Recent Advancements in Motion Control with Long-Term Nanoscale Stability, Including a Novel, Comparative Validation Technique

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ABSTRACT

An insidious nanoscale instability process is the quasi-asymptotic settling due to lubricant flow processes in drive, alignment and adjustment elements such as leadscrews and micrometers. It has been thought that this progresses at the nanoscale over many minutes, but conventional position-metrology instrumentation is typically less stable than recent process tolerances over the timescales involved, so quantification of these issues has been lacking.

EMERGING PIEZO-BASED, LONG-TRAVEL TECHNOLOGIES PROVIDE SELF-LOCKING

Familiar piezo stack actuators provide limited travels even when multiplied by lever amplifiers. Recently, novel types of piezo actuation have been developed. Resonant piezo actuators and walking piezo actuators offer a ceramic/ceramic interface which eliminates the lubricant film interface of screw-based mechanisms.

QUANTIFICATION OF LONG-TERM, NANOSCALE POSITION STABILITY

Researchers in the field of single-molecule biophysics utilized optical tweezers [FIGURE 1] in a configuration that allowed quantitative comparison of the stabilities of screw-driven and piezomotor-driven stages with sub-nanometer sensitivity over many minutes [1]. As in many semiconductor-industry applications, the test setup stacks coarse-positioning (resolution 0.1 micron) and fine-positioning motion elements (resolution 0.1 nanometer) in a sophisticated microscopy configuration. By swapping the coarse-positioning stage between screw-driven and piezomotor-driven models, the long-term, nanoscale stability provided by the piezomotors was quantitatively revealed.

600nm-diameter polystyrene beads were adhered to a glass coverslip and mounted on the nanopositioning stage carried by the stacked X-Y substages. The beads' positions were measured by back-focal plane detection [2] using a laser imaged onto a position-sensitive diode (PSD); the combination of clever optics and processing of the PSD signals provided sub-nanoscale localization of the bead in three dimensions. The position of the beads was tracked at five minute intervals, allowing compilation of the long-term overall system drift trends shown in FIGURE 3.

