Survey Of Thermoelectric Generator Performance In A Harsh Automotive Environment

Southwest Research Institute®

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Scope of Work

- Determine present day road worthiness of thermoelectric generators for automotive use
- Perform analysis for engine exhaust recovery apparatus

Southwest Research Institute

- 1,200 Acres
- 2M square feet of Laboratories and Offices
- 2,700 Employees
- $350M Revenue in FY03
- 11 Technical Divisions
- 1/3 Dedicated to Automotive R&D

Operational Characteristics

- Independent
- Nonprofit
- Technical and Scientific Breadth
- Decentralized Organization
- Stable and Conservative
- Project Management Approach
- Revenue Provided by R&D Contracts
- Internal Research Encouraged
- Confidentiality Enforced
- Unique Patent Rights Policy
- A Good Teaming Partner

SwRI Technical Divisions

- Engine, Emissions, and Vehicle Research (03)
- Fuels and Lubricants Research (08)
- Chemistry and Chemical Engineering (01)
- Aerospace Electronics and Training Systems (09)
- Automation and Data Systems (10)
- Instrumentation and Space Research (15)
- Signal Exploitation and Geolocation (16)
- Mechanical and Materials Engineering (18)
- Center for Nuclear Waste Regulatory Analyses (20)

TEG Advancements

- Increased efficiency
- Commercial acceptance
  - Comfort and convenience features
- Increased development areas

Procedure Description

- Validate commercially available TEG performance
- Determine TEG performance in a harsh automotive environment
  - Shaker Table Evaluation
  - Failure Evaluation
- Determine engine exhaust energy recovery potential
- Determine automotive commercial viability

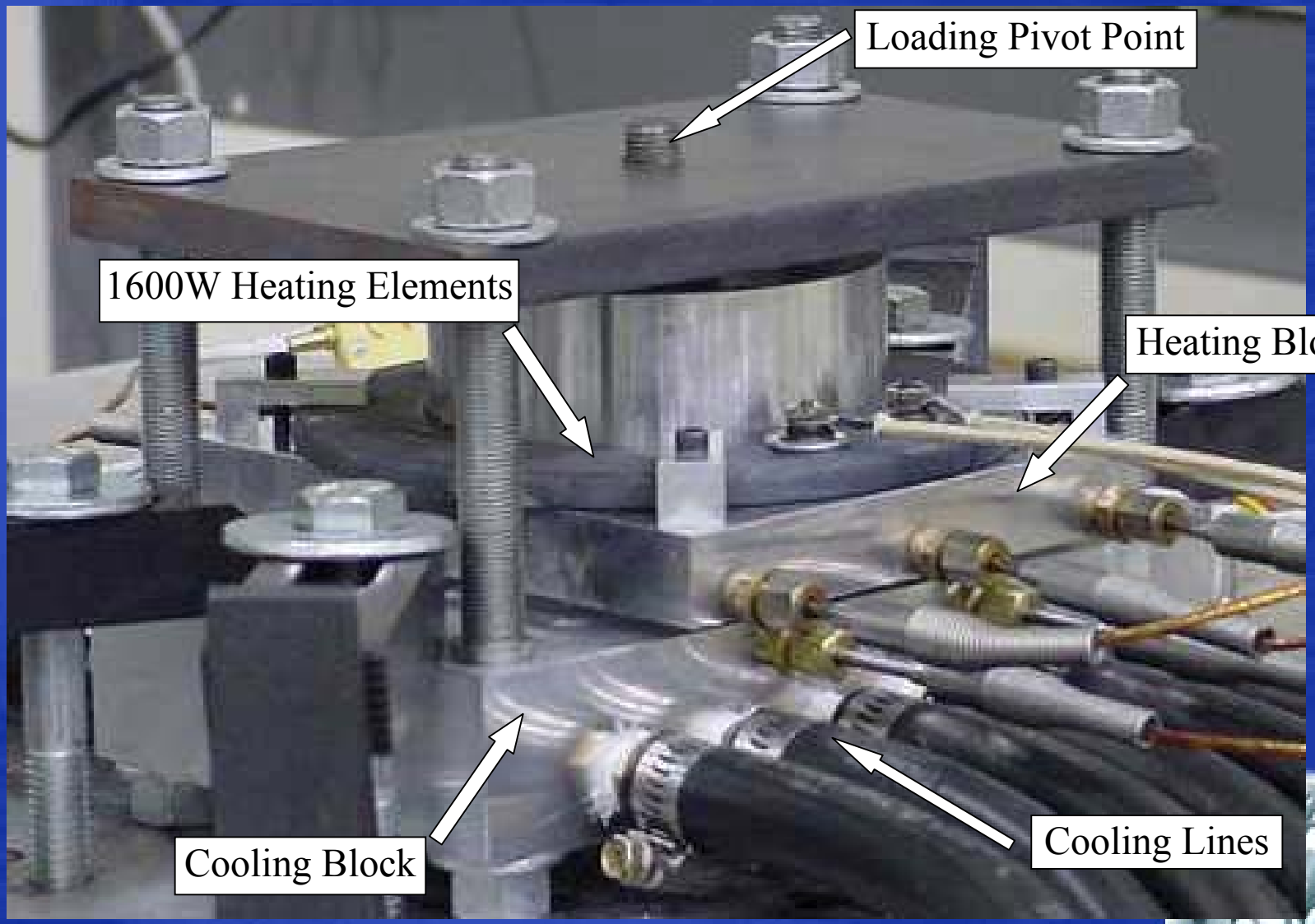
TEG Modules Evaluated

Manufacturer	Model
Hi-Z Technologies	HZ14
	HZ20
Marlow Industries	TEC – 32
	TEC – 70
Thermonamics Electronics	TEP1-1256-0.6
Ferrotec USA	9500/127/085AS

Test Apparatus

- Adaptive testing fixture for modules varying in:
  - size
  - power
- Constant temperature gradient across heat transfer surfaces
- Compressive load of ~200 psi necessary to keep good thermal contact and keep the modules from experiencing shear and tensile forces
- Apparatus suitable for both stationary and harsh vibration situations

