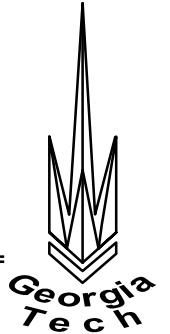


Characterization and Modeling of the Holding Force in a Magnetic Chuck

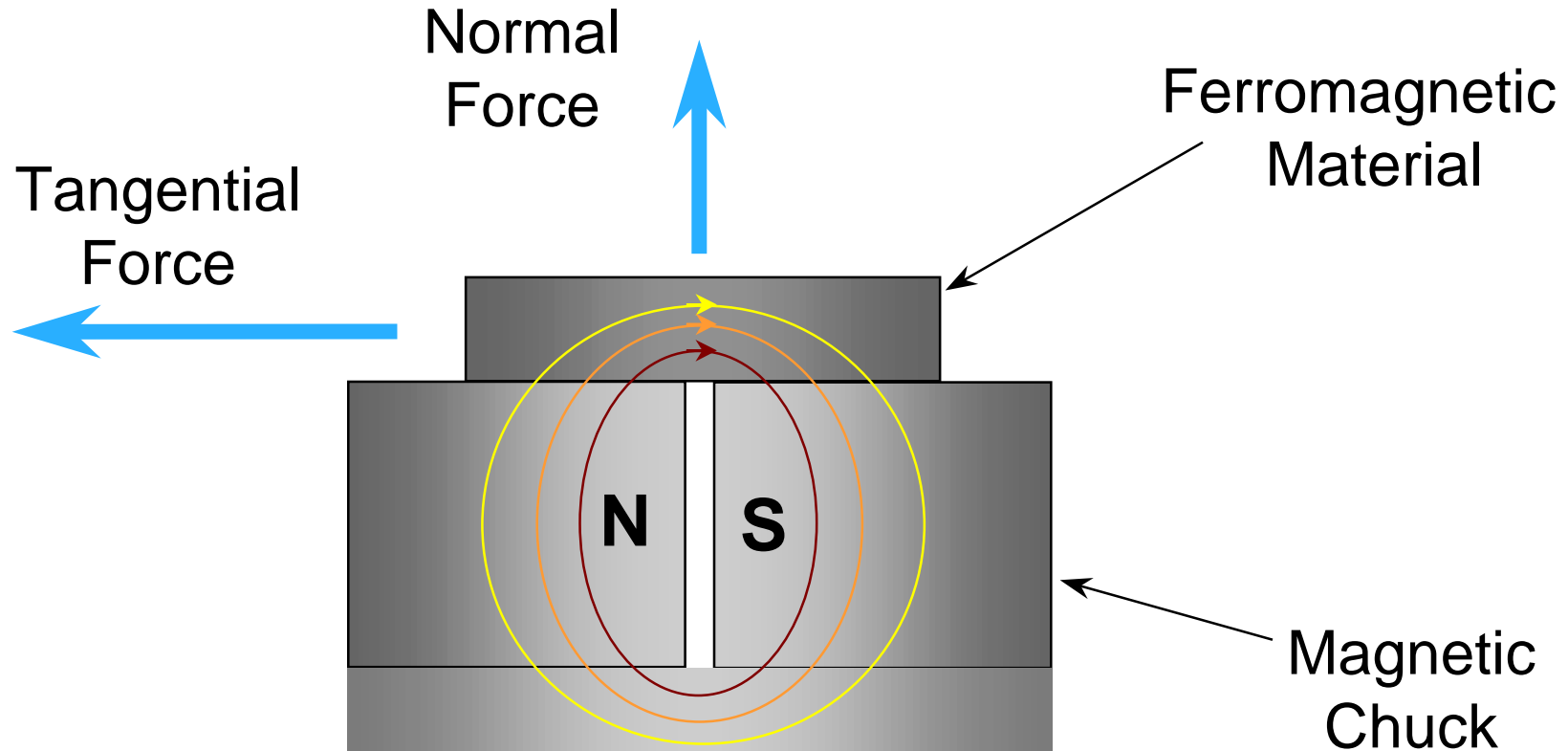
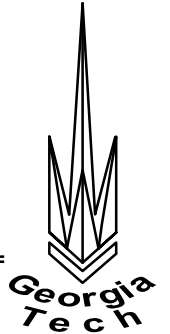