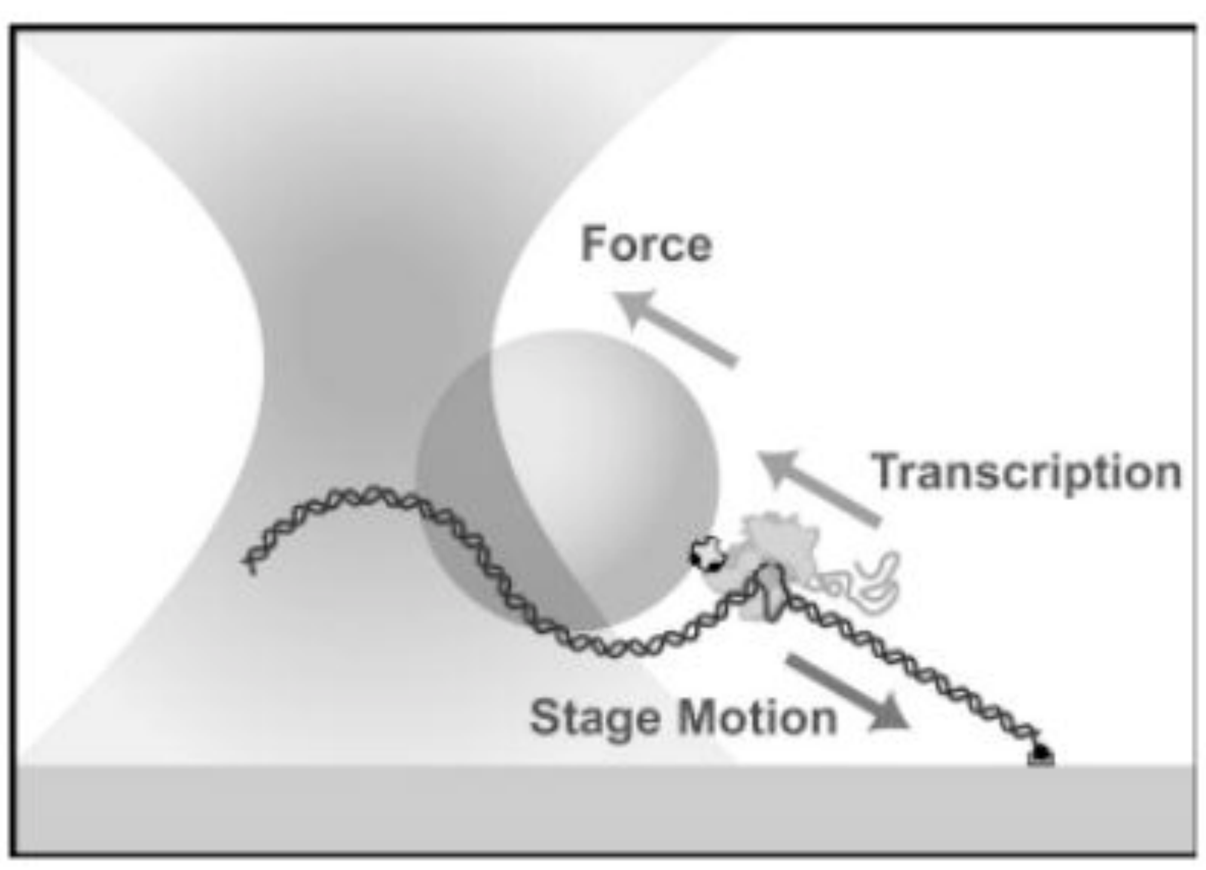

FIGURE 1. Optical tweezers are a tool of single-molecule biophysics which allow quantitative measurement of position with sub-nanometer resolution and, in dual-trap configurations, commensurate long-term stability. (From Neuman, Block [2])

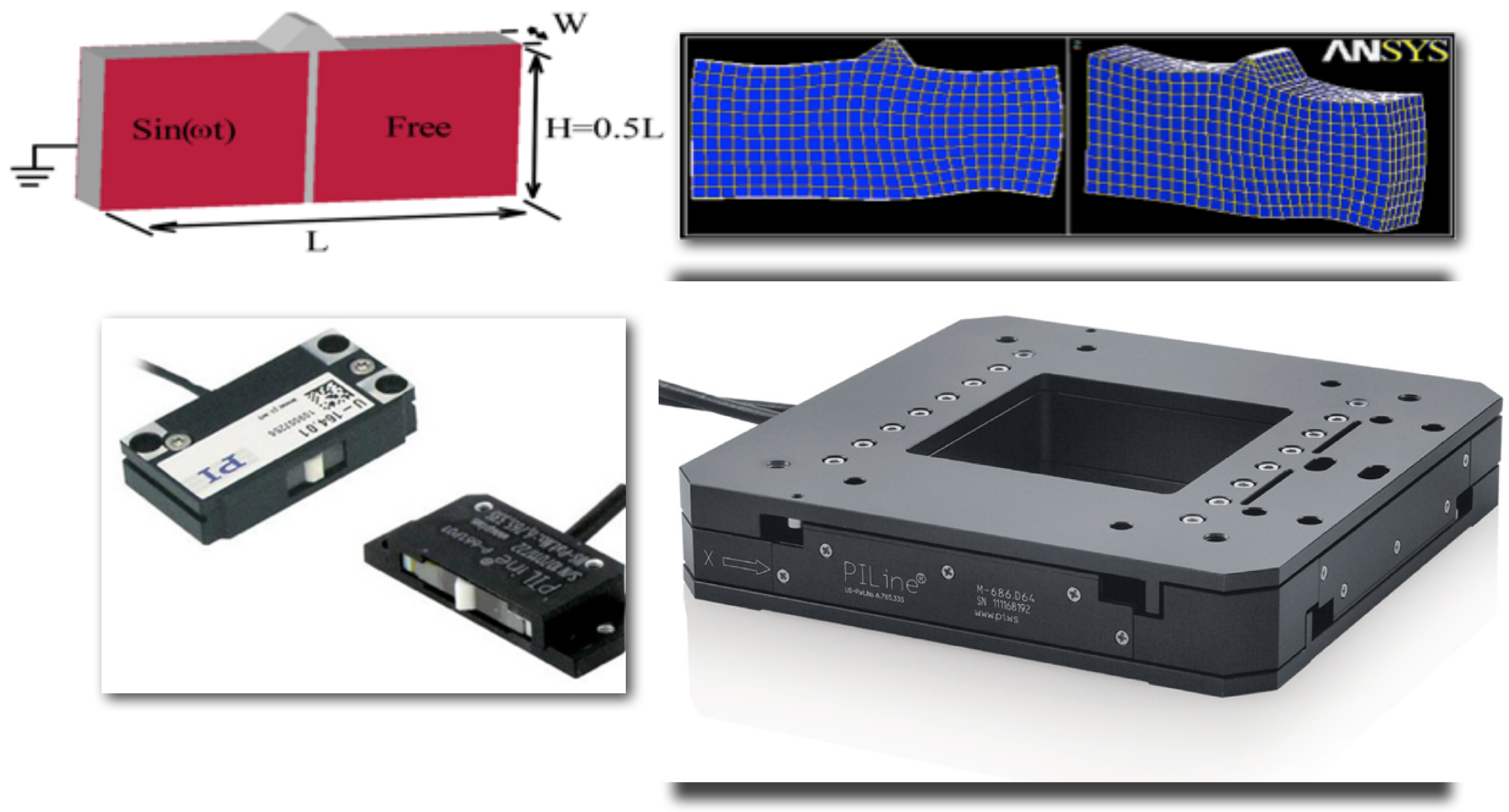

FIGURE 2. Resonant piezo linear motors (shown) and walking piezo motors have a ceramic-ceramic interface between motor and driven element which eliminates the lubricant-driven drift seen in in screw-driven mechanisms.

