Cost-Effective, Agile Temperature Control--the Missing Link in Precision Manufacturing

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A focus on technologies that enable modern, agile control methods has led to improved manufacturing accuracies. One noteworthy obstacle remains: thermal error. These authors describe how a similar approach can be applied to reducing thermal effects.

In 1965, Jim Bryan et al published a paper entitled "Thermal Effects in Dimensional Metrology," wherein the first sentence includes the famous phrase that "…in the field of close tolerance work, thermal effect is the largest single source of error…" The authors promoted a 'brute force' approach to temperature control, an example of which was the 'oil shower' that used recirculating temperature-controlled oil to flood an entire machine. By relying on averaging effects, a good oil shower could maintain a diamond turning machine to +/-0.01 ^{0}C. Air shower systems of the time were similarly rudimentary.

In 1983, Prof. Norio Taniguchi predicted the long-term accuracy capabilities of various precision material removal processes. Starting with early 20th century data, and projecting to 2020, Prof. Taniguchi predicted accuracy improvements of about 7X to 10X per decade for individual manufacturing processes.

Prof. Taniguchi's predictions have proven to be reasonably accurate; In general, "Taniguchi performance" has resulted from electro-mechanical design features that together yielded enhanced resolution, accuracy and bandwidth: synthetic materials, low friction guideways, high specific modulus components, high-force/low inertia actuators (e.g., linear motors), and close-coupled linear scales were all integrated into dynamically stiff structures using modern, multi-loop control strategies. The result? Finesse has replaced brute force in precision-engineered motion-control systems.

Except for thermal control. While Bryan et al developed effective temperature control systems, they are no longer compatible with modern manufacturing designs. With no obvious replacement poised to enter the market, we defined an appropriate set of specifications and developed a solution.

Specifications:

- Medium: laminar flow air
- Air distribution: Perforated plenum or porous fabric
- Mixing fans: Multiple fast response (low inertia) fans
- Mixing efficiency: Compact turbulators
- Control strategy: two-loop cascaded PID; one fast loop, one setpoint loop
- Heating and cooling source: Heat pump
- Enclosure windows: thin (1.0-2.0mm) PVC, IR-reflective
- Lighting, internal: LED, constant intensity, no shadowing
- Lighting, external: minimal, constant intensity, minimum shadowing

Solution: The Praecis Air Temperature Control Unit (ATCU)

- Portable, stand-alone, cost-effective local control
- 100% compliant with above specifications
- Three standard sizes, supporting enclosures from 0.5 m^2 to 20 m^2
- 50/60 Hz, 208/230V
- Monitoring (8 channels temperature, 1 channel control voltage)
- 10.4” touch screen
- Alarms
- Remote monitoring and programming (USB, Ethernet or wireless)
- Guaranteed performance metric: Variation at ‘critical point’ < 1/50 x variation in room
- Gold standard performance metric: Variation at ‘critical point’ <1/500 x variation in room