Frictional systems under periodic loads

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Nominally static contacts such as bolted or shrink-fit joints typically experience regions of microslip when subjected to oscillatory loading. This results in energy dissipation, reflected as apparent hysteretic damping of the system, and also may cause the initiation of fretting fatigue cracks. Early theoretical studies of the Hertzian contact problem by Cattaneo and Mindlin were confirmed experimentally by Johnson, who identified signs of fretting damage in the slip annulus predicted by the theory.

For many years, tribologists assumed that Melan's theorem in plasticity could be extended to frictional systems – i.e. that if there exists a state of residual stress associated with frictional slip that is sufficient to prevent periodic slip in the steady state, then the system will shake down, regardless of the initial condition. However, we now know that this is true only if there is no coupling between the normal and tangential loading problems, as will arise notably in the case where contact occurs on a symmetry plane.

For all other cases, periodic loading scenarios can be devised such that shakedown occurs for some initial conditions and not for others. The initial condition here might be determined by the assembly protocol – e.g. the order in which a set of bolts is tightened – or by the exact loading path before the steady cycle is attained. This non-uniqueness of the steady state persists at load amplitudes above the shakedown limit, in which case there is always some dissipation, but the dissipation per cycle (and hence both the effective damping and the susceptibility to fretting damage) depends on the initial conditions.

This also implies that fretting fatigue experiments need to follow a well-defined assembly protocol if reproducible results are to be obtained. We shall also present results showing that when both normal and tangential forces vary in time, the energy dissipation is very sensitive to the relative phase of the oscillatory components, being greatest when they are out of phase.

With sufficient clamping force, 'complete' contacts (i.e. those in which the contact area is independent of the normal load) can theoretically be prevented from slipping, but on the microscale, all contacts are incomplete because of surface roughness and some microslip is inevitable. In this case, the local energy dissipation density can be estimated from relatively coarse-scale roughness models, based on a solution of the corresponding 'full stick' problem.