Test Apparatus

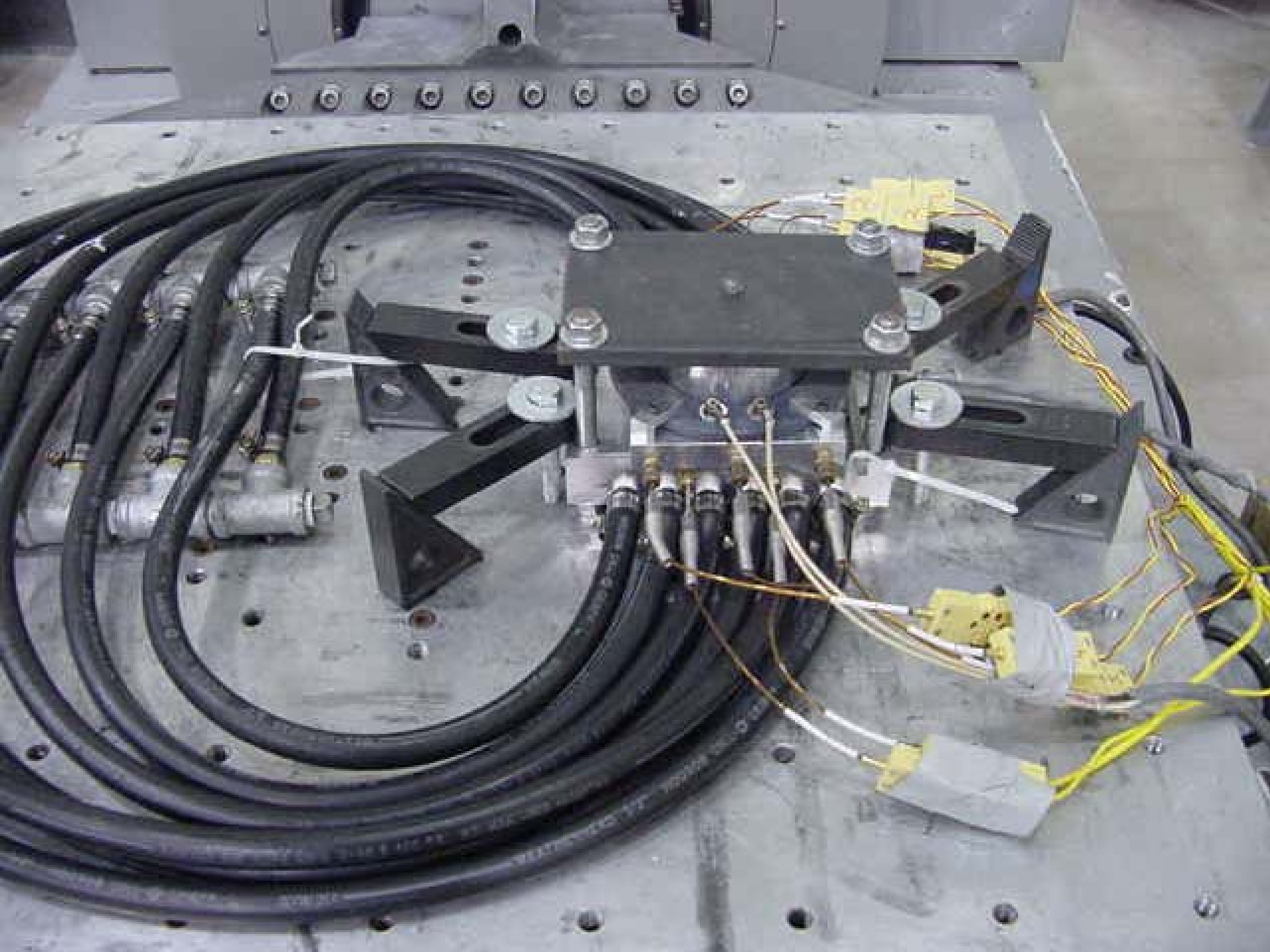


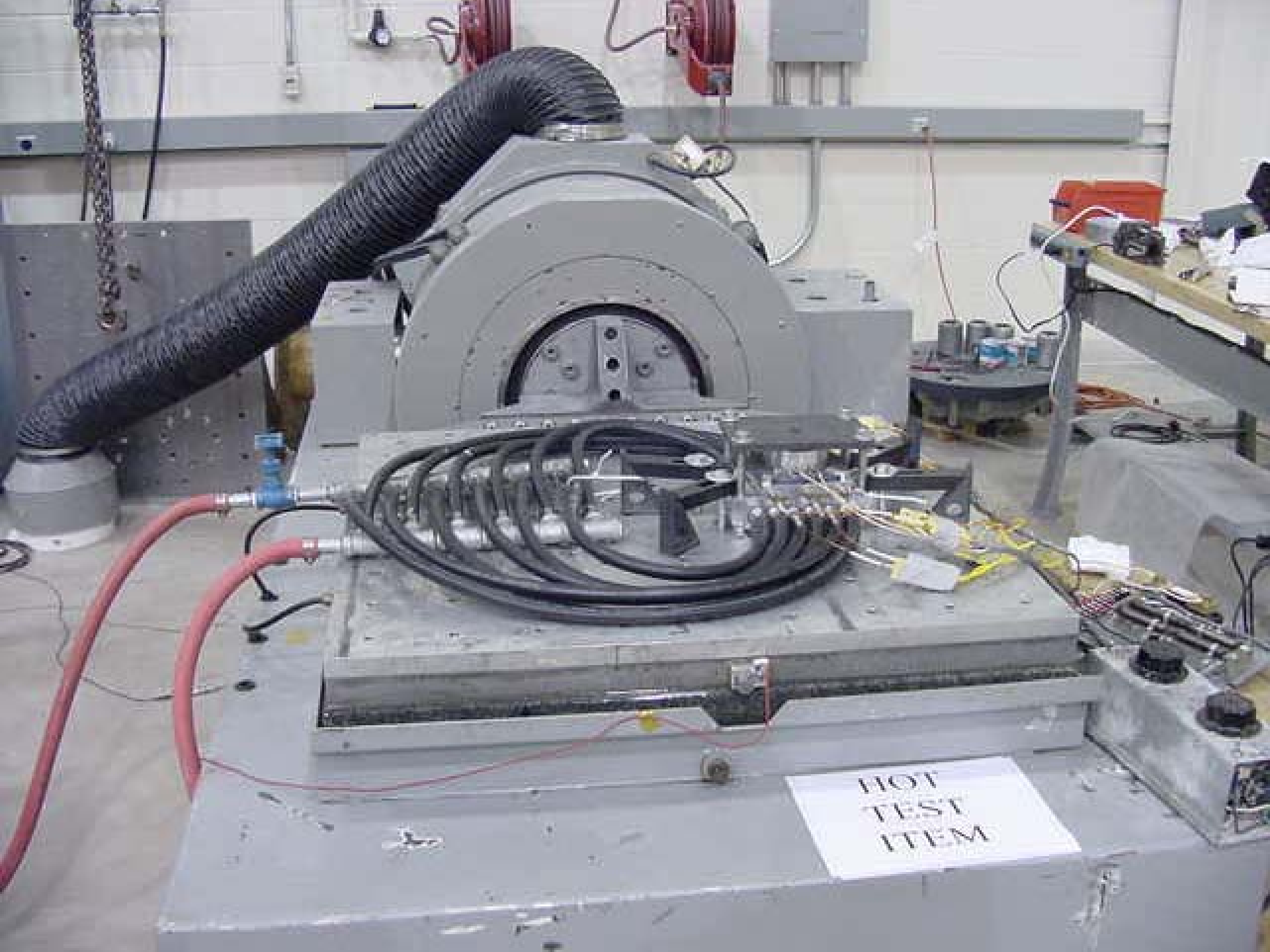
Stationary Testing

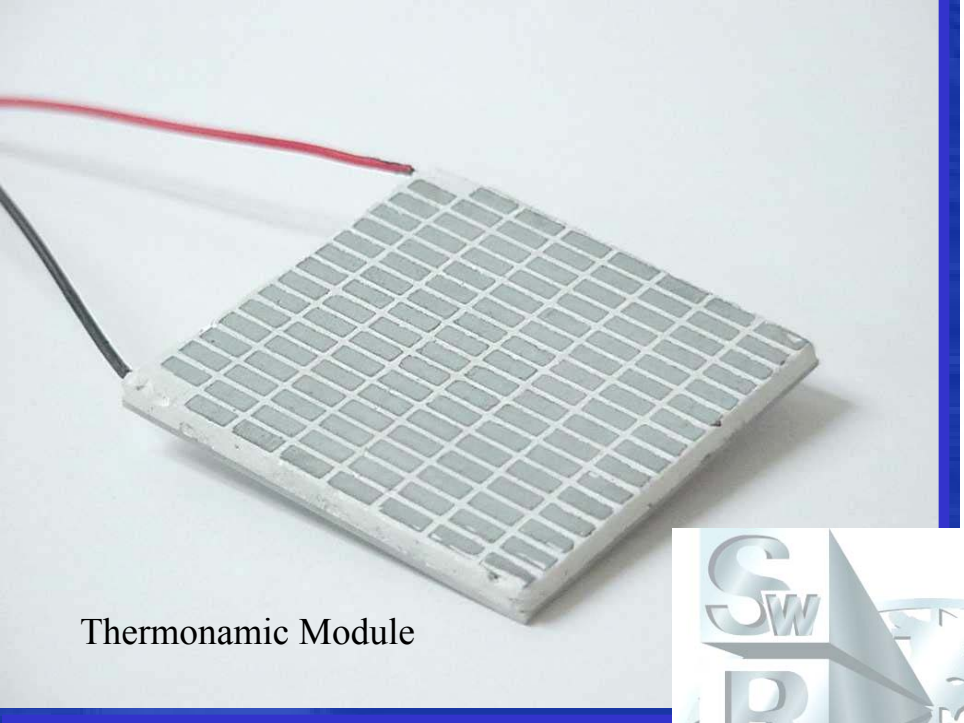
- Module performance measured during temperature ramp up and cool down.
- Temperature operation from room temperature to 250°C
- Curve fit for power as a function of ΔT

Vibration Testing

- Vibration testing simulates loads TEGs would face under harsh automotive driving conditions
- Testing not intended as durability testing, rather expose possible problems inherent to commercially available TEGs
- Shaker table - Unhotz-Dickie 6000 pound shaker table
- Random vibration profile
  - Constant power spectral density (PSD) = 0.02 g^2/Hz
  - Frequency range 10 to 1000 Hz
  - Overall vibration level of 4.45 g's rms
  - Same profile as catalytic converters




