A round robin friction hysteresis test at Politecnico di Torino and Imperial College London

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Abstract. One of the major challenges for the joint mechanics community is the accurate modelling of the dynamic response of jointed structures subjected to vibration. This modelling is particularly challenging due to the presence of frictional contacts at the joints. Frictional contacts are generally modelled by means of friction hysteresis loops (see Fig. 1a). In order to replicate hysteresis loops, several input parameters are required, such as friction coefficient and tangential contact stiffness. These parameters cannot be accurately predicted by current contact models due to a lack of understanding of the complex friction mechanisms. Hence, experiments are required, which are often expensive in terms of time and cost. Several test rigs have been developed at different institutions to measure high-frequency hysteresis loops [1-6], and a series of measurements published, but a complete study of high frequency data is still missing. In addition, due to a lack of direct comparisons, the reliability of these friction rigs remains unknown and there is no standardized approach for conducting measurements. The joint mechanics community has in fact been talking for a long time about comparing contact parameters measured from those friction rigs to provide more confidence in the data sets used for nonlinear dynamic analysis. This research partially addresses this issue by presenting a complete study on hysteresis measurements based on a purposely designed round robin test that includes the two high-frequency friction rigs of Imperial College London [1] and Politecnico di Torino [2].

Description of the round robin test

The round robin test attempted to measure tangential contact stiffness and friction coefficient values via the two existing friction rigs. Specimens were manufactured from the same batch of stainless steel. A large matrix of tests was designed to record hysteresis loops (see Figure 1a) at room temperature for a wide range of loading conditions chosen based on the compatibility of the rigs, but also to expand the test range beyond what each rig could do. The experimental matrix is shown in Fig. 1b and consists of four normal loads (17, 87, 180 and 253 N), four displacement amplitudes (1, 14, 25 and 50 μm) and four nominal areas of contact (1, 5, 10 and 40 mm^2).

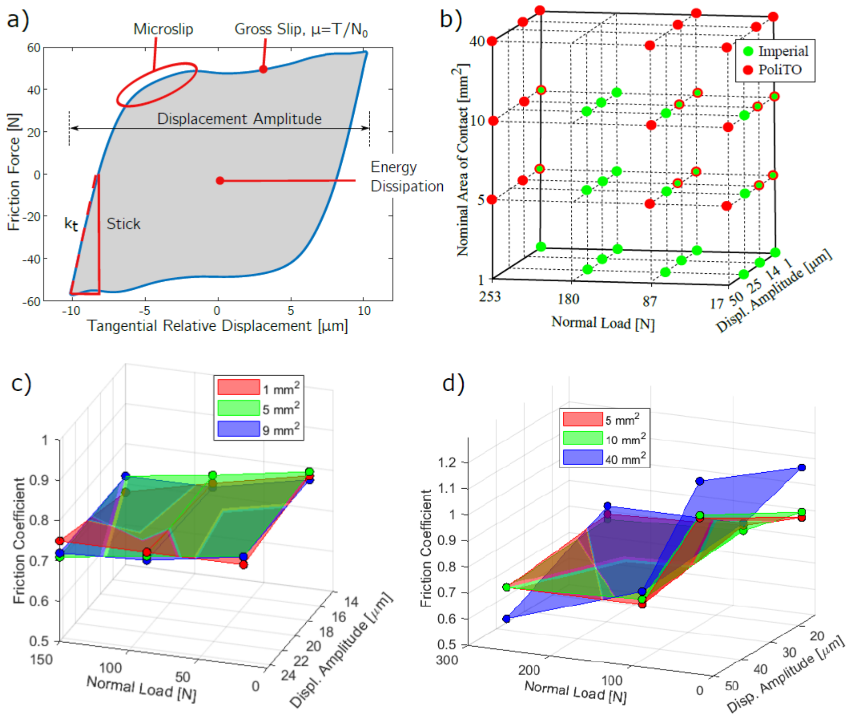

Fig. 1. a) Typicial hysteresis loop (μ is the friction coefficient, k_t is the tangential contact stiffness, T is the friciton force during gross slip and N_0 is the normal load); b) round robin test matrix; c) steady state values of μ for the Imperial friction rig; d) steady state values of μ for the PoliTO friction rig.

The ranges of normal loads and displacement amplitudes were chosen to measure hysteresis loops in all the different contact regimes, namely full stick, microslip and gross slip. The two rigs operate at slightly different excitation frequencies (100 Hz and 175 Hz), which correspond to the optimal excitation frequencies of each rig, but this difference was not considered to relevant for the observed behaviour. The selected range of nominal areas of contact was chosen to check for the scalability of the results, but also to understand the best way of modelling frictional contacts in dynamics simulations (e.g. if it is better to discretise the interfaces with many 1 mm^2 contact patches or with fewer 40 mm^2 patches). For every load combination, a new unworn specimen pair was used and run for 2.5 consecutive hours to investigate the evolution with wear. Before and after every test, scans of the contact interfaces were acquired with optical microscopes. In this way, the condition of each specimen interface could be visually assessed before the experiments to ensure that the interface did not have scratches or imperfections. In both rigs, Ra roughness values were below 2.5 μm.

Preliminary comparison in the friction coefficient measurements

The large experimental matrix and the completion of all the tests resulted in more than 100 tested specimen pairs being tested and more than 300 hours of testing, which, at an average excitation frequency of 140 Hz, correspond to roughly 150 million recorded hysteresis loops. In general, hysteresis loops strongly varied at the beginning of the test and then reached a steady state after an initial 30 minutes running-in. For every hysteresis loop, three parameters were extracted, the friction coefficient μ (calculated as the ratio between friction force during gross slip and normal load), the tangential contact stiffness k_t (calculated as the gradient of the stick portion of the loop from the reversal up until the force is equal to zero) and the energy dissipated (evaluated as the area inside the loop, i.e. the integral of the friction force over the relative displacement), as indicated in Fig. 1a.

This extended abstract only shows preliminary results on the friction coefficient measurements by means of Fig. 1c-d, which show the steady state values of μ for the two rigs at different load conditions and nominal areas of contact. The Figures show that μ is mostly unaffected by the loading conditions, except a slight normal load dependency. It in fact decreases by up to 15% with increasing normal loads, especially in PoliTO tests. This slight normal load dependency might be due to the fact that, at larger normal loads, a full established gross slip has not been achieved within the relatively small investigated displacement amplitudes (14 μm and 50 μm). Trends with regards to the displacement amplitude and nominal areas of contact are less clear, suggesting that these parameters do not affect μ estimations to a large extent.

In general, μ stabilises to an average value of 0.79. This value can be considered as a reference value to be used as input in nonlinear dynamic analysis for stainless steel contacts under the load ranges analysed, namely 100-175 Hz excitation frequency, 14-50 μm displacement amplitudes and 17-254 N normal loads. With regards to the repeatability, measurements on the individual rigs for the same loading conditions were quite repeatable (uncertainty below 4% at Imperial and below 6% at PoliTO). The PoliTO rig provided larger values than Imperial