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THE DEVELOPMENT OF A HEAT PIPE DRIVEN MANIKIN WITH VARIABLE FLOW IRRIGATED SKIN

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INTRODUCTION

Accurate thermal evaluation of clothing systems is strongly dependent on manikin skin temperature uniformity and control of evaporative cooling. Measurement Technology Northwest (MTNW) has developed a thermal manikin system on contract with **U.S.** Army Research Institute of Environmental Medicine using heat pipe technology to produce unequaled surface temperature uniformity. Manikins utilizing fabric wicking skins typically have inherently high thermal resistivity, negating the efforts of the designers to achieve isothermal performance. **A** novel porous metallic skin was produced for MTNW's heat pipe thermal manikin (HPTM) to provide an even distribution of simulated perspiration without compromising thermal performance.

METHOD

Heat pipes, typically used in high heat flux applications, can also be utilized to produce isothermal surfaces under non-uniform low flux heat transfer(1). MTNW has applied heat pipe operation to a thermal manikin, taking advantage of this isothermal characteristic. Each manikin zone is configured as an annular sealed vessel, lined with a wick structure and containing a working fluid. The manikin skin is the isothermal condenser and a heated core serves as the evaporator. Once vaporized, working fluid condenses preferentially on the coldest areas of the manikin shell, effectively equilibrating the skin temperature. Development and production of the HPTM system has involved extensive testing and required numerous specialized manufacturing processes to produce reliable, leak tight heat pipe sections with a robust sweating *skin.*

Heat Pipe Design and Testing: Wick design and performance verification were conducted using a concentric copper tube test fixture. A fine grid resistive heater was mounted on the inner surface of the evaporator tube and an array of ten high accuracy thermistors were bonded to the skin surface of the condenser tube. Rigid end caps with gaskets were clamped on to produce an annular heat pipe space suitable for short-term operation. Numerous wick materials, wick configurations, and working fluids were evaluated to meet the performance specification of ±0.1°C spatial temperature uniformity. The assembled and filled test fixture was temperature controlled to a setpoint and surface temperatures logged to disk for analysis.

Anatomical Form Fabrication: A fiberglass manikin form was sculpted to match the anthropometric 50th percentile male(2) to serve as the dimensional plug for the generation of tooling. Tooling was produced using an aluminum filled epoxy resin, cast into split female forms and reinforced by a steel shell. Full soft copper tubing was fined in the tooling forms and explosively formed in a multi-step process. Tubing diameter and wall thickness were selected based on circumferences of the finished anatomical parts. The elongation from explosive forming produced seamless parts of sufficiently hard temper to support the low internal pressures within the heat pipes.

Heat Pipe Assembly and Filling: Heat pipe components were fixtured in a fiberglass alignment mold and trimmed to exact lengths. Evaporator tubes and end caps were measured and cut to fit within the copper shells. All parts were cleaned and assembled, and wicks were installed in a cleanroom environment- To assure purity of heat pipe components while maintaining a reliable seal, electron beam welding was used to join the copper parts. After welding, all parts were subjected to helium leak tests with a mass spectrometer before degassing and charging with working fluid.

Irrigated Skin: The irrigated skin was installed after completion of heat pipe sections. Flamespraying, or metalizing, was used to apply a porous metallic layer over all manikin sections. Variable rate metering pumps supply fluid to each section where it is distributed by an imbedded capillary network. Numerous flamesprayed metals were studied to achieve a stable, wettable surface with a reliable bond to copper.

Control System: The HPTM control system was developed to be accurate and user-friendly. An extensive error budget analysis spreadsheet was developed to account for all component tolerances, temperature coefficients, and quantization errors. The Macintosh based system includes control software developed in National Instruments LabView (USA), a graphical user interface package. Interface electronics use modular printed circuit boards for easy calibration and troubleshooting.