HOT
TEST
ITEM



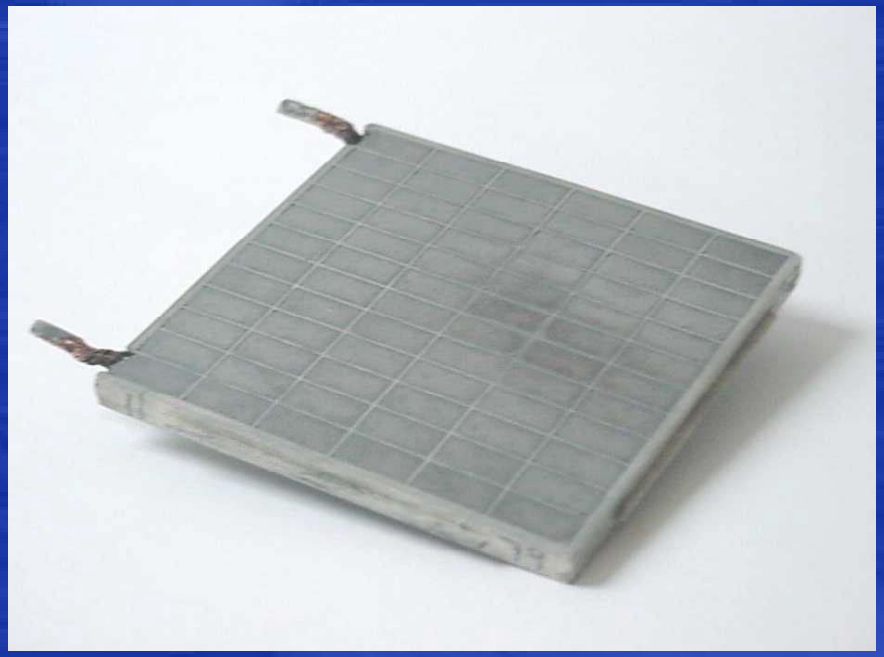
Thermonamic Module

Hi-Z Module HZ20 hot side

Ferrotec Module 9500/127

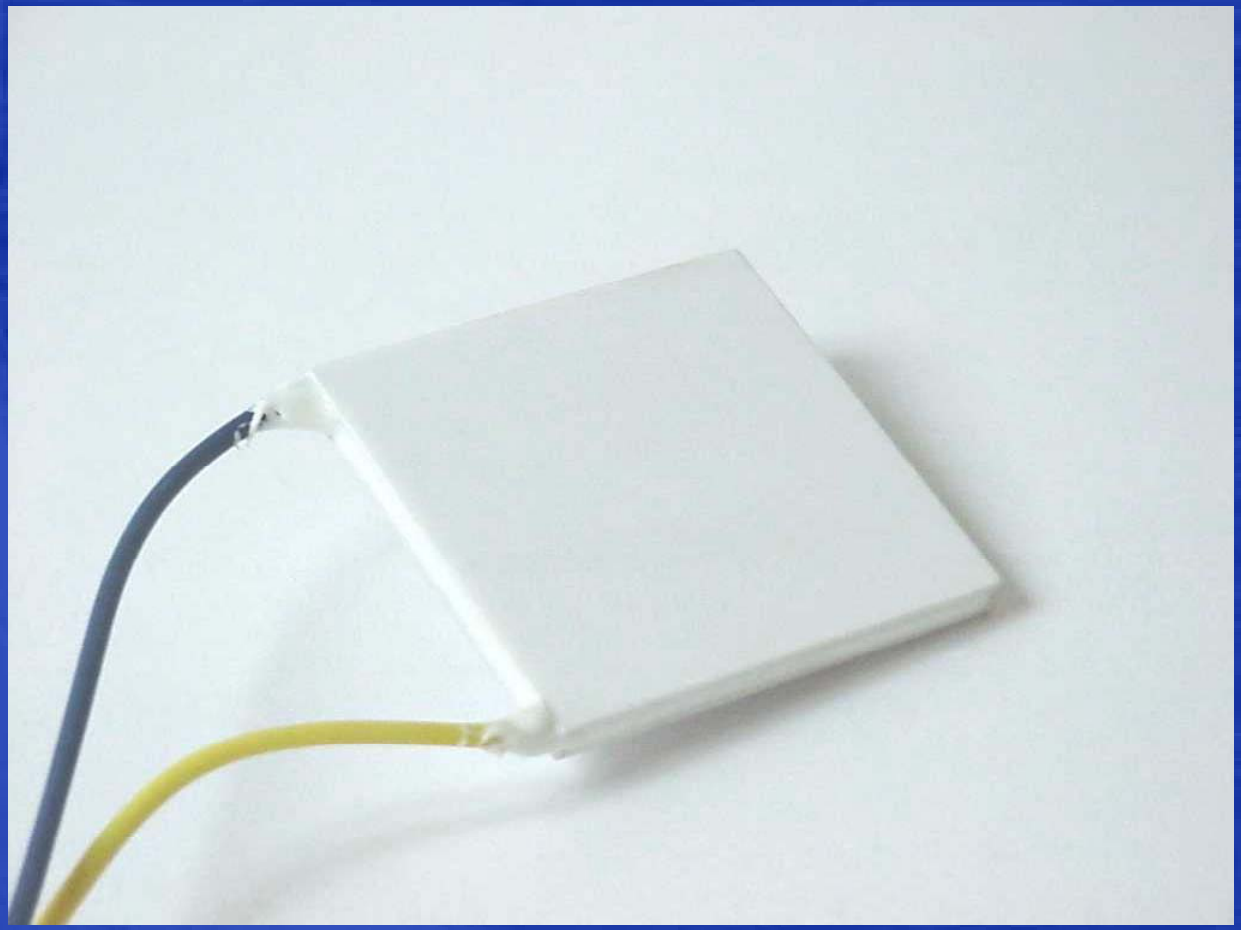
Hi-Z Module HZ20 cold side

HZ20 - Cold Side

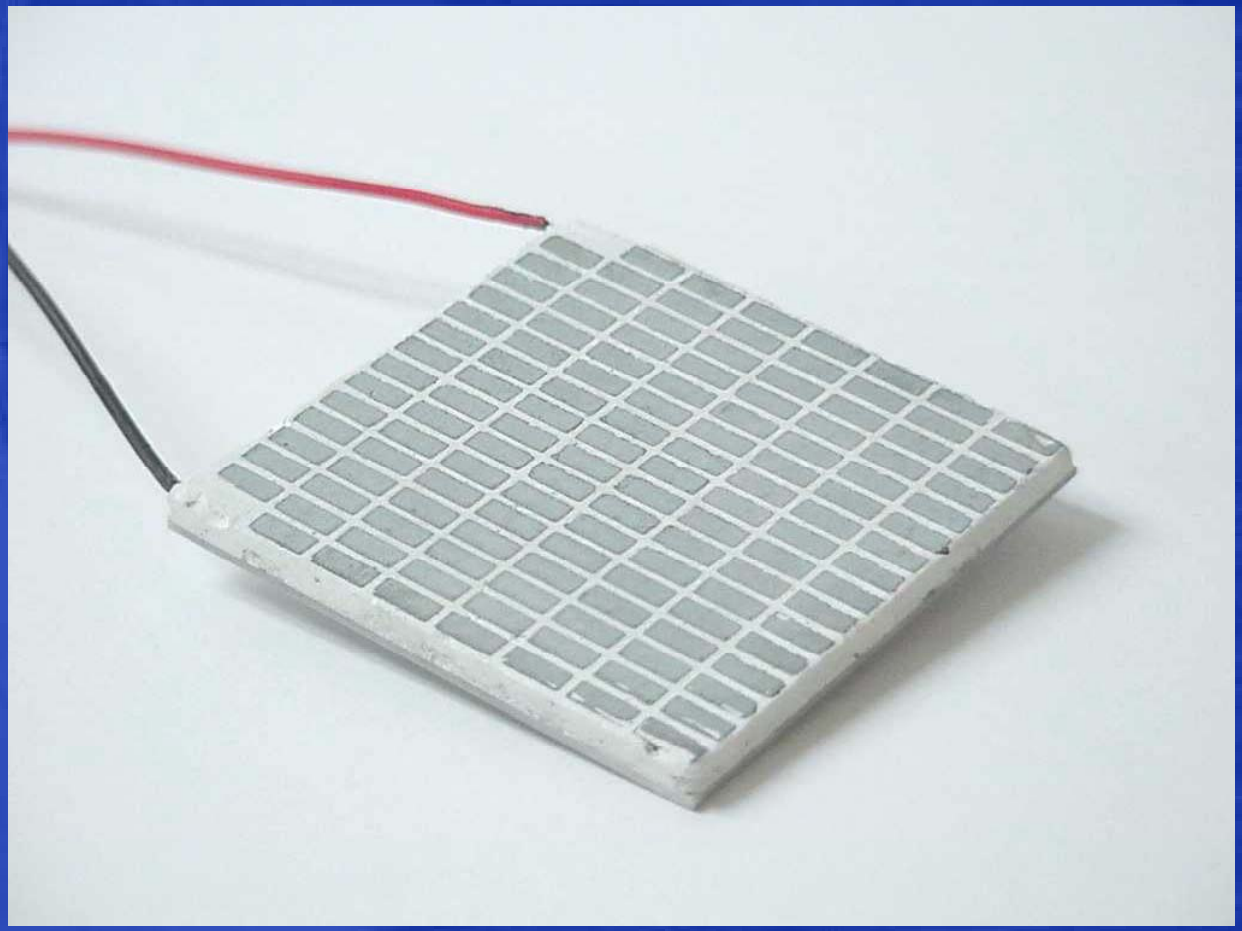


HZ20 - Hot Side

Ferrotec 9500

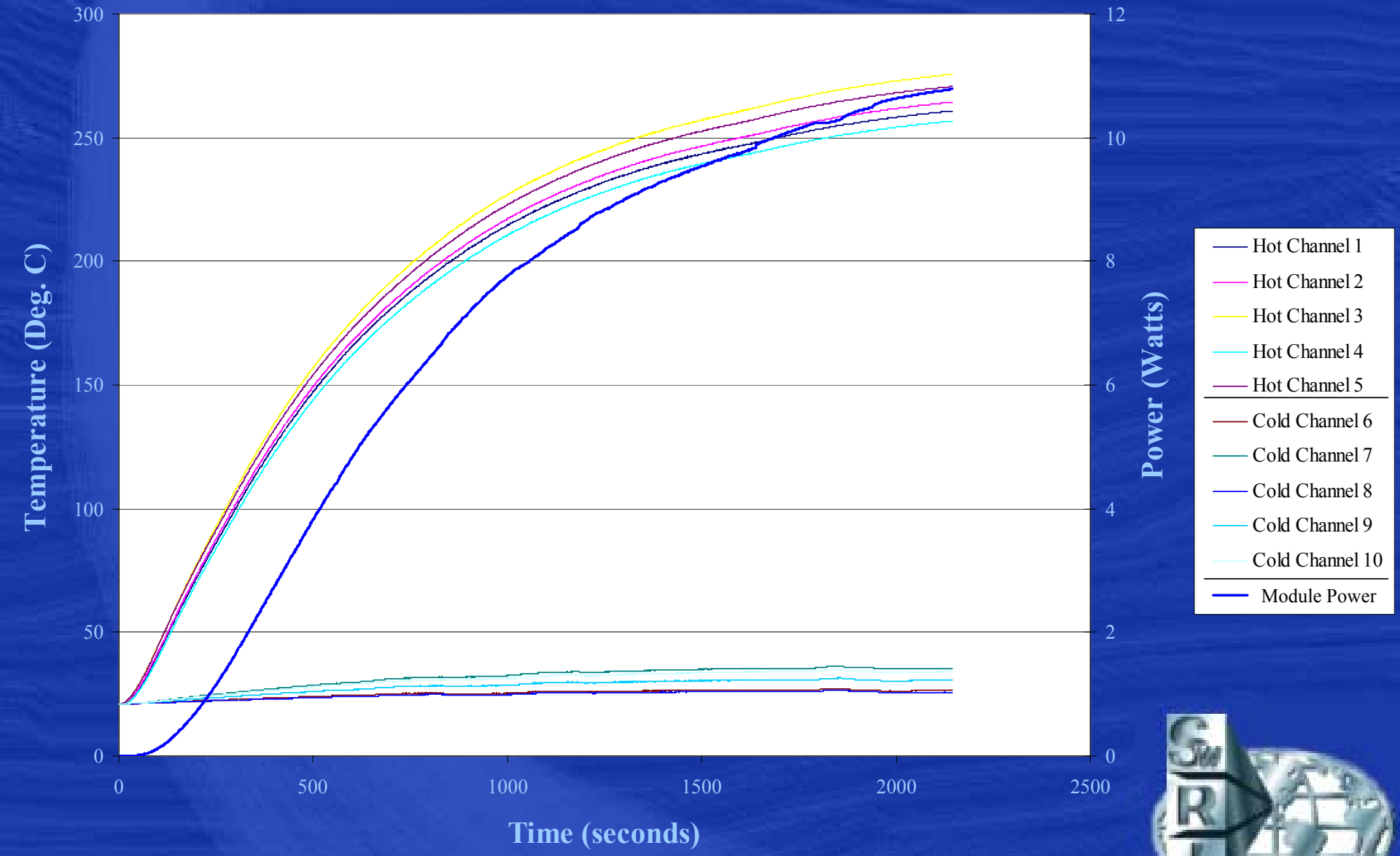