Precision Machining Research Consortium

George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
October, 1998

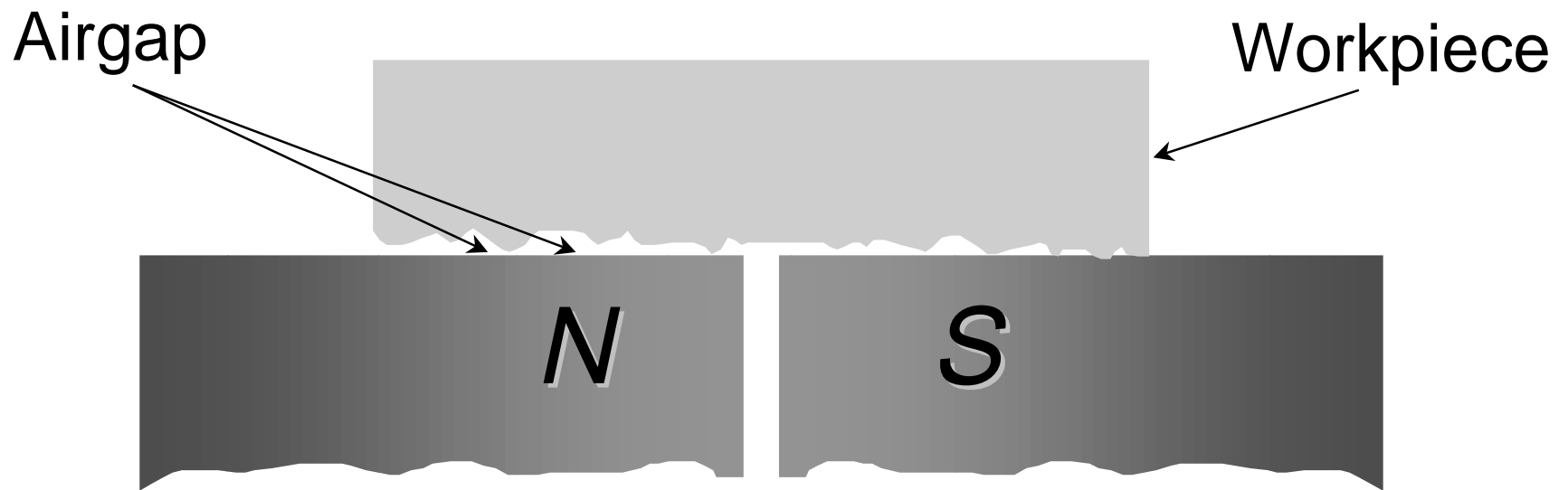
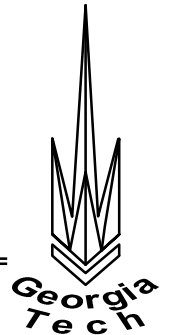
GRA: Alejandro Felix
PI: Dr. Shreyes N. Melkote
SPONSOR: The Timken Co.

Introduction



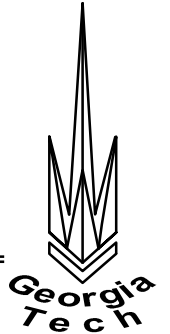
Adequate tangential holding force needed to prevent workpiece slip in precision machining operations.

Introduction (Continued)



- Contact surface conditions influence workpiece holding forces and hence workpiece slip.

Objectives



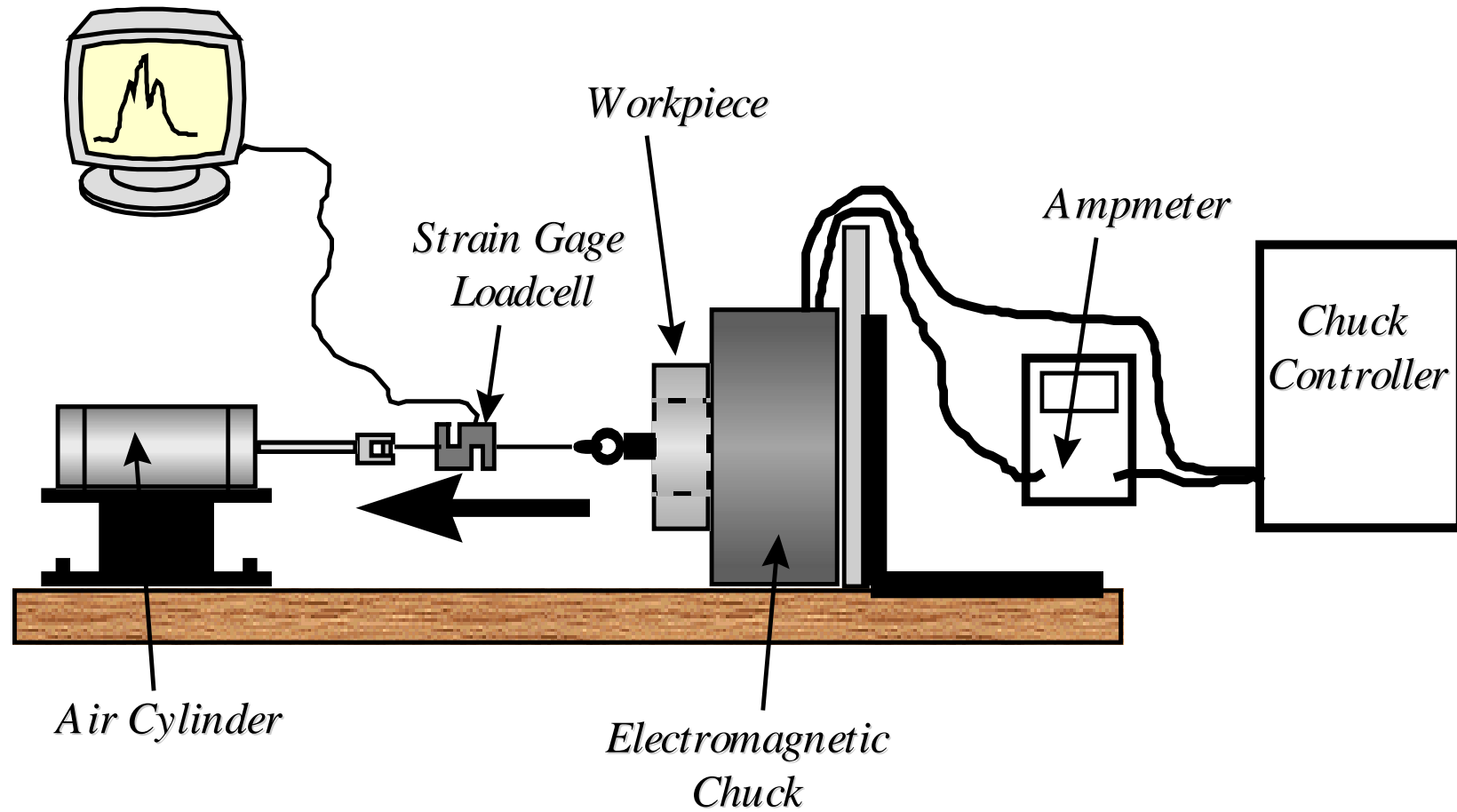
Primary:

Characterize and model the effects of workpiece surface attributes (texture, flatness) on the normal and tangential holding force in an electromagnetic chuck.

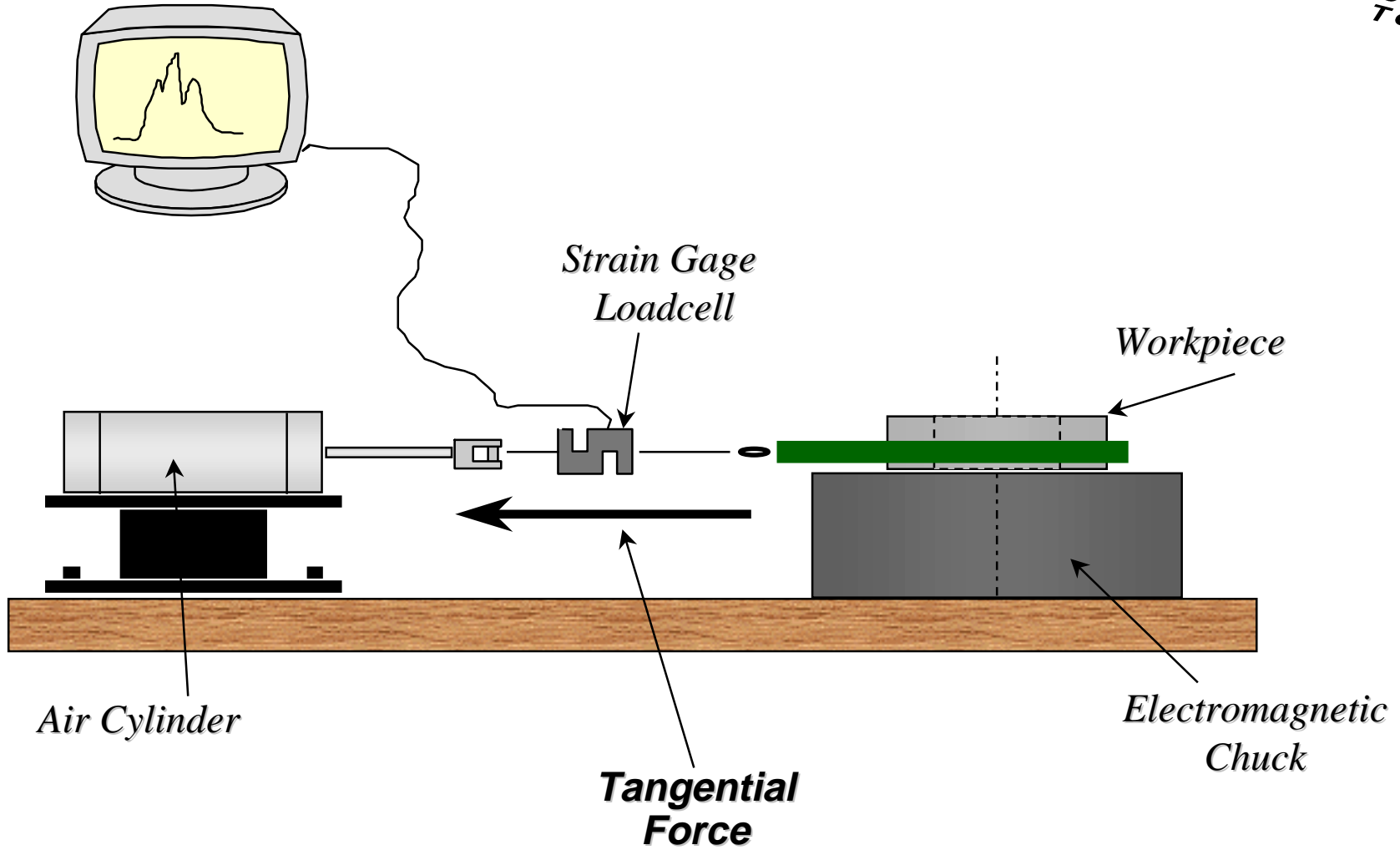
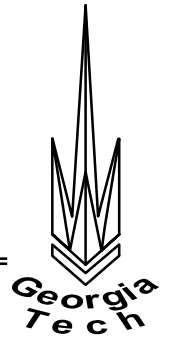
Secondary:

Characterize and model the effects of workpiece geometry (dimensions) and material properties (hardness, microstructure) on the normal and tangential holding force in an electromagnetic chuck.

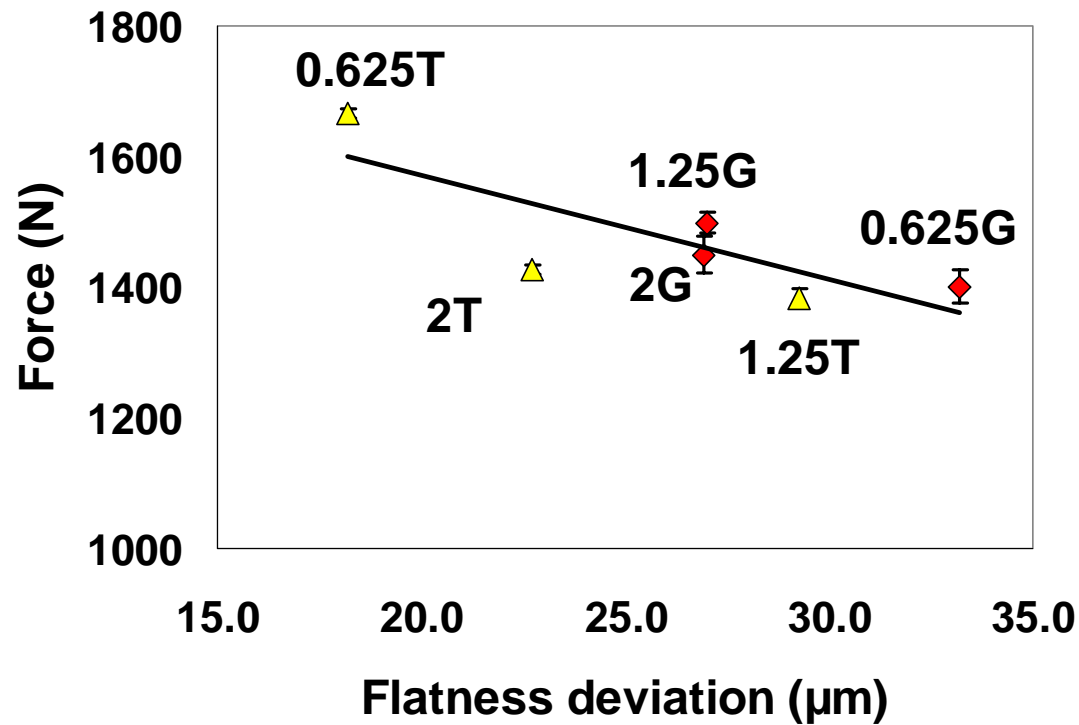
Modified Experimental Setup (Normal Force)



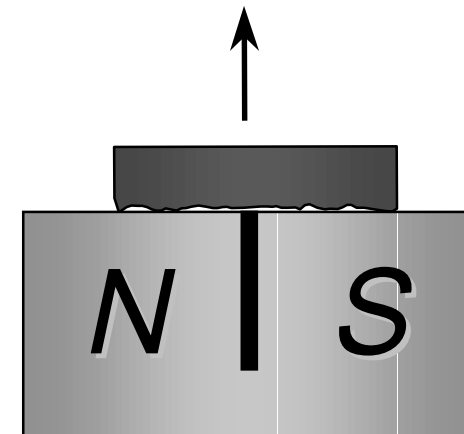
Experimental Setup (Tangential Force)



