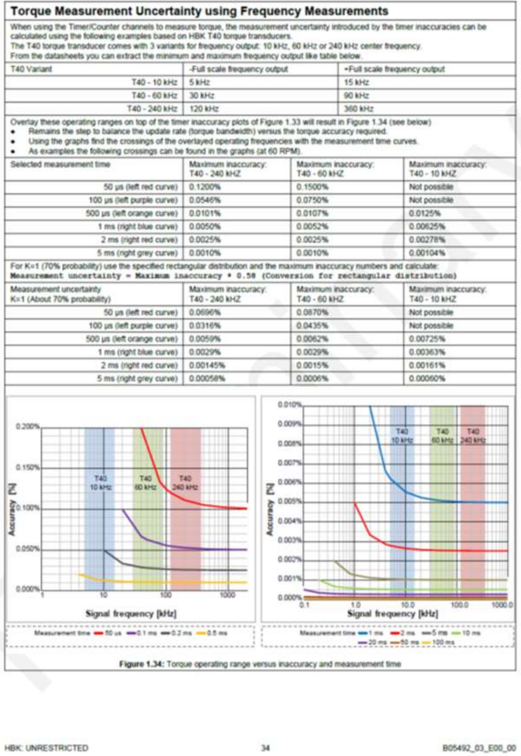

Torque Measurement Uncertainty using Frequency Measurements

When using the Timer/Counter channels to measure torque, the measurement uncertainty introduced by the timer inaccuracies can be calculated using the following examples based on HBK T40 torque transducers.
The T40 torque transducer comes with 3 variants for frequency output: 10 kHz, 60 kHz or 240 kHz center frequency.
From the datasheets you can extract the minimum and maximum frequency output like table below.

T40 Variant	-Full scale frequency output	+Full scale frequency output
T40 - 10 kHz	5 kHz	15 kHz
T40 - 60 kHz	30 kHz	90 kHz
T40 - 240 kHz	120 kHz	360 kHz

Overlay these operating ranges on top of the timer inaccuracy plots of Figure 1.33 will result in Figure 1.34 (see below)

- Remains the step to balance the update rate (torque bandwidth) versus the torque accuracy required.
- Using the graphs find the crossings of the overlayed operating frequencies with the measurement time curves.
- As examples the following crossings can be found in the graphs (at 60 RPM).

Selected measurement time	Maximum inaccuracy: T40 - 240 kHZ	Maximum inaccuracy: T40 - 60 kHZ	Maximum inaccuracy: T40 - 10 kHZ
50 µs (left red curve)	0.1200%	0.1500%	Not possible
100 µs (left purple curve)	0.0546%	0.0750%	Not possible
500 µs (left orange curve)	0.0101%	0.0107%	0.0125%
1 ms (right blue curve)	0.0050%	0.0052%	0.00625%
2 ms (right red curve)	0.0025%	0.0025%	0.00278%
5 ms (right grey curve)	0.0010%	0.0010%	0.00104%

For K=1 (70% probability) use the specified rectangular distribution and the maximum inaccuracy numbers and calculate:
`Measurement uncertainty = Maximum inaccuracy * 0.58 (Conversion for rectangular distribution)`

Measurement uncertainty K=1 (About 70% probability)	Maximum inaccuracy: T40 - 240 kHZ	Maximum inaccuracy: T40 - 60 kHZ	Maximum inaccuracy: T40 - 10 kHZ
50 µs (left red curve)	0.0696%	0.0870%	Not possible
100 µs (left purple curve)	0.0316%	0.0435%	Not possible
500 µs (left orange curve)	0.0059%	0.0062%	0.00725%
1 ms (right blue curve)	0.0029%	0.0029%	0.00363%
2 ms (right red curve)	0.00145%	0.0015%	0.00161%
5 ms (right grey curve)	0.00058%	0.0006%	0.00060%

Figure 1.34: Torque operating range versus inaccuracy and measurement time

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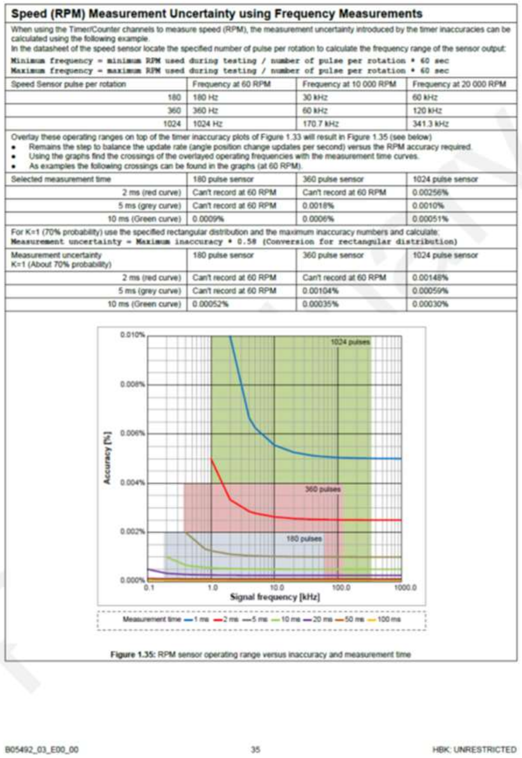

Speed (RPM) Measurement Uncertainty using Frequency Measurements

When using the Timer/Counter channels to measure speed (RPM), the measurement uncertainty introduced by the timer inaccuracies can be calculated using the following example.
In the datasheet of the speed sensor locate the specified number of pulse per rotation to calculate the frequency range of the sensor output:
`Minimum frequency = minimum RPM used during testing / number of pulse per rotation * 60 sec`
`Maximum frequency = maximum RPM used during testing / number of pulse per rotation * 60 sec`

Speed Sensor pulse per rotation	Frequency at 60 RPM	Frequency at 10 000 RPM	Frequency at 20 000 RPM
180	180 Hz	30 kHz	60 kHz
360	360 Hz	60 kHz	120 kHz
1024	1024 Hz	170.7 kHz	341.3 kHz

Overlay these operating ranges on top of the timer inaccuracy plots of Figure 1.33 will result in Figure 1.35 (see below)

- Remains the step to balance the update rate (angle position change updates per second) versus the RPM accuracy required.
- Using the graphs find the crossings of the overlayed operating frequencies with the measurement time curves.
- As examples the following crossings can be found in the graphs (at 60 RPM).

Selected measurement time	180 pulse sensor	360 pulse sensor	1024 pulse sensor
2 ms (red curve)	Can't record at 60 RPM	Can't record at 60 RPM	0.00256%
5 ms (grey curve)	Can't record at 60 RPM	0.0018%	0.0010%
10 ms (Green curve)	0.0009%	0.0006%	0.00051%

For K=1 (70% probability) use the specified rectangular distribution and the maximum inaccuracy numbers and calculate:
`Measurement uncertainty = Maximum inaccuracy * 0.58 (Conversion for rectangular distribution)`

Measurement uncertainty K=1 (About 70% probability)	180 pulse sensor	360 pulse sensor	1024 pulse sensor
2 ms (red curve)	Can't record at 60 RPM	Can't record at 60 RPM	0.00148%
5 ms (grey curve)	Can't record at 60 RPM	0.00104%	0.00059%
10 ms (Green curve)	0.00052%	0.00035%	0.00030%

Figure 1.35: RPM sensor operating range versus inaccuracy and measurement time

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6. Summary

- HBK offers a reduced MU and a better understanding of its contributors
  This is achieved through a number of features, services and tools
  - HBK provides detailed data to calculate MU
    - Not only for the electrical but also for the mechanical part
    - Measurement uncertainty friendly specification (pass/fail spec)
  - Auto range for current and voltage
  - Dual Torque for dynamic and accurate torque simultaneously
  - Outstanding experience on MU, from GUM concept training to consultancy

6. Summary

- What tools does HBK provide for this purpose?
  - High quality datasheet contains all relevant parameters to support complex MU calculation
    - Determining MU is a customer process
    - But we can contribute to resolve this pain point
    - Training (please check https://www.hbm.com/en/0224/seminars-trainings-events-tradeshows/)
    - Consultancy

Questions?

- Please type any questions you have into the WebEx Q&A dialog
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