

# REPORT DOCUMENTATION PAGE

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<b>6. AUTHOR(S)</b> Adnan Akay			<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
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<b>13. ABSTRACT (Maximum 200 Words)</b> The goal of this project concerned the development of an experimental method to accurately infer and identify friction force in a dynamic system. During this one-year project, it was proposed to develop a method to measure friction and identify its damping and tangential stiffness components. From the measurements between surfaces of selected materials, tangential stiffness, friction damping properties, and coefficient of friction values were inferred. These results favorably compared with computational results obtained using available theories. The regime of relative motion used in the tests was primarily in the microslip region, which closely replicates bolted joints in large space structures as well as contact dampers between gas turbine blades. A comparison of measurement results for tangential stiffness with those obtained using Cattaneo-Mindlin theory is shown in Fig. 4 for two cases. The theoretical results agree well with those obtained from measurements for fresh surfaces, suggesting that the theories need further development for worn surfaces. This is a unique measurement device that allows repeatable and accurate measurements of relative motion and forces from which coefficient of friction, tangential stiffness, and friction damping properties can be inferred. Measurements are largely devoid of ancillary dynamic effects common in measurement systems.				
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MEASUREMENT OF FRICTION IN DYNAMIC SYSTEMS  
AFOSR GRANT NUMBER: F49620-02-1-0393

FINAL PERFORMANCE REPORT

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## 2. OBJECTIVES

The goal of this project concerned the development of an experimental method to accurately infer and identify friction force in a dynamic system. During this one-year project, it was proposed to develop a method to measure friction and identify its damping and tangential stiffness components. Specifically, the following information about a friction pair was to be identified:

- tangential stiffness
- friction damping properties
- coefficient of friction

A secondary objective was to conduct tests using the method developed to identify the same parameters for several materials.

## 2. STATUS OF EFFORT

A new friction test and identification apparatus was designed and built. From the measurements between surfaces of selected materials, tangential stiffness, friction damping properties, and coefficient of friction values were inferred. These results favorably compared with computational results obtained using available theories.

The regime of relative motion used in the tests was primarily in the microslip region, which closely replicates bolted joints in large space structures as well as contact dampers between gas turbine blades.

The design of the measurement apparatus focused on generating controlled motion in one dimension. The design requirements imposed on the apparatus included:

- Negligible roll of sliding surfaces because "rolling" of the measurement samples leads to inaccurate relative motion measurements.
- Ability to make measurements for large and small sliding distances.

The measurement apparatus and its accessories are shown in Figures 1 and 2. The moving sample is attached to a beam clamped at both ends. Vibrating the beam by an exciter provide the relative motion between the samples. To ensure the beam oscillates at the excitation frequency (which corresponds to its first natural frequency), beam was designed with a variable cross section so that: (1) beam acted as if it had simply-supported boundaries and (2) second and higher frequencies were far removed from its first (excitation) natural frequency to avoid contribution by these modes to cause asymmetric motion of the beam and thus produce a roll of the specimen associated with relative motion. This apparatus also uses sufficiently small contact specimens so as to produce negligibly small inertial forces.

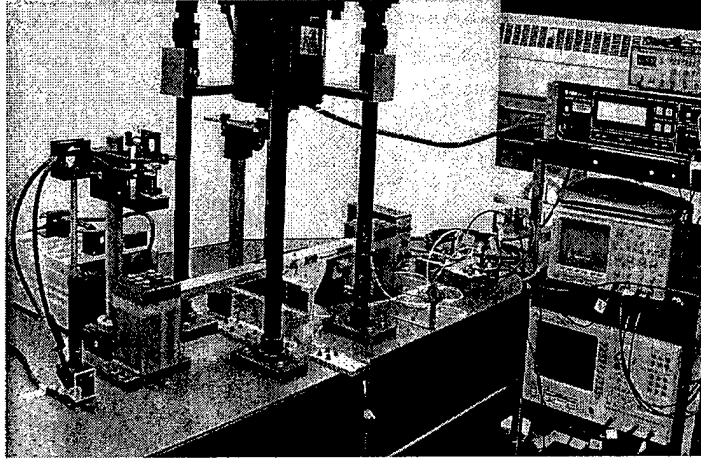


Figure 1. Experimental apparatus to measure contact parameters.

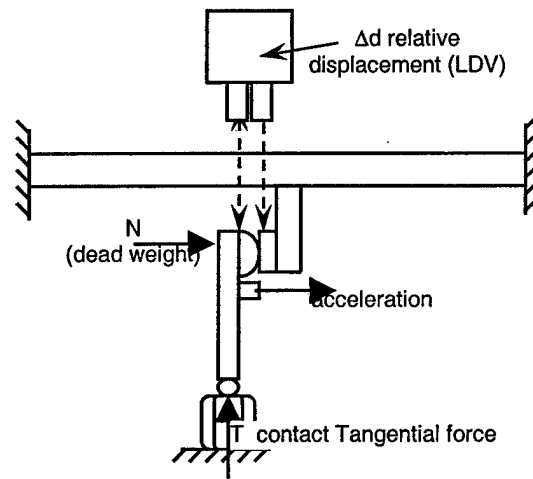


Figure 2. Schematic description of the measurement.

The sample measurement in Fig. 3 shows a typical relationship between friction force and relative displacement at contact. Although experimental results show that tangential contact stiffness does not have a completely linear behavior, the initial slope of the hysteresis curve provides the stiffness value used in linear models.

A comparison of measurement results for tangential stiffness with those obtained using Cattaneo-Mindlin theory is shown in Fig. 4 for two cases. The theoretical results agree well with those obtained from measurements for fresh surfaces, suggesting that the theories need further development for worn surfaces.

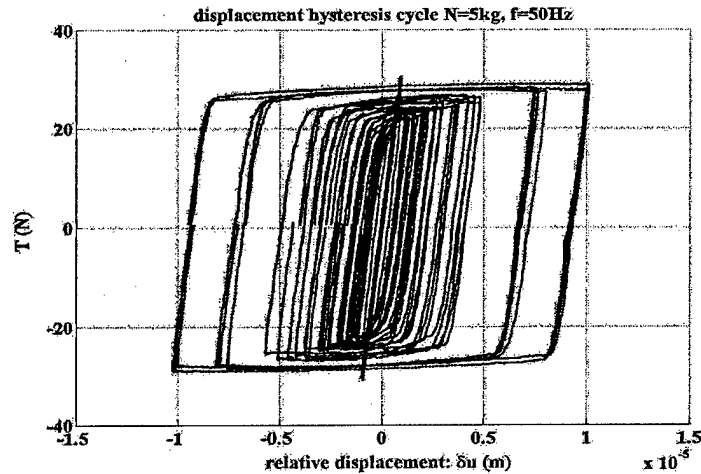


Figure. 3 – Friction (Tangential) force under different excitation amplitudes.

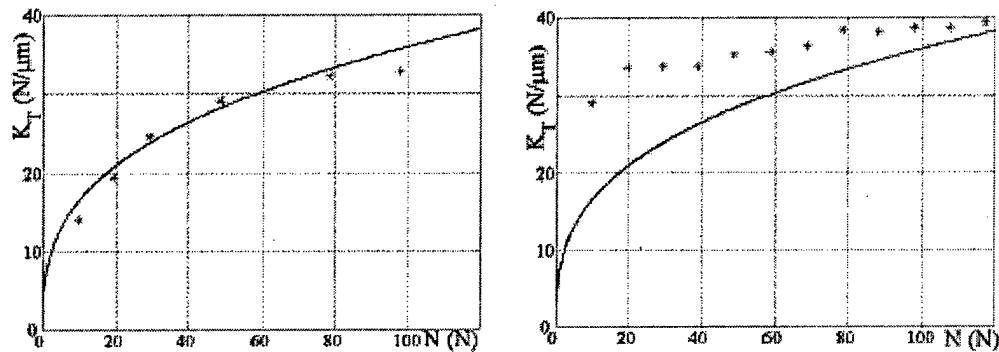


Figure. 4 – Tangential stiffness inferred from measurements (\*) compared with the analytical predictions using the method by Cattaneo and Mindlin. The comparison is very favorable when surfaces are fresh (left) as compared with worn surfaces (right).

#### 4. ACCOMPLISHMENTS/NEW FINDINGS

A new apparatus was designed and constructed to measure friction force between to small surfaces under cyclic motion. This is a unique measurement device that allows repeatable and accurate measurements of relative motion and forces from which coefficient of friction, tangential stiffness, and friction damping properties can be inferred. Measurements are largely devoid of ancillary dynamic effects common in measurement systems.

#### 5. PERSONNEL SUPPORTED

Adnan Akay – Professor  
 Sergio Filippi -- Post-doctoral researcher  
 Zhaoshun Xu -- Researcher

## 6. PUBLICATIONS

- S. Filippi, A. Akay, and M. M. Gola, "Measurement of tangential contact hysteresis during microslip," *ASME Journal of Tribology* (2003) [Accepted].
- S. Filippi, M. Citelli, and A. Akay, "Measurement of Transient Friction Hysteresis," *Proc. Leeds-Lyon Symposium on Tribology*, 2-5 September 2003.

## 7. INTERACTIONS/TRANSITIONS

### a. Participations, presentations at meetings, conferences, seminars

- S. Filippi, M. Gola and A. Akay, "A new design to measure contact hysteresis," *Proc. ESDA2002: 6th Biennial Conference on Engineering Systems Design and Analysis, Istanbul, Turkey, July 8-11, 2002.*
- A. Akay, S. Filippi, and M. Citelli, "Measurement of Friction Force and Hysteresis," *7<sup>th</sup> National Congress on Applied Mechanics*, Albuquerque, NM, July 27 – 31, 2003 – Invited Keynote
- M. Citelli and A. Akay, "Characterization of friction between brake pad and rotor materials," *SAE Brake Colloquium*, October 19 – 22, 2003, Hollywood, FL.
- K-H. Koh, J.H. Griffin, S. Filippi, and A. Akay, "Characterization of turbine blade friction dampers," *8<sup>th</sup> National Turbine Engine High Cycle Fatigue (HCF) Conference*, 14-16 April 2003, Monterey, CA

### b. Consultative and advisory functions

Technical Advisory Committee – Pratt & Whitney

### c. Transitions

The results of preliminary measurements and the description of the experimental method described above have been presented at an AFOSR-sponsored workshop on contact mechanics. They have also been presented at conferences and are submitted for publication in relevant journals. As importantly, the research is carried out in conjunction with professor Griffin's group and, through Professor Griffin, the results are being made available to researchers and industry participants within the GUIde III Consortium community.

8. NEW DISCOVERIES, INVENTIONS, PATENTS

None

9. HONORS AND AWARDS

Adnan Akay

Lord Professor of Engineering (1997)

Fellow, American Society of Mechanical Engineers (1989)

Fellow, Acoustical Society of America (1989)

Gershenson Distinguished Faculty Fellow (1987)

Jerry Griffin

William J Brown Professorship (2002)

Fellow, American Society of Mechanical Engineers