Experimental Results: Normal Force

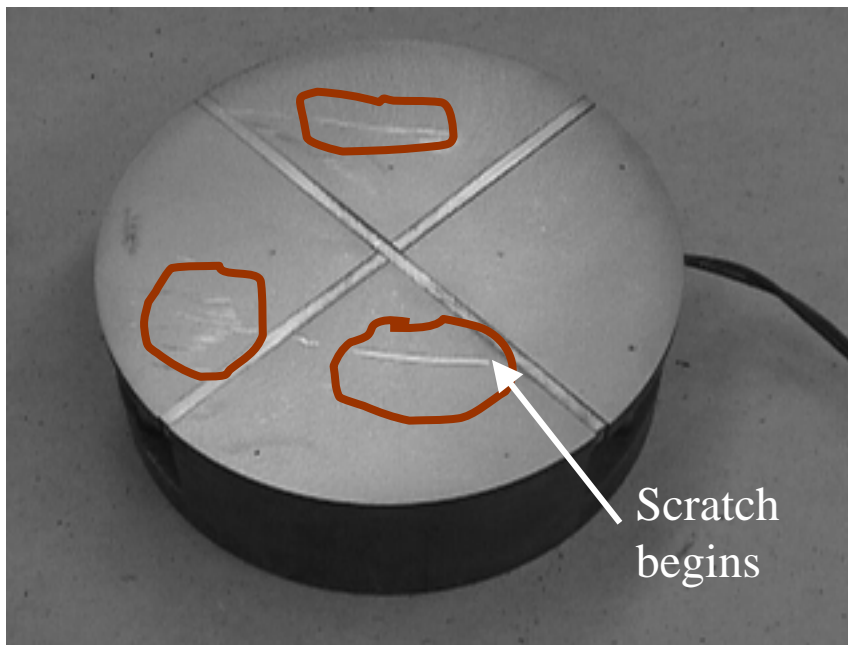


- 1.25G refers to a ground specimen with 1.25 μm Ra.
- 1.25T refers to a turned specimen with a 1.25 μm Ra.



Ploughing of the Chuck Surface

Pulling Direction
←

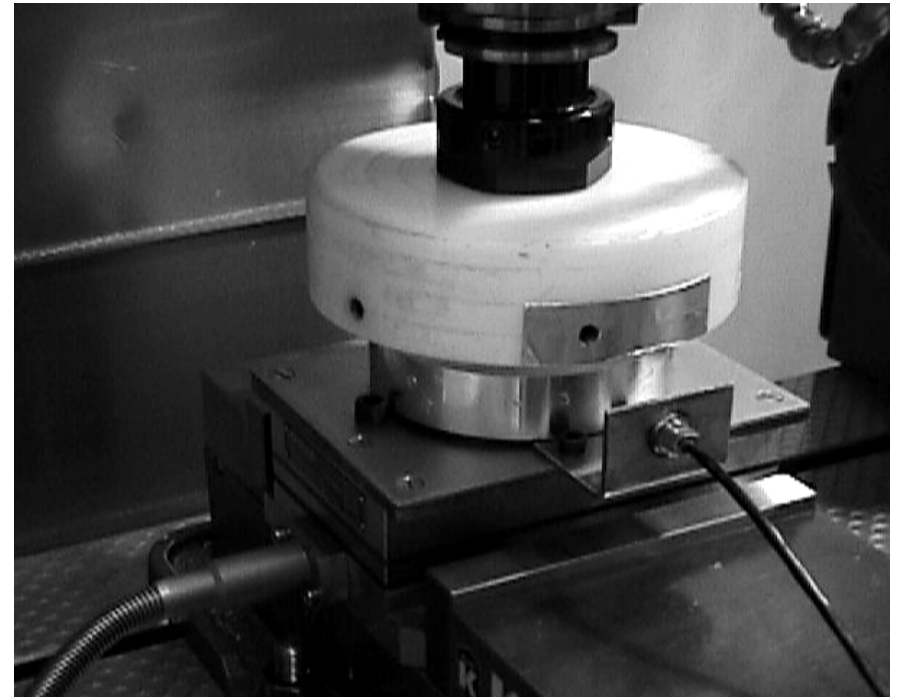
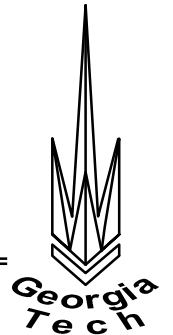


4-Pole chuck after a tangential test with the $2\mu\text{m}$ turned specimen

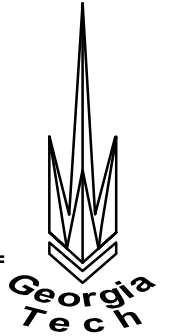


Beginning of a scratch on the 4-Pole chuck after a tangential force test with the $2\mu\text{m}$ turned specimen

Static Coefficient of Friction Experiment (Ploughing Included)

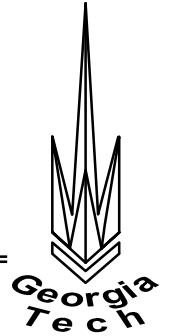


A CNC milling machine was used to apply the normal force and the tangential motion. Displacement was detected with an eddy current displacement sensor.