Thermonamics TEP1

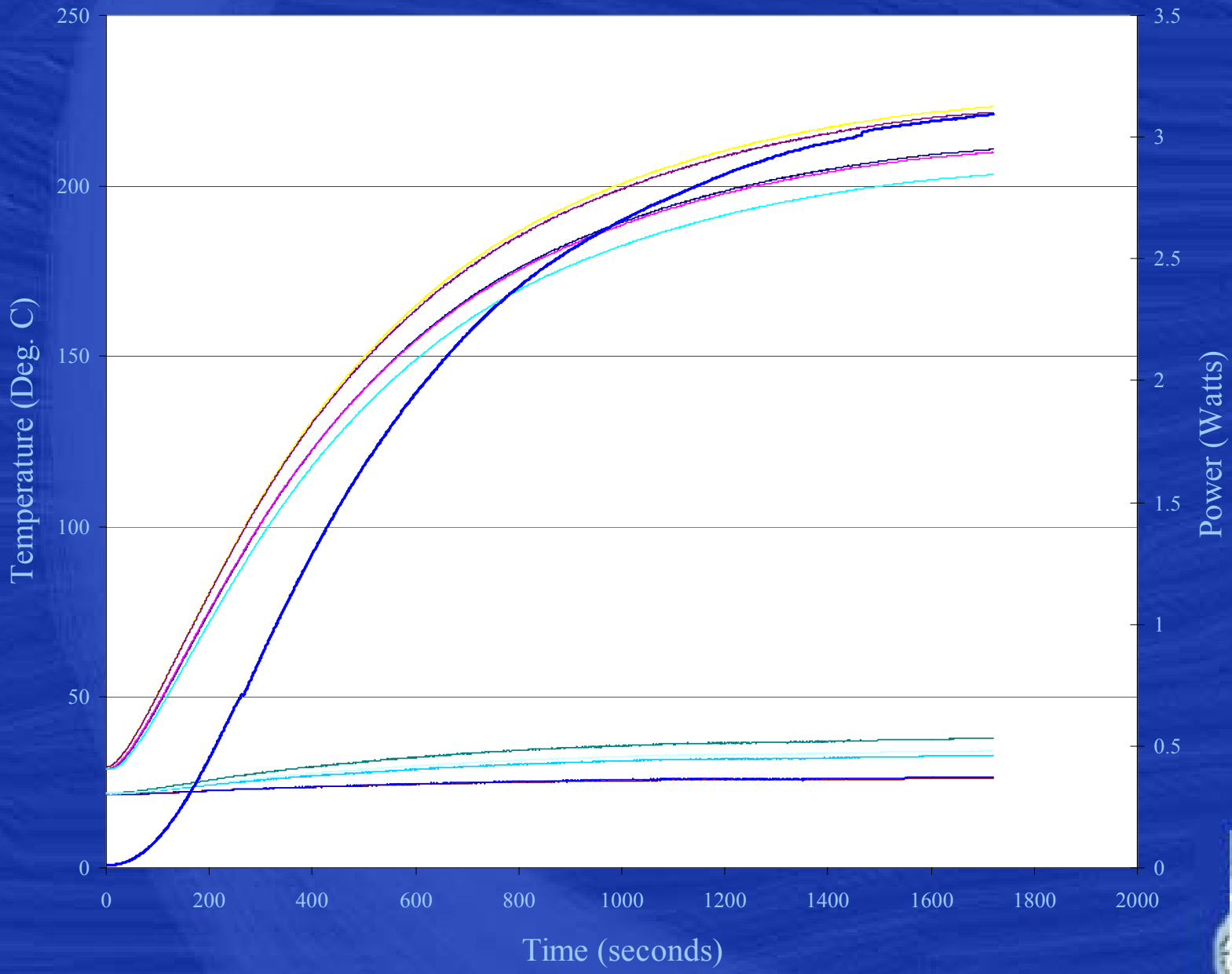


Module Type	Description
1	49 thermocouple module using a high temperature plastic matrix for couple separation
2	71 thermocouple module using an a high temperature plastic matrix for couple separation
3	32 thermocouple module using integrated ceramic surface plates, air gap between couples
4	70 thermocouple module using integrated ceramic surface plates, air gap between couples
5	125 thermocouple module using ceramic matrix for couple separation
6	127 thermocouple sealed module with integrated ceramic thermal plates, air gap between couples

