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Designer Tribology: Opportunities of(f) the Surface[ψ]

by

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I am honoured to be conferred the privilege of being invited to give the first talk this morning. I am more than a little embarrassed by being scheduled ahead of a Fellow of the Royal Society, Prof. John Pethica, and — as a mere IIT-Madras product — even ahead of a Kharagpur Professor. I take this sequencing as a hint from the organisers that I am to say my piece in short-order and make way as quickly as possible for the distinguished and vastly more knowledgeable speakers to follow.

There are two perspectives from which I will approach the topic that I have chosen to call "Designer Tribology": The first will be from the vantage point of a supporter of basic research: the second through an overview of the cross-disciplinary opportunities that are emerging in our country — opportunities we should clasp so as to advance the sciences in tribology; and should exploit to advance the state-of-the-art.

There are three sections to my presentation: The first explains what I mean by 'Designer Tribology'; the second is a brief description of a few experimental techniques and instruments of significance to tribology which have been developed in India, and the third is a forecast of the incipient emergence of what I have chosen to call 'quantum tribology'.

I. What do I mean by Designer Tribology?

If I know only the "texture properties" of material surfaces; candidate "lubricants" (if any), the "physics-dynamics" of the contact(s) between them, and the operating conditions, can I design on an engineering scale a combination of material, "surface texture" and "lubricant" which, *without testing the combination*, I can guarantee will have predicted tribological behaviour in the specified operating environment?

Conversely, if I wish particular tribological behaviour in an operating environment, can I design *a priori* a combination of "surface-texture", materials and "lubricants" which will (with some concession to trial iteration between these three parameters) guarantee that behaviour — again without actual test of the combination?

By "designer tribology" I mean the knowledge-base that is piece-wise tunable to providing affirmative answers to both those questions.

This very distinguished gathering knows much better that I do how far we are from providing affirmative answers to either of the questions just posed. Many of you might even believe that time, money, graduate-students and imagination are better expended in "getting on with the job"; and, furthermore, that it is not worthwhile even to attempt such first-principle approaches. Even analytically inclined research managers can be relied upon to advise deferment of investments in such approaches; at least until economically affordable solutions can no longer be demonstrably provided by the use of empirical, experience-based design-tools, supported by — if I may use a term from discredited cricketing practice — "match-fixing" between analysis and experiment.

Given the social psychology of real-world engineers I am reconciled that such "getting on with the job" will continue for quite sometime to be the approach of choice for shop-floor, field-deployment and product-design use. But this approach has at least four limiting infirmities built into it. First, what is affordable in an industrially advanced, rich country can be prohibitively expensive in an unrich one — as India is. Second, there are whole sets of new-application, novel, cost-effective, surface-engineering, lubricant, cutting-tool and friction-material technologies which are not available to us in

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India because they are "dual-use" (i.e. have also significant military application), even if you can afford to buy them. Third, you cannot hope to be even contemporary with the emerging-technology envelope, not to speak of being competitively ahead of it, if you are dependent on internationally marketed commercial technology — again assuming you can afford it. Fourth, unless you have knowledge-mastery over the full range of your operating parameter-space, "getting on with a (different) job" on an industrial scale even with familiar technology can cause ruinously expensive — even catastrophic — failure.

Now the braves of the tribology community will find that each time those limiting infirmities are sought to be overcome, they have to turn increasingly 'fundamentalist'. And they will quickly realise that the techniques and instruments necessary to support their welcome ideological re-orientation will need to be developed and validated if the inexorable paradigm shift is not to be frustrated.

