Introduction

A fixed joint can be defined as any interface between two solids intended to experience no gross relative motion. Whether it is a bolted joint in a machine tool, a riveted joint in an aircraft structure, or a clamp or locator acting on a workpiece held in a fixture, the basic interfacial dynamics are the same. The focus here is on the basic modeling of a uniformly loaded interface, not a specific joint and its geometrically non-uniform loading (e.g., a bolted joint).

Past works have addressed the modeling of a uniformly preloaded interface subjected to an applied time-varying load in either the normal or tangential direction. The model presented here extends those works to account for generically time-varying bi-directional loading, where generically refers to the time variation being not necessarily periodic or harmonic, and bi-directional implies that both loads (normal and tangential) are time varying. While the model and its numerical implementation are valid for these conditions, it is demonstrated by exploring the effects of phase and relative load amplitudes under harmonically time-varying bi-directional loading — a type that occurs in many physical structures. One such example is the original motivator of this undertaking — the dynamics of machine-tool joints subjected to machining process loads.

Approach

Interfacial dynamics are dictated by the interactions that occur at the asperity level. A dynamic surface interaction model embodies two basic building blocks — an asperity-interaction model, which describes the mechanical response of mating asperities, and a statistical surface model, which describes the distribution of asperity characteristics across the surface. Research on asperity interaction modeling has addressed the mechanical response of mating asperities, and a statistical-surface model of the Greenwood and Williamson (GW) approach. The two rough surfaces in contact are approximated as an ideal statistical-surface model of the Greenwood and Williamson (GW) approach.

The reformulated asperity interaction model is then combined with the statistical-surface model of the Greenwood and Williamson (GW) approach. The two rough surfaces in contact are approximated as an ideal statistical-surface model of the Greenwood and Williamson (GW) approach.

Results

Figure 4 (top) shows the hysteretic loops for simulations made for a preload of \( P = 800 \) N, a tangential load amplitude of \( T = 110 \) N and a normal load amplitude of \( N = 110 \) N (i.e., \( N/T = 1 \)). Also shown is a baseline for which only a tangential load exists (i.e., \( N = 0 \)). For consistency, each graph is for the fifteenth loading cycle, at which point some of the loops are not closed because the response is not at steady state. The baseline hysteretic loop for \( N = 0 \) is consistent with previously published closed-form solutions, taking on its steady-state path after the first one-quarter cycle (initial loading).

As can be seen from Fig. 4 (bottom), the energy dissipation per cycle is maximized at phases around 90° and 270°. Analogous to the varying effects of phase on the walking and skewness, the peaks are not quite symmetric about 90° and 270°. Though not shown here, the equivalent static stiffness decreases and then increases between 0° and 360°, reaching a minimum at 270°.

Both the energy dissipation and equivalent stiffness for \( N \neq 0 \) are at times greater than, and at other times less than, their respective values during purely tangential loading. This behavior is dictated mainly by the value of the preload and its ratio to the normal load amplitude.

Benefits

- Model-based orientation of joints to optimize damping and/or stiffness based on the load amplitude ratio and/or phasing seen by the joint.
- Model-based preload specification to balance stiffness and damping.

Costs

- The cost of model-based orientation of joints to optimize damping and/or stiffness based on the load amplitude ratio and/or phasing seen by the joint.
- The cost of model-based preload specification to balance stiffness and damping.