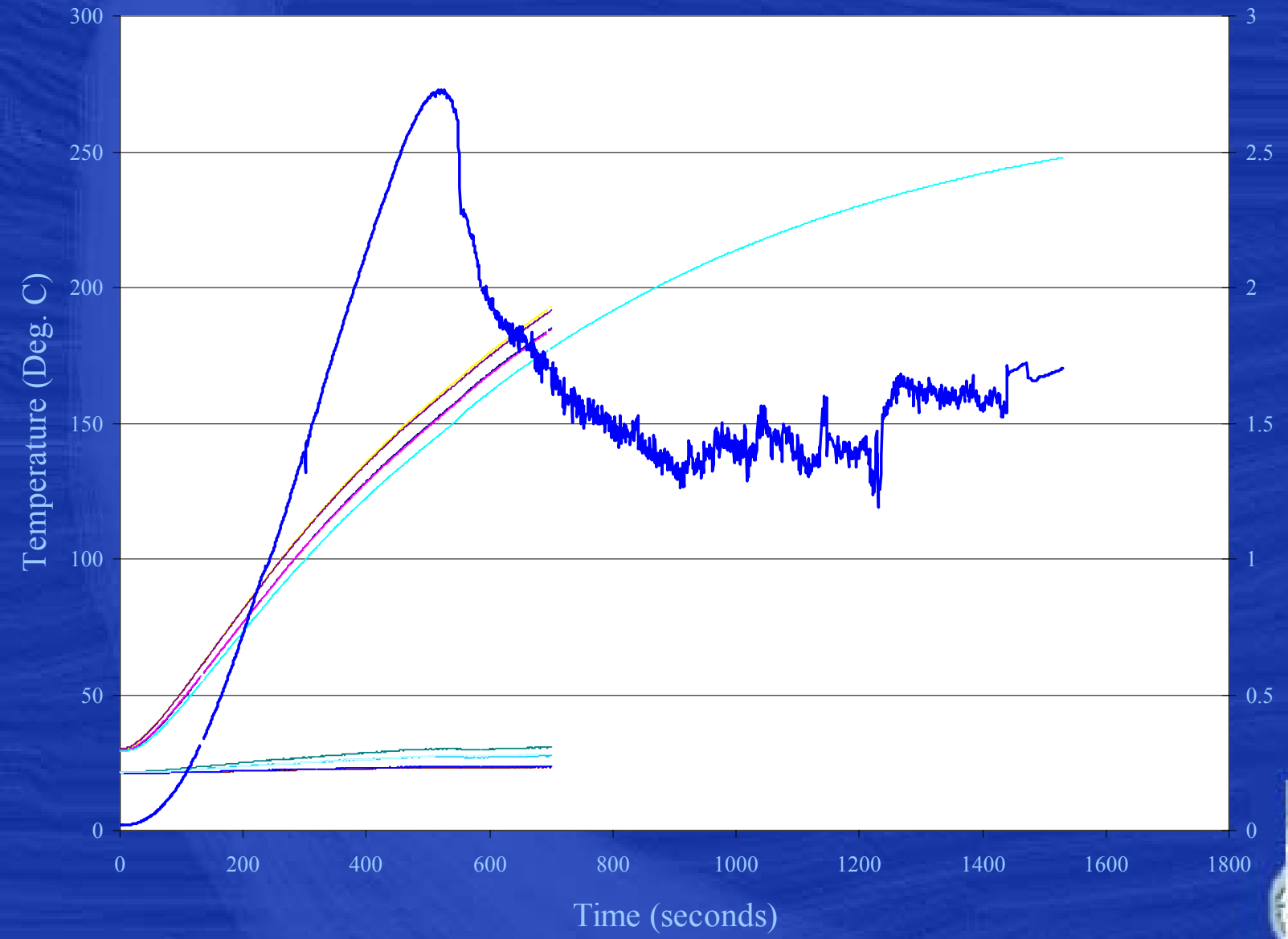
Test Module Type 1 on Shaker



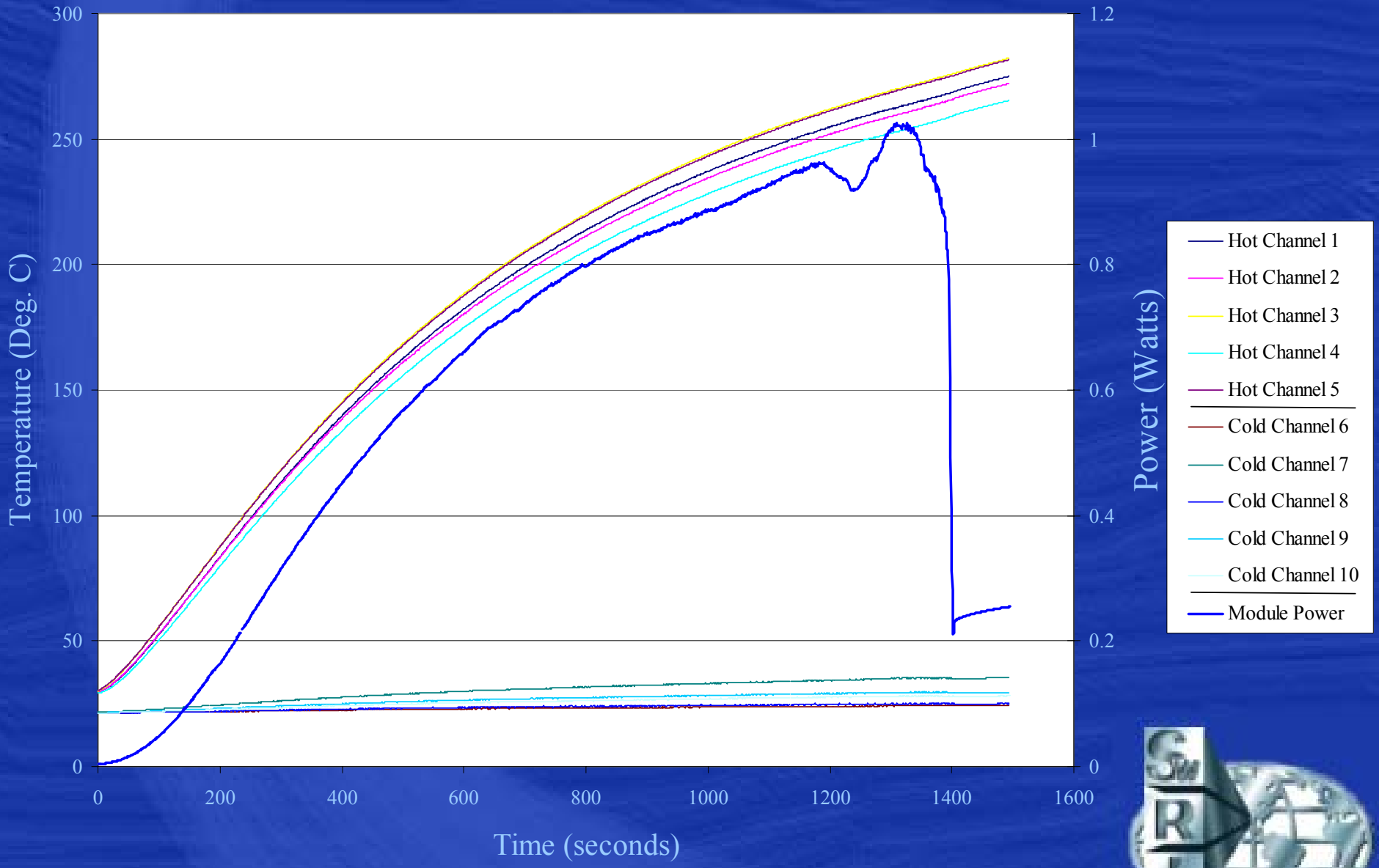
Test Module 5 on Shaker



Test Module Type 4 on Shaker



Test Module Type 6 on Shaker

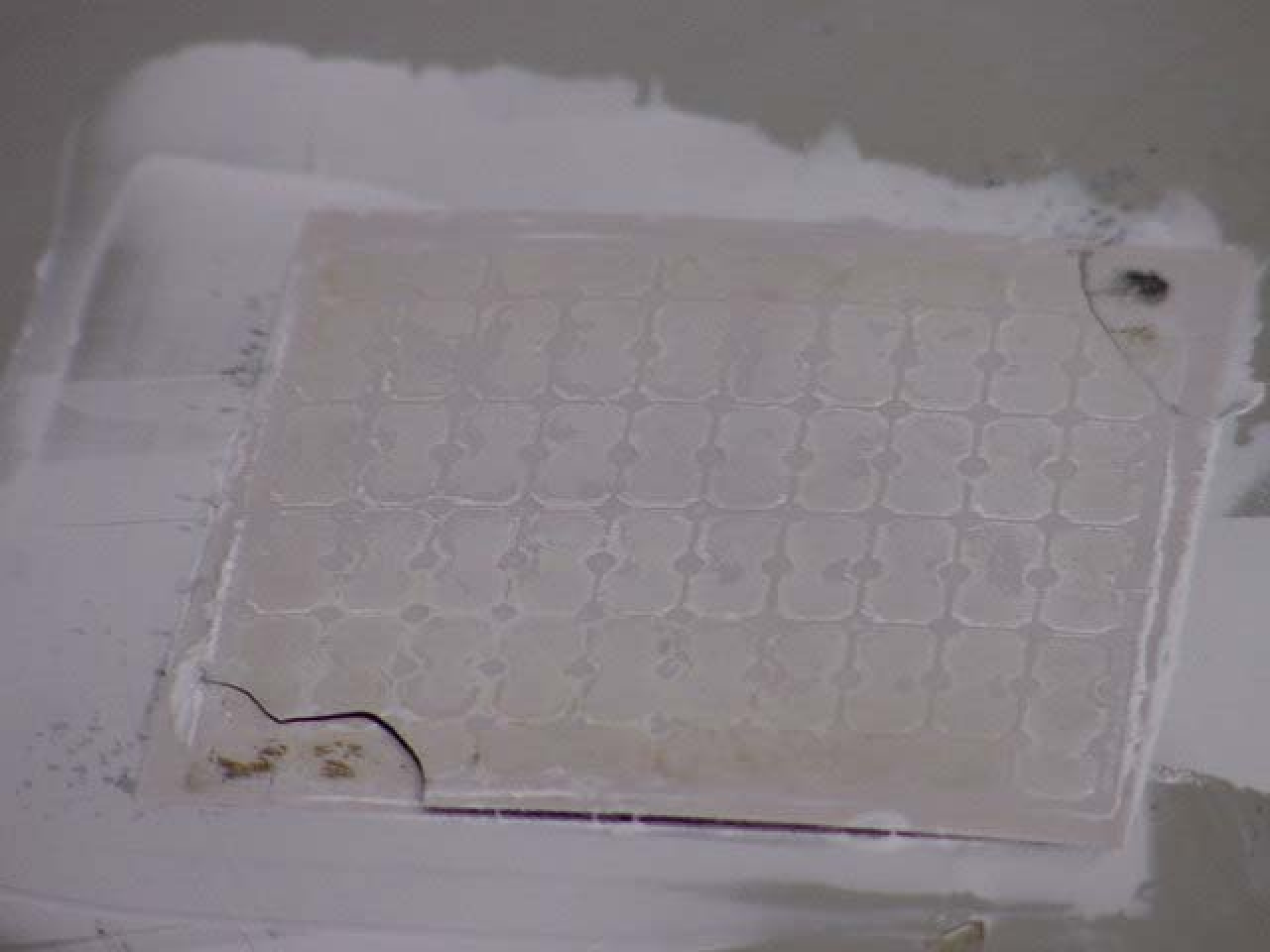


Vibration Testing

- Vibration conditions caused 4 out of 10 modules to fail
- Failure was evidenced by a sudden decrease of output voltage and current not correlated to ΔT
- Modules usually failed at a somewhat elevated T_H (>120°C) after more than 10-15 minutes of vibration

Failure Evidence

Electrical Isolation



Abrasive Pitting

Module Number	Passed/Failed
Type 1- #1	Passed
Type 1- #2	Passed
Type 2 - #1	Passed
Type 2 - #2	Passed
Type 3 - #1	Failed
Type 4 - #1	Failed
Type 5 - #1	Passed
Type 5 - #2	Passed
Type 6 - #1	Failed
Type 6 - #2	Failed

Failure Evaluation

- All modules that failed did not have matrix material surrounding thermoelectric couples
- Effective matrix varied in material
  - Ceramic
  - High Temperature plastic
- Surface/Edge loading critical in applications

Questions