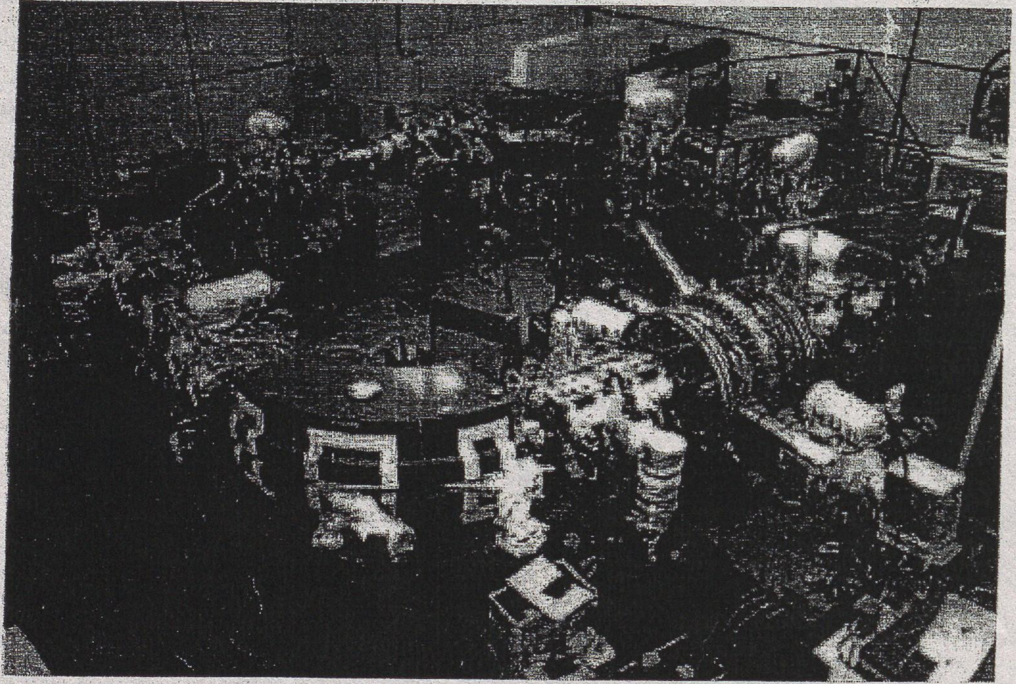
II. Techniques and instruments for Designer Tribology

Designer Tribology will, *inter alia*, call for very precise, high-resolution techniques of probing and measurement of material properties, contact behaviour and surfaces structure.

I will now briefly mention two such techniques and one instrument that have been developed in India.

Small-angle neutron scattering: Ceramic cutting-tools are now commonplace. As these get smaller in size, for use in micro-machining for example, micro-pores and other inhomogeneities in the ceramic material can degrade their performance as tools. It turns out that such performance-degrading inhomogeneities are strongly scattering of neutrons. This property has been exploited at the Solid State Physics Division of the Bhabha Atomic Research Centre (BARC). A small-angle neutron scattering instrument has been built[1] with resolution superior to the conventional slit collimation instrument. May I urge research mentors to exploit in full the capabilities of this excellent instrument, and explore with it new, imagination-driven possibilities?

Synchrotron Radiation: Another powerful tool built indigenously and now available in our country is the Indus-1 synchrotron radiation source at the Centre for Advanced Technology in Indore. The beam lines of this radiation source can be used for both surface diagnostics and shaped micro-machining[2] (of tribological reference materials and surfaces, for example).



The Indus-1 synchroton radiation source at the Centre for Advanced Technology, Indore has an angle-integrated photoelectron spectroscopy beamline which can be used to study the physics of surfaces.

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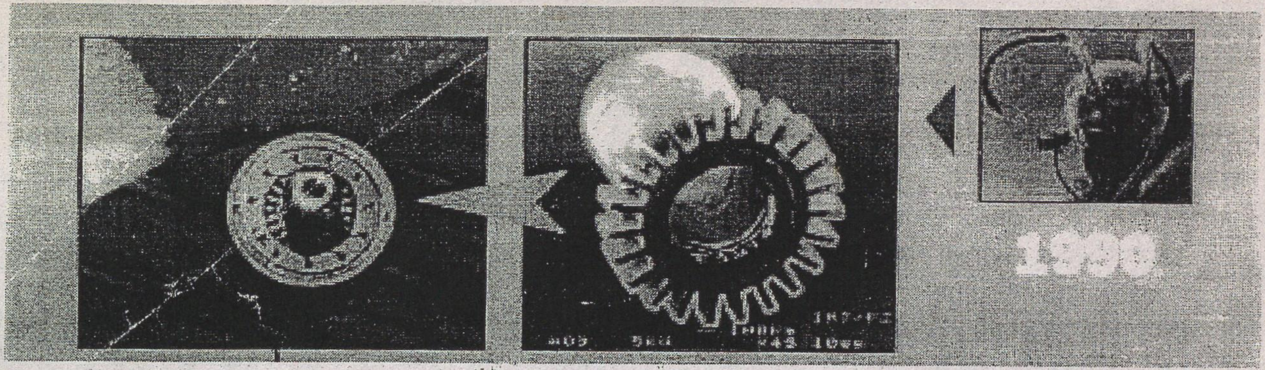
1 S. Mazumder, D. Sen, T. Saravanan, P.R. Vijayaraghavan, A medium resolution double crystal based small-angle neutron scattering instrument at Trombay, *Current Science*, Vol.81,.No.3, August 10, 2001

2 Special Section: Indus-1 Synchroton, *Current Science*, Vol.82, No.3, February 10, 2002

Where could such a diagnostic tool be used? Perhaps here.



