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14. ABSTRACT The primary equipment purchased is a Phoenix Tribology Ltd. DN55 High Temperature Sliding and Fretting Machine. The machine was designed from the ground up specifically for high temperature (up to 800oC) fretting experiments. The system has a lower mass actuator system which is ideal for fretting and reciprocal sliding experiments to enable cycling at higher frequencies (up to 500 Hz) while minimizing dynamic effects. The system can also perform reciprocating sliding with maximum stroke of 20 mm at 5 Hz, allowing fretting wear experiments to be also conducted. The motivation for obtaining the new equipment is to further validate and understand microstructural changes occurring during fretting of gas turbine engine alloys, primarily Ti and Ni-base alloys. These projects are aimed at improving reliability of attachments between components through improving the physics basis of the fatigue life prediction modeling as well as developing new tools to assess the influence of material microstructure on resistance to crack formation. The end goal is improved reliability of DoD mission-critical components and reduction in maintenance costs.					
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Final Performance Report  
Defense University Research Instrumentation Program

**Elevated Temperature Fretting Apparatus**

Grant # F49620-03-1-0260

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## Abstract

The primary equipment purchased is a Phoenix Tribology Ltd. DN55 High Temperature Sliding and Fretting Machine. The machine was designed from the ground up specifically for high temperature (up to 800°C) fretting experiments. The system has a lower mass actuator system which is ideal for fretting and reciprocal sliding experiments to enable cycling at higher frequencies (up to 500 Hz) while minimizing dynamic effects. The system can also perform reciprocating sliding with maximum stroke of 20 mm at 5 Hz, allowing fretting wear experiments to be also conducted. The motivation for obtaining the new equipment is to further validate and understand microstructural changes occurring during fretting of gas turbine engine alloys, primarily Ti and Ni-base alloys. These projects are aimed at improving reliability of attachments between components through improving the physics basis of the fatigue life prediction modeling as well as developing new tools to assess the influence of material microstructure on resistance to crack formation. The end goal is improved reliability of DoD mission-critical components and reduction in maintenance costs.

## Equipment Acquired

The primary equipment purchased with the DURIP funds is

Phoenix Tribology Ltd. DN55 High Temperature Sliding and Fretting Machine.  
Including split furnace. Including control and analysis software. Including  
installation, commissioning and training. Including packing and delivery. \$167,119

The following items are associated with installation, calibration, and additional features added by us for the DN55:

Vishay Micro-Measurements 4-channel Signal Conditioning Amplifier	\$6,695
Salem Speciality Balls (Ti-6Al-4V, 52100 bearing steel, WC, Alumina)	\$1,027
Force transducer calibrator (Transducer Techniques)	\$865
Thermocouple calibrator (Omega)	\$404
Georgia Tech Facilities charge for hooking up utilities to machine	\$3,733

The following items were purchased to be used for specimen preparation, measurements, and analysis:

Struers Labotom-3 Abrasive Cut-out Saw and accessories	\$10,664
Denver Instruments Analytical Balance, PI-225D with 0.01 mg resolution (0-60 g range)	\$2,616
Computer and additional software/hardware for data analysis and storage	\$6,877

Total Cost \$200,000

The primary equipment is located in the Mechanical Properties Research Laboratory, Hibay Lab of the Manufacturing Research Center (MaRC) building, on Georgia Tech's campus. The installation was completed May 2004.

The DN55 High Temperature Sliding and Fretting Machine was designed from the ground up specifically geared for high temperature fretting experiments. The system has a lower mass actuator system which is more ideal for fretting and reciprocal sliding experiments to enable cycling at higher frequencies while minimizing dynamic effects. Oscillating frequencies up to 500 Hz may be controlled under fretting conditions ( $< 100 \mu\text{m}$  of cyclic displacement). The system can also perform reciprocating sliding with maximum stroke of 20 mm at 5 Hz, allowing fretting wear experiments to be also conducted.

The moving specimen carrier is designed to hold a ball or roller of 20 mm diameter in either point, line or area contact. The fixed specimen tooling comprises two forks each carrying a fixed specimen and loaded against either side of the moving specimen. This arrangement ensures that there are no significant out of balance forces acting on the moving specimen. Each fork reacts against its own independent piezo-force transducer, thus allowing the friction between the moving specimen and each fixed specimen to be monitored independently. This allows two different fixed specimen materials or contact geometries to be tested simultaneously under identical conditions of cyclic displacement, normal force, and temperature. Force is applied to the fixed specimen forks by means of a PID controlled pneumatic bellows with force transducer feedback which potentially allows normal force to be variable during a cycle. The loading system is mounted freely on a horizontal linear slide allowing the fixed specimens to self-center on the moving specimen.

An electrically fired furnace allows the test to be run at temperatures up to 800°C. The system is design to use simple specimen geometries that are inexpensive to fabricate.

### **Research Projects Impacted by New Equipment**

The primary motivation for obtaining the new equipment is to further validate and understand microstructural changes occurring during fretting of Ti and Ti alloys for AFOSR projects funded through the Metallic Materials program, grant numbers F49620-01-1-0034 and FA9550-04-1-0418. Professors R.W. Neu and D.L. McDowell, both faculty at Georgia Tech, are co-PIs on these projects. In addition, this equipment will also be immediately utilized in a NAVAIR-sponsored project N68335-03-C-0085 involving fretting fatigue of gas turbine engine alloys.

These projects are aimed at improving reliability of attachments between components through improving the physics basis of the fatigue life prediction modeling as well as developing new tools to assess the influence of material microstructure on resistance to crack formation. The end goal is improved reliability of DoD mission-critical components and reduction in maintenance costs.

The requested equipment will give us more flexibility in choosing our fretting conditions. This new system together with our current fretting fatigue apparatus will allow us to achieve a wider variation of independent parameters to fully validate deformation and degradation models and to

study evolution of material degradation and changes in microstructure induced by fretting. The effect of temperature on fretting has not been extensively studied even though several of the applications where fretting is a potential failure mode are at elevated temperatures (e.g., the dovetail attachment in gas turbines). The deformation and degradation mechanisms are highly temperature dependent (e.g., fretting corrosion effects, relaxation of residual stress, ...). The new equipment will allow us to explore these effects.

The equipment will also be utilized in several other current and future research and research-related education programs, many of which are associated with critical DoD missions. One study involves using the new system to investigate the effect of crystallographic orientation on the fretting and friction behavior of a single crystal Ni-base superalloy used in gas turbine blade applications. Another study will examine the fretting and wear properties of Diamond-like Carbon (DLC) coatings on Ti-6Al-4V. The system is ideal for fundamental investigations of elevated temperature wear and the use of wear resistant coatings for gas turbine engine applications.