RESULTS

The heat pipe thermal manikin system is shown schematically in Figure 1. The sixteen zone manikin incorporates ten independent heat pipes comprising 90% of the active manikin surface area. Shoulders could not be adapted to the annular heat pipe geometry, and were investment cast from aluminum. Head, hands, and feet function as thermal guards, and are also aluminum. Rotary articulation is provided at the shoulders to facilitate manikin dressing. The Macintosh Quadra 950 control computer is mounted within the interface electronics enclosure, and uses a remote monitor and keyboard. Separate sensor and heater cables connect to the manikin eyes, and irrigated skin supply tubes pass through a preheater into the manikin head.

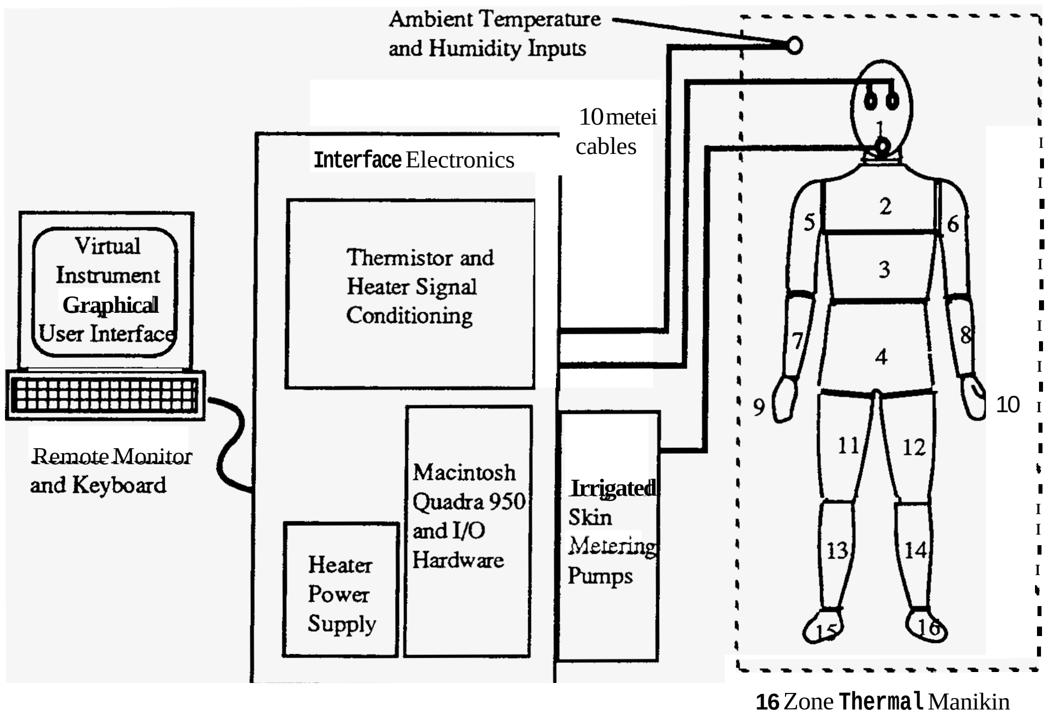

Figure 1 - Heat Pipe Thermal Manikin System

Performance of the complete system is within target specifications: Heat pipe regions were shown to achieve spatial temperature uniformity to within ±0.1° C at a heat flux of 44 Watts/square meter, compared to ±0.5 °C or greater for typical non-heat pipe manikins. A modified PID control algorithm brings the system to steady state quickly with little overshoot. Temperature setpoint is user selectable from 5-38°C with heat fluxes from 0-620 Watts/square meter. The irrigated skin provides uniform simulated perspiration controllable from 50-500 ml/hour/square meter. Software features real time operator selectable display of temperatures, heater powers, or clo values. Vapor resistance testing(3) is fully supported by the system, and incorporates data from previous dry clo tests to calculate real time permeability indices for individual sections and the entire manikin. Comparative testing against existing sweating manikins has not been completed as of this writing.

CONCLUSIONS

A development effort has demonstrated that application of heat pipes to thermal manikin systems can effectively minimize spatial variations of skin temperature, even under non-uniform heat fluxes. The completed HPTM system allows previously unattainable levels of thermal accuracy. The irrigated skin developed for the HPTM accurately reproduces physiological evaporation rates without the thermal de-coupling associated with soft artificial skin systems.

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