Micro-turbine milling cutter for unblocking coronary vessels. Soft-tissue abrasive (?) wear at macro-molecular scale. Karlsruhe, 1996

Surface Force Apparatus: This audience knows that although boundary lubrication has been in existence for 40-50 years, the mechanisms which render it effective are still far from being fully understood. The main hurdles in the path of securing the required understanding have been the unavailability of high-resolution instruments and the absence of dynamic simulation procedures at the molecular level. As part of the effort to understand the basic mechanisms of boundary lubrication, an unique Surface Force Apparatus with a force resolution of 1nN and displacement resolution of less than 1nm has been designed and fabricated at the Indian Institute of Science, Bangalore. The equipment is designed to generate, under hot conditions, molecular-level rheological and physical information in sliding gaps containing boundary lubricants of molecule dimensions.

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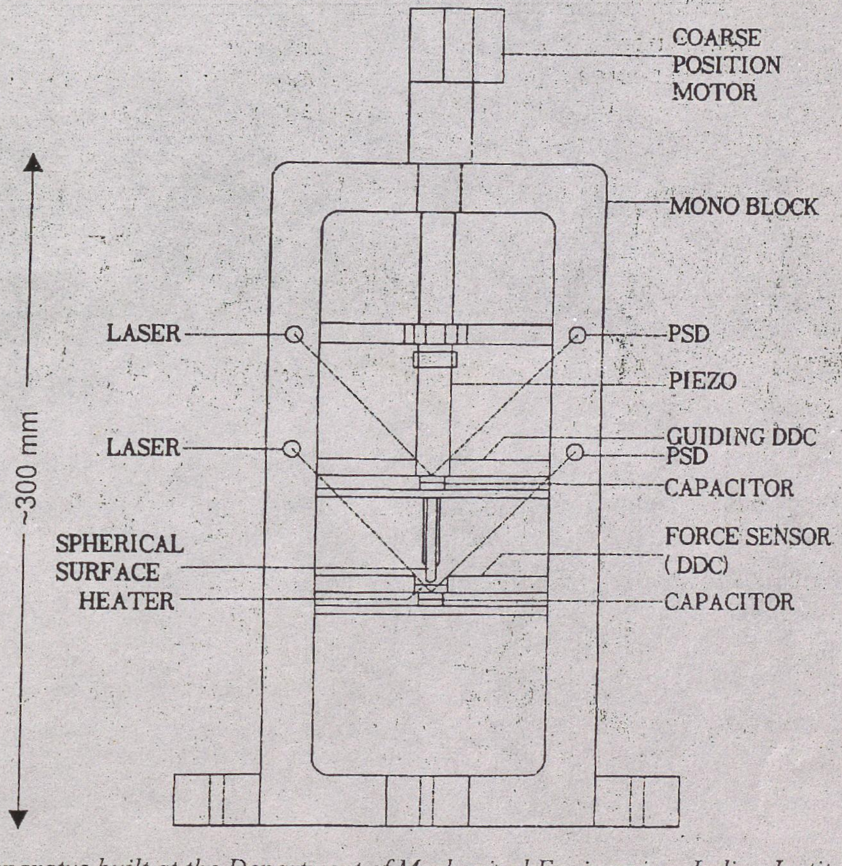


Surface Force Apparatus built at the Department of Mechanical Engineering, Indian Institute of Science

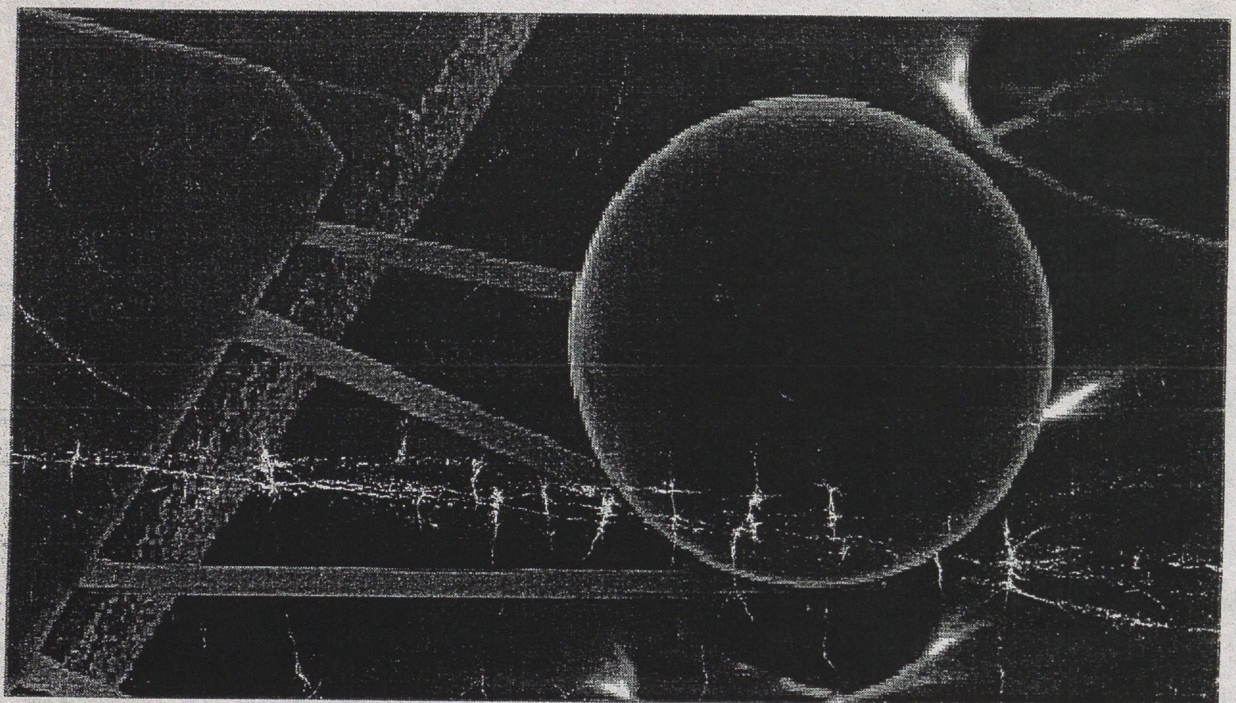
The information generated in this Surface Force Apparatus is correlated with the results of molecular dynamics simulation to provide spatial distribution of molecules subjected to dynamic conditions. Thus states of order and disorder of these molecules which play important influence on tribology properties are detectable by this technique.

III. Towards "quantum tribology" — are we nearly there?

Micro-mechanical and Micro Electro-Mechanical Systems (MEMS) are now commercially available. We in India now have, as part of the national programme on smart materials, a modest programme on the development in national laboratories and academic institutions of a variety of sensors and MEMS actuators.

As MEMS get to become smaller, the surfaces of the devices can be in very close proximity (≤100 nm). At these distances, quantum electro-dynamic effects caused by what is known as the 'Casimir Force' come into play. This force — named after the predictor of its existence — originates from quantum-mechanical zero-point fluctuations of the electromagnetic field between uncharged metallic surfaces.

Anushree Roy, a young Professor now at IIT Kharagpur, and her erstwhile colleague Umar Mohideen at the University of California have measured the normal Casimir force for the first time.[3]



Roy and Mohideen (1998) brought this 200-µm-diameter sphere mounted on a cantilever to within 100 nm of a flat surface to detect the Casimir force.

Mohideen and colleagues have recently confirmed the existence of the lateral Casimir force.[4]

As micro-mechanical devices get smaller in size, their design and construction may well have to contend with and accommodate the strangeness of Casimir or "quantum" friction.[5]

And if "quantum friction" is thus here, can "quantum tribology" be far behind?

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3 U. Mohideen and Anushree Roy, Precision Measurement of the Casimir Force from 0.1 to 0.9 *µm*, Phys. Rev. Lett. 81, 4549-4552 (1998).

4 F. Chen, U. Mohideen, G.L. Klimchitskaya, V.M. Mostepanenko, Demonstration of the Lateral Casimir Force, Phys. Rev. Lett. 88, 101801 (2002).

5 Mehran Kardar: The "Friction" of Vacuum, and other Fluctuation-Induced Forces, ITP Colloquium, October 10, 2001
(See at http://online.itp.ucsb.edu/online/colloq/kardar1/pdf/kardar.pdf)

Cf: 'Directed Basic Research' using synchrotron Radiation (INDUS), specifically mentioned at II overleaf. Regs.

PSA Dr. V. Siddhartha [signature]

Thanks. Very interesting. RC/28.8 28 Aug 09