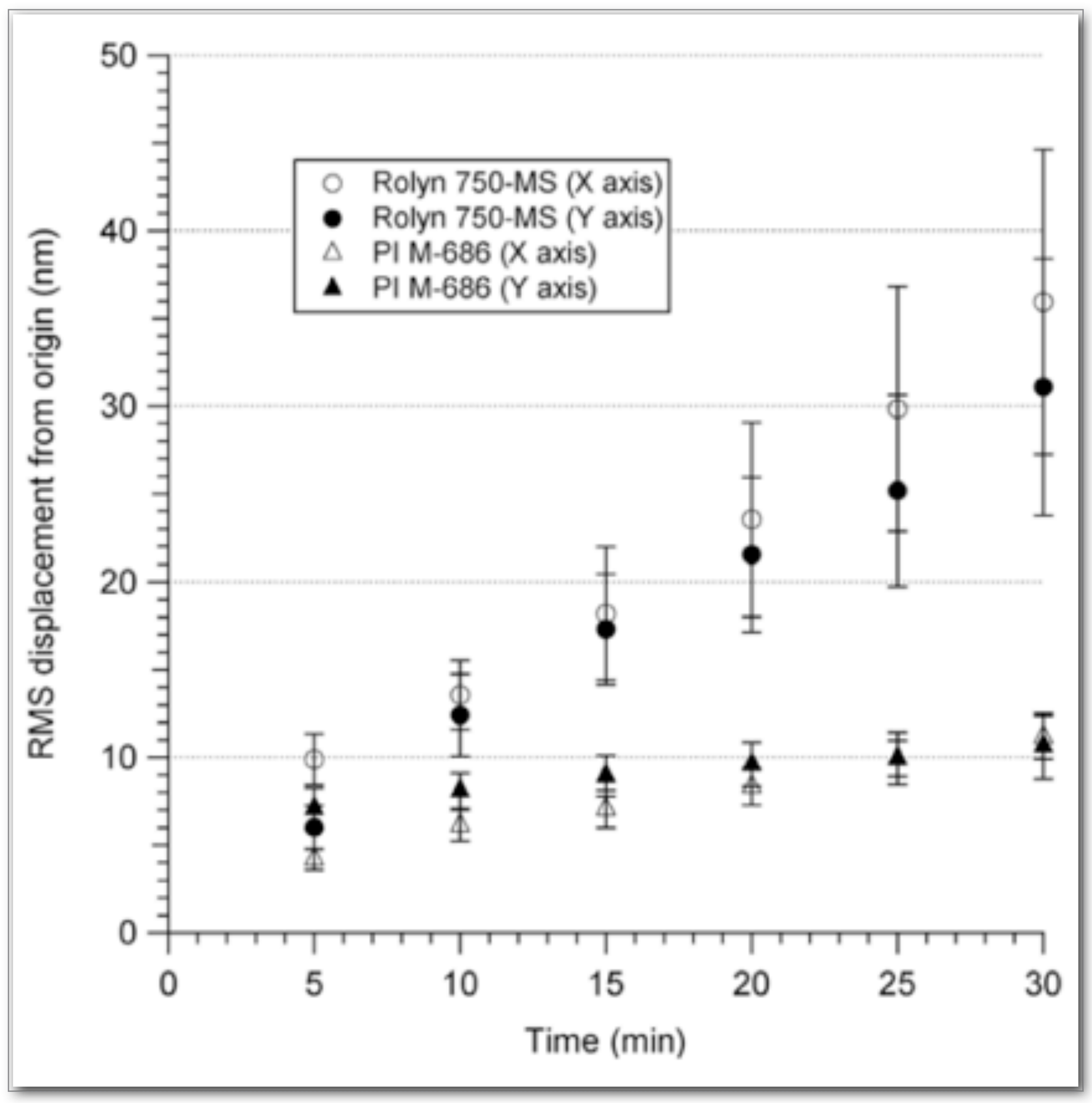

FIGURE 3. Comparison of the long-term nanoscale stability of the dual-trap setup with screw-driven substage versus piezomotor substage reveals approximately an order of magnitude better stability through elimination of the lubricant interface in the screw drive. (From Jordan, Anthony [1].)

CONCLUSION

The native (open loop, quiescent) position-hold stability of piezomotors is demonstrated to surpass that of spindle drives.

REFERENCES

[1] Jordan, S. and Anthony, P. (2009), Design Considerations for Micro- and Nanopositioning: Leveraging the Latest for Biophysical Applications, Curr. Pharm. Biotechnology, 2009, 10, 515-521

[2] Neuman, K.C. and Block S.M. (2004) Optical trapping. Rev Sci Instrum., 75 (9), 2787-2809.