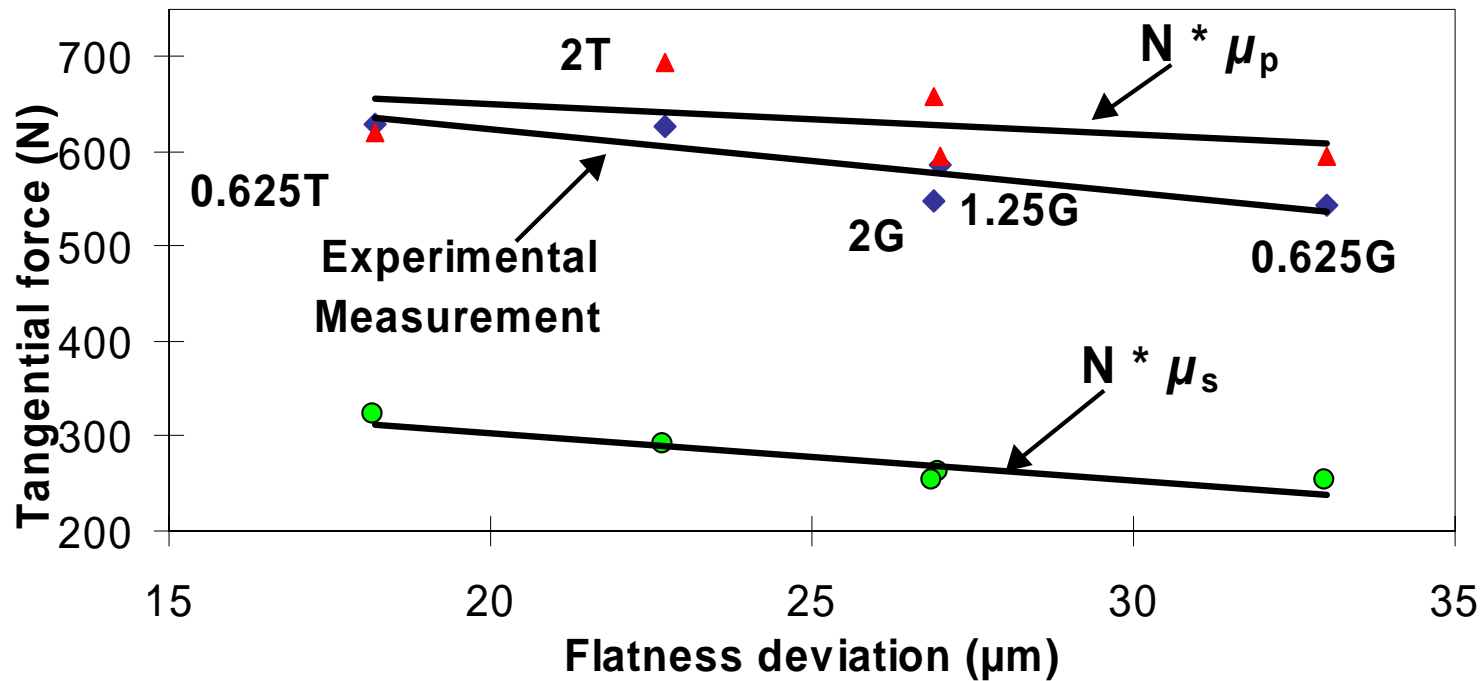


- Knowledge of the tangential holding force is important to set machining parameters.
- An electromagnetic analysis can be done to calculate the normal holding force.
- The Coulomb friction model can be used to estimate the tangential holding force.

Comparison of Measured with Estimated Tangential Force (Ploughing Effect Incl.)

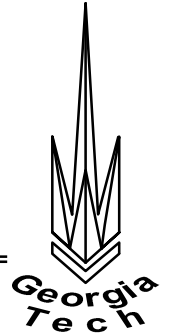


Tangential holding force is estimated by: $F_t = \mu \cdot N$



Ploughing due to scratching of the chuck's surface has a considerable effect on the holding force

Experiment Design

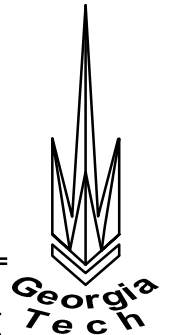


Two more sets of experiments were designed to characterize the effects of surface flatness and roughness:

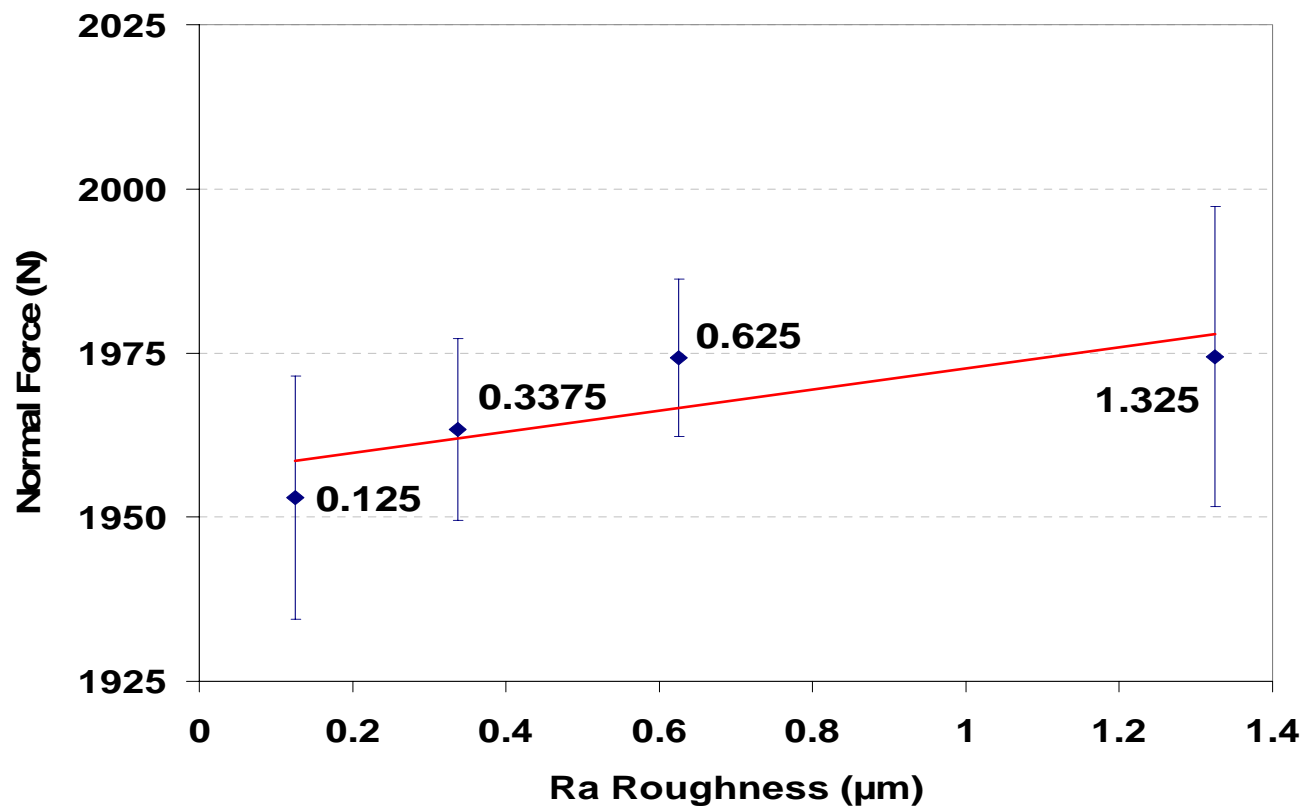
- Surface roughness: 1 factor with 4 levels.

- Surface flatness: 2 factors with 3 levels:
 - *Real area of contact.
 - *Volume of air at the contact interface.

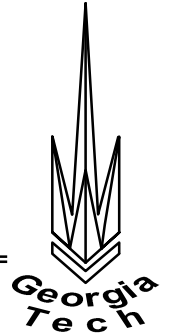
Surface Roughness Experiments



An ANOVA conducted to the data, resulted in a P-value of 0.26, indicating that there is no significant effect of the surface roughness on the normal force at a 95% α -level.

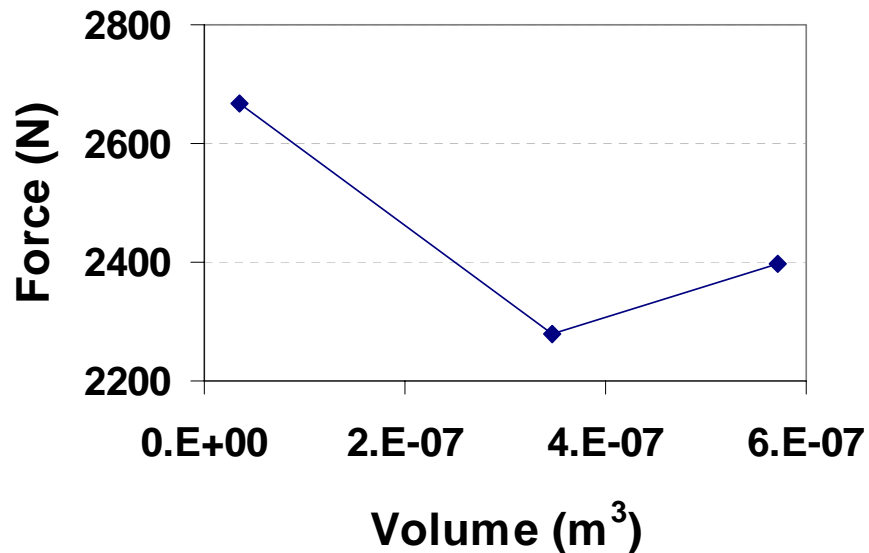


Surface Flatness Experiments

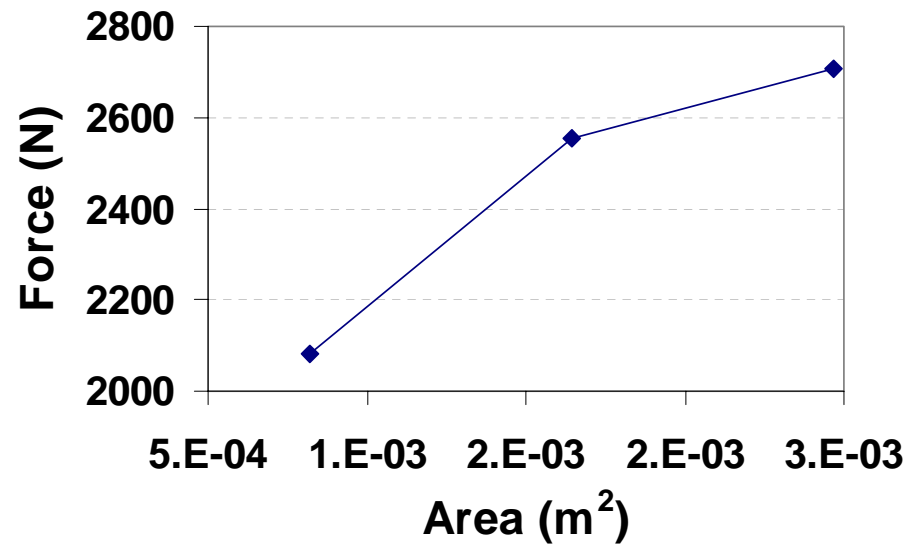


An ANOVA concluded that both factors have a significant effect at an α -level of 99%.

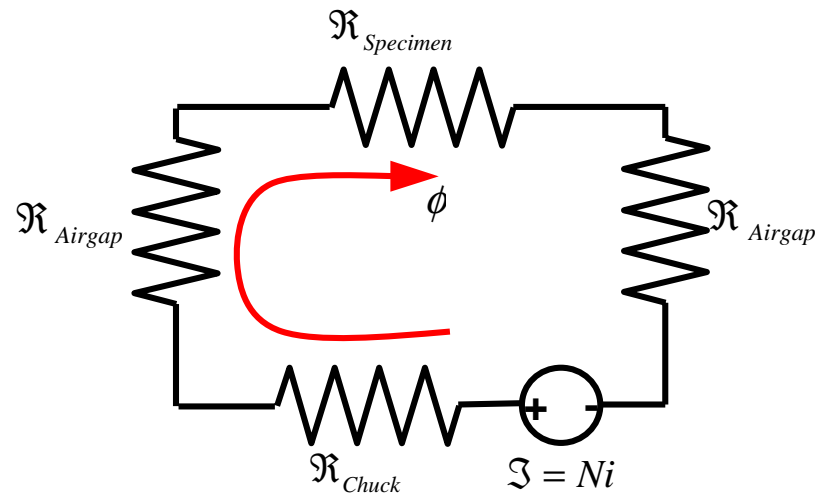
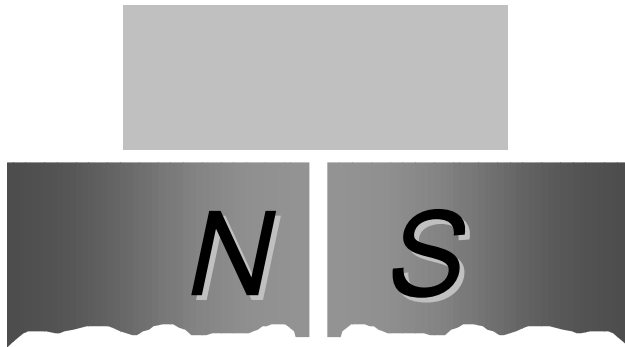
Main Effect Plot for the Volume



Main Effect Plot for the Area



Modeling of the Normal Force



The force in a magnetic core is defined as:
$$\mathbf{F} = \frac{1}{2} \mathbf{BH} = \frac{1}{2} \frac{\phi^2}{\mu_0 \cdot A}$$

B = Magnetic flux density

H = Magnetic field strength

A = Cross sectional area

μ_0 = Permeability of air

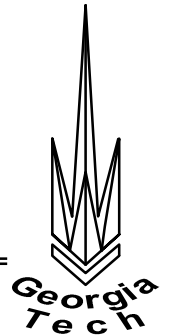
\mathcal{S} = Magnetomotive force

\mathcal{R} = Reluctance

ϕ = Magnetic flux

F = Mechanical force

Conclusions



- The normal holding force for a radial pole electromagnetic chuck decreases as the flatness error of the workpiece increases. It has been found that over a $15\mu\text{m}$ flatness range, the holding force was reduced by more than 15%.
- The tangential holding force for a radial pole electromagnetic chuck is affected by the flatness and surface finish of the workpiece. The observed decrease is about 13% for the same flatness range.
- To make adequate predictions of the tangential force using the Coulomb friction model, a coefficient of friction that takes into account ploughing must be considered.
- There is no significant effect of the surface roughness on the normal holding force of the magnetic chuck.