TEST REPORT · INSTRUMENT VALIDATION · PRELIMINARY

Effect of shaft temperature on the sensitivity of the PaddleMate Pro strain-gauge sensor on a water-conditioned carbon tube, 2–35 °C

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Report number	PM-TR-2026-04
Version	1.0 (preliminary), 15 November 2026
Device under test	PaddleMate Pro (test unit; not the unit of PM-TR-2026-03), single strain gauge, firmware offset compensation only
Software	In-house PaddleMate calibration tool; two-point (unloaded → loaded) slope per loading
Specimen	Unidirectional carbon tube, OD 30 × 1 mm; three-point bending, span 1000 mm, load at mid-span; gauge on the top fibre at mid-span
Temperature	Water circulated through the bore; 2, 18 and 35 °C, measured with a thermometer
Loading	9.880 kg dead weight hung at mid-span; 26 independent loadings in three blocks, 12 November 2026
Measurand	Change of sensitivity (counts per kg) with shaft temperature, relative to 18 °C

ABSTRACT

Background. Paddles are used in cold water and warm air, so a shaft-mounted force sensor must keep its calibration over the temperature range of use. A frequent concern is that a warm carbon shaft becomes softer, bends more and makes the sensor read high.

Methods. A PaddleMate Pro was mounted at mid-span on a 30 × 1 mm unidirectional carbon tube in three-point bending (span 1000 mm). Water from a temperature-controlled circulator flowed through the bore. At shaft temperatures of 2, 18 and 35 °C, a 9.880 kg mass was hung at mid-span 7, 9 and 10 times. Each loading was an independent two-point calibration with re-placement of the mass. Block means were compared with the 18 °C block by Welch's *t*-test.

Results. The sensitivity was 23.10, 23.22 and 22.86 counts/kg at 2, 18 and 35 °C. Relative to 18 °C, the change was −0.54% at 2 °C (95% CI −2.2 to +1.1%, not significant) and −1.55% at 35 °C (95% CI −2.8 to −0.3%). The sensitivity did not increase in either direction. Within each block the scatter of single loadings was 1.1–1.7% CV. This is larger than the stroke-to-stroke scatter (≤ 0.99%) of the PaddleMate Nano measured without re-placing the load, and corresponds to hook-position errors of a few millimetres.

Conclusion. Over 2–35 °C the sensitivity of the Pro changed by at most 1.6%, and it decreased rather than increased with warming. Shaft softening therefore did not make the sensor read high. Most of the scatter, and possibly part of the 35 °C difference, comes from re-placing the mass, not from the sensor. The worst-case change is well inside the ±10% class A tolerance of ISO 20957 for rowing training equipment. A temperature-controlled test without re-hanging is planned to confirm the result.

KEYWORDS instrumented paddle; strain gauge; temperature; carbon fibre; sensitivity; static calibration

1. Introduction

Shaft-mounted strain gauges are the most common way to measure force on instrumented paddles [1, 2]. The calibration slope converts shaft bending to force. If this slope changes with temperature, a paddle calibrated indoors will read differently in cold water or in the sun.

Two physical effects act on the slope. The shaft itself may become stiffer when cold and softer when warm, which would change the strain for a given load. In a unidirectional carbon tube loaded along the

fibres, the bending stiffness is dominated by the fibres, so only a small change is expected well below the glass transition of the resin. The gauge, its adhesive and the measuring electronics also respond to temperature [3]. The PaddleMate Pro firmware compensates the temperature-dependent offset of the gauge but not its sensitivity, so any change of the slope appears directly in the reading.

This report measures how much the sensitivity of the Pro changes between 2 and 35 °C, and in which direction. It also asks how much of the observed scatter comes from the sensor and how much from replacing the calibration mass.

2. Materials and methods

2.1 Device and software

The device under test was a PaddleMate Pro test unit with a single strain gauge. It is a different unit from the one in PM-TR-2026-03 [10]. For each loading, the in-house calibration tool records an unloaded reading, then a loaded reading after the mass is hung, and computes the sensitivity

$$S_i = |R_{loaded,i} - R_{unloaded,i}| / m \quad (1)$$

The gauge sits on the compressed top fibre, so the raw difference is negative; its magnitude is used. The exported readings were offset-compensated by the software and are not analysed as absolute levels. The sensitivity is a difference and does not depend on the offset.

2.2 Specimen and loading

The specimen was a unidirectional carbon tube with an outer diameter of 30 mm and a 1 mm wall, resting on two simple supports 1000 mm apart (Figure 1). The Pro was mounted at mid-span with the gauge on the top fibre. The mass was hung from a hook at mid-span. For a load at distance $a \geq L/2$ from the left support, the moment at mid-span is [11]

$$M = F\,(L - a)\,/\,2, \quad M\,/\,M_0 - 1 = -2|\delta|\,/\,L \quad (2)$$

where $M_0 = F\,L/4$ is the moment for a centred load and $\delta = a - L/2$ is the offset of the hook from the centre. On a 1000 mm span, each millimetre of offset lowers the moment at the gauge by 0.2%. An off-centre hook always lowers the moment, whichever side it is on.

The reference load was 9.880 kg, made up of two masses (4944 g and 4936 g) weighed on a calibrated, verified scale with 1 g resolution and ±2 g maximum error. Its relative standard uncertainty, 0.02%, is negligible here. The mass was entered into the tool as 10.00 kg, so all slopes were recomputed with the actual mass.

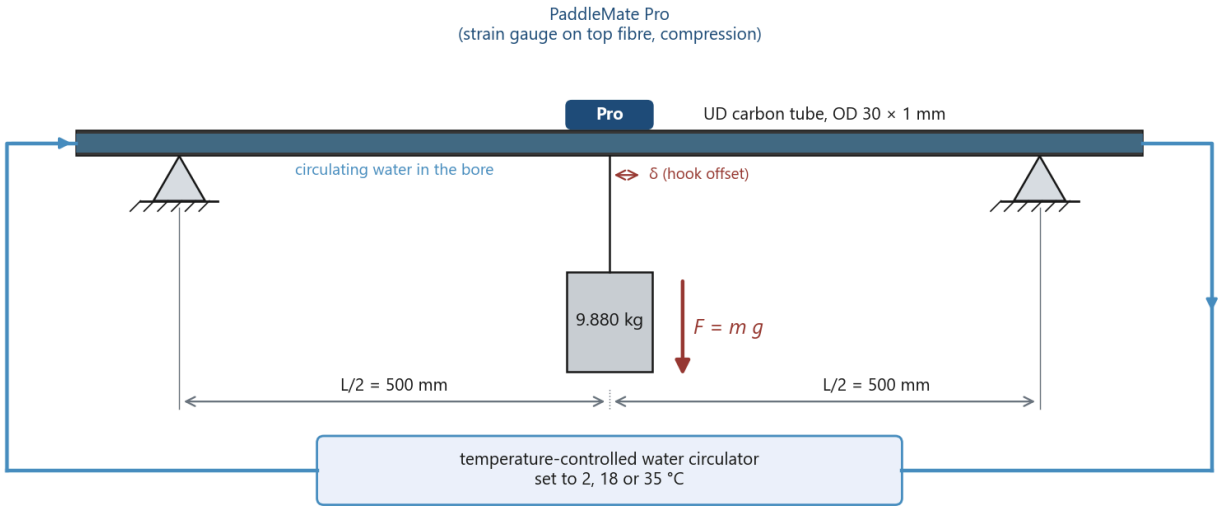


Figure 1. Test set-up, side view (schematic). Unidirectional carbon tube, OD 30 × 1 mm, on two simple supports 1000 mm apart. The PaddleMate Pro sits at mid-span with its gauge on the top (compressed) fibre. A 9.880 kg mass hangs from a hook at mid-span; δ is the hook offset from the centre, equation (2). Water from a temperature-controlled circulator flows through the bore.

2.3 Temperature conditioning

Water from a temperature-controlled circulator flowed through the bore of the tube during the readings. The temperature at each condition was measured with a thermometer. At 12:23 it read 2 °C (photograph); the circulator remained in cooling mode, and the 2 °C block was recorded at 13:20–13:22. The circulator may have been turned up slightly further during the final part of the 35 °C block; this was not recorded. The temperature of the Pro electronics was not measured.

2.4 Procedure

All three blocks were recorded on 12 November 2026 in the order 2 °C, 18 °C, 35 °C (Table 1). For each loading the unloaded reading was taken, the mass was hung, the loaded reading was taken and the mass was removed. Each loading was therefore an independent two-point calibration, including re-placement of the hook. The Pro was switched off between the 2 °C and the 18 °C block; this re-zeroes the offset but does not affect the slope.

Table 1. Measurement blocks, 12 November 2026 (tool time stamps).

Block	Shaft temperature	Temperature basis	Time	Loadings
Cold	2 °C	thermometer (photograph at 12:23), circulator on	13:20–13:22	7
Reference	18 °C	thermometer	16:18–16:21	9
Warm	35 °C	thermometer; possibly higher at the end	17:17–17:24	10

2.5 Evaluation

For each block, the mean, standard deviation, CV and 95% confidence interval of S_i were computed, treating the scatter as a Type A evaluation [5]. The 2 °C and 35 °C blocks were compared with the 18 °C block by Welch's *t*-test, which does not assume equal variances. The differences are reported in per cent of the 18 °C mean with 95% confidence intervals, and as a temperature coefficient in % per kelvin. To show how large the hook-position errors must be to explain the scatter, deviations were also converted to equivalent hook-position changes with equation (2). No loading was excluded.

3. Results

Table 2. Sensitivity per temperature block (counts/kg, 9.880 kg). CI: 95% confidence interval of the mean.

Shaft	*n*	Mean	SD	CV	95% CI	Range	Change vs 18 °C (95% CI)	*t* (df)
2 °C	7	23.10	0.39	1.69%	±0.36	22.40–23.56	−0.54% (−2.17 to +1.09%)	−0.74 (9.6)
18 °C	9	23.22	0.25	1.06%	±0.19	22.71–23.51	–	–
35 °C	10	22.86	0.33	1.44%	±0.24	22.37–23.24	−1.55% (−2.76 to −0.35%)	−2.72 (16.5)

Temperature coefficients relative to 18 °C: +0.034%/K towards 2 °C (not significant); −0.091%/K towards 35 °C.

At 2 °C the mean sensitivity was 0.54% below the 18 °C value. The difference is smaller than the scatter of the block means and is not significant; the confidence interval includes zero (Table 2, Figure 2). At 35 °C the mean was 1.55% lower, which is significant at the 5% level. In neither direction did the sensitivity increase.

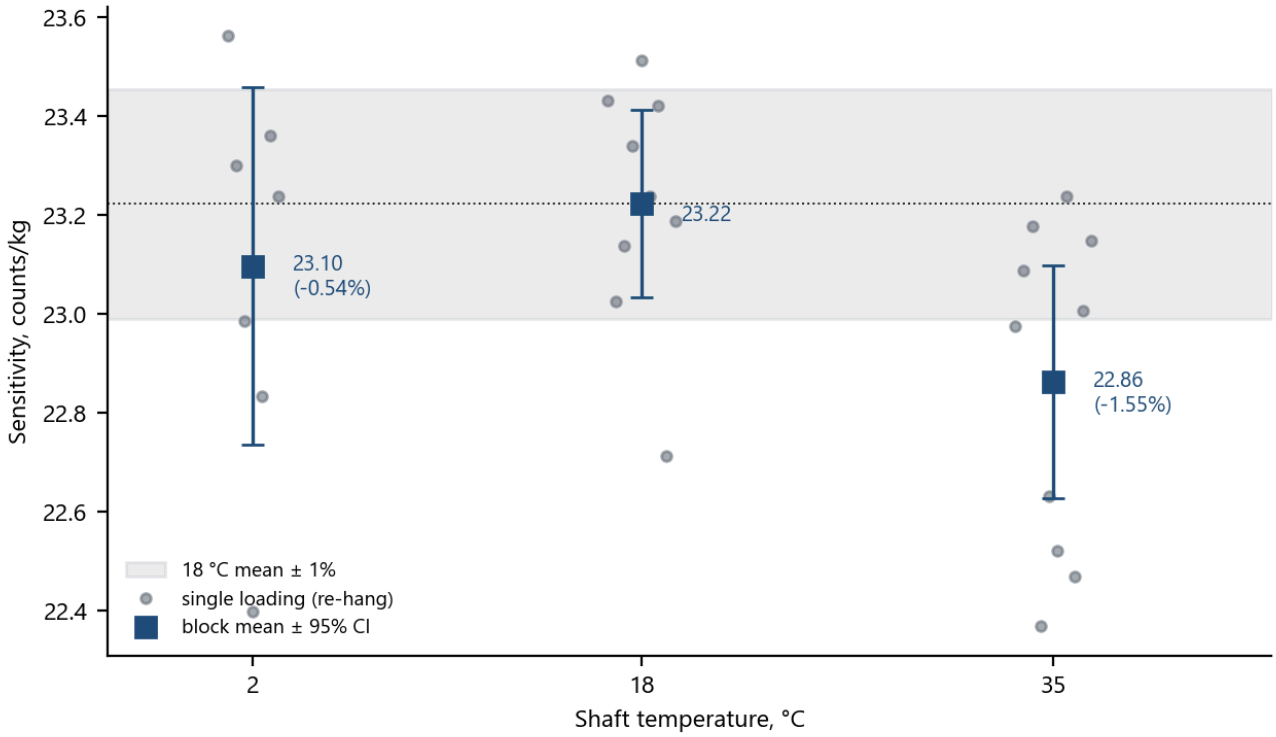


Figure 2. Sensitivity against shaft temperature. Grey: single loadings, each with re-placement of the mass. Blue squares: block means ± 95% confidence interval. Shaded band: 18 °C mean ± 1%.

The scatter of single loadings within a block was 1.1–1.7% CV, pooled 1.4% (Figure 3). By equation (2), a deviation of 1.4% corresponds to a hook-position change of about 7 mm on the 1000 mm span. The 35 °C block contains six loadings close to the 18 °C mean (−1.1 to +0.1%) and four that are 2.5–3.7% lower; the low values (17:21–17:22) are interleaved with higher ones rather than forming a steady trend.

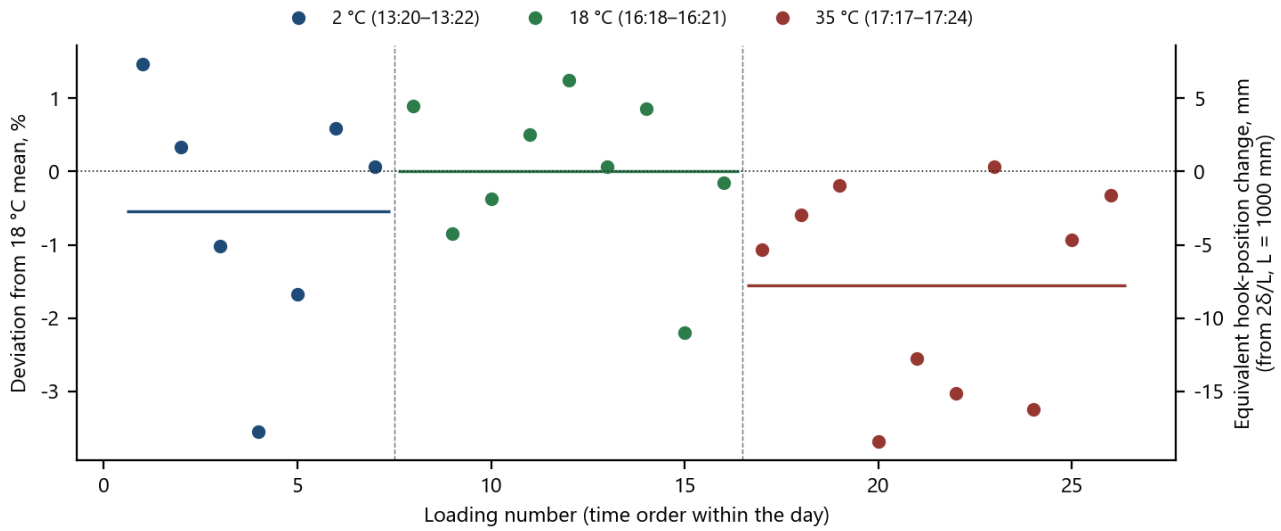


Figure 3. Deviation of every loading from the 18 °C mean, in time order. Horizontal lines: block means. Right axis: hook-position change that would produce the same deviation, from equation (2).

4. Discussion

Direction of the effect. A softer warm shaft would bend more under the same load and raise the sensitivity. The opposite was observed: at 35 °C the sensitivity was lower, and at 2 °C it was not measurably different. Shaft softening is therefore not the dominant effect over this range, consistent with the fibre-dominated stiffness of a unidirectional tube. The small decrease at 35 °C may come from the gauge, its adhesive or the electronics, since the firmware does not compensate sensitivity [3].

Most of the scatter comes from re-placing the mass. Three observations support this.

- Without re-placement of the load, the stroke-to-stroke scatter of the PaddleMate Nano on a pneumatic bending rig was ≤ 0.99% CV [9]. The Pro has a higher sensitivity and is expected to do at least as well, but its dynamic repeatability has not yet been measured. The single-loading scatter here, 1.1–1.7%, is larger, although the load was static.
- In this geometry the moment at the gauge depends directly on the hook position: 0.2% per millimetre, equation (2). The observed scatter corresponds to hook-position changes of only a few millimetres, which is realistic for a hook hung by hand on a round tube. Force-proving instrument calibration treats re-mounting as a separate reproducibility component for the same reason [6].
- An off-centre hook always lowers the moment. Placement errors therefore pull a block mean down as well as widening its scatter. The −1.55% difference at 35 °C corresponds to a mean extra offset of about 8 mm, and six of the ten 35 °C loadings lie within 1.1% of the 18 °C mean. Part of the 35 °C difference may thus come from placement rather than temperature; the measured −1.55% is best read as an upper estimate of the temperature effect.

The repeatability of the sensor itself is a separate quantity and is reported for the dynamic case in PM-TR-2026-02 [9]. The present scatter should not be read as sensor repeatability [4].

Practical significance. Taking the measured values at face value, a shaft 17 K warmer than at calibration reads about 1.6% low, and the upper confidence limit is 2.8%. For rowing training equipment, ISO 20957 class A allows ±10% on displayed power [7, 8]. The temperature effect found here is well inside that tolerance. Calibrating at a temperature close to the conditions of use reduces it further.

Limitations.

- One device, one tube and one day were tested, with 7–10 loadings per temperature.

- The temperature was read with a thermometer at each condition but not logged continuously, and it may have risen slightly at the end of the 35 °C block. The gauge temperature was not measured directly.
- The temperature of the electronics was not measured, so the effects of the shaft, the gauge and the electronics cannot be separated.
- Re-placing the mass by hand adds scatter and a downward bias that cannot be separated from a temperature effect of similar size.
- Only one load level was used. A temperature change of the zero and of the slope can therefore not be separated beyond what the offset compensation removes.

A follow-up test on the pneumatic rig of PM-TR-2026-02 is planned: the shaft conditioned by circulating water, the load applied by the actuator at a fixed position, an in-line load cell as reference, and the shaft and electronics temperatures logged. This removes the hook-placement error and allows the shaft and electronics to be tested separately.

5. Conclusion

On a water-conditioned carbon tube, the sensitivity of the PaddleMate Pro was 23.10, 23.22 and 22.86 counts/kg at 2, 18 and 35 °C. Relative to 18 °C, the change was −0.54% at 2 °C (not significant) and −1.55% at 35 °C. The sensitivity did not rise with temperature, so softening of the carbon shaft did not make the sensor read high. The scatter of single loadings, 1.1–1.7%, is dominated by the re-placement of the calibration mass, which may also account for part of the 35 °C difference. Even the worst case is well inside the ±10% class A tolerance of ISO 20957. These results are preliminary and will be confirmed on the temperature-controlled pneumatic rig.

Conflict of interest

The author is the CEO of PaddleMate, which develops and sells the device under test and the in-house calibration software. The measurements were made by the manufacturer and have not been independently verified.

Data availability

The per-loading CSV file and the analysis script are available on request from contact@thepaddlemate.com.

References

1. Cruz, M.I.; Sarmento, H.; Amaro, A.M.; Roseiro, L.; Gomes, B.B. Advancements in performance monitoring: a systematic review of sensor technologies in rowing and canoeing biomechanics. *Sports* **2024**, 12, 254. doi:10.3390/sports12090254
2. Rosdahl, H.; Aitken, D.; Osborne, M.; Willén, J.; Nilsson, J. A new versatile jig for the calibration and validation of force metrics with instrumented paddles in sprint kayaking. *Sensors* **2024**, 24, 4870. doi:10.3390/s24154870
3. Hoffmann, K. *An Introduction to Measurements using Strain Gages*; Hottinger Baldwin Messtechnik: Darmstadt, 1989.
4. JCGM 200:2012. *International vocabulary of metrology — Basic and general concepts and associated terms* (VIM), 3rd ed.; Joint Committee for Guides in Metrology, 2012.
5. JCGM 100:2008. *Evaluation of measurement data — Guide to the expression of uncertainty in measurement* (GUM); Joint Committee for Guides in Metrology, 2008.
6. ISO 376:2011. *Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines*; International Organization for Standardization: Geneva, 2011.
7. ISO 20957-1:2024. *Stationary training equipment — Part 1: General safety requirements and test methods*; International Organization for Standardization: Geneva, 2024.
8. ISO 20957-7:2024. *Stationary training equipment — Part 7: Rowing equipment — Additional specific safety requirements and test methods*; International Organization for Standardization: Geneva, 2024.
9. Schulcz, A. *Stroke-to-stroke repeatability of the PaddleMate Nano strain-gauge paddle-shaft sensor under pneumatic square-wave bending*. PaddleMate Technical Report PM-TR-2026-02, 2026.
10. Schulcz, A. *Static linearity of the PaddleMate Pro strain-gauge paddle-shaft sensor on a carbon dragon-boat paddle, 5–20 kg*. PaddleMate Technical Report PM-TR-2026-03, 2026.

11. Gere, J.M.; Goodno, B.J. *Mechanics of Materials*, 8th ed.; Cengage Learning: Stamford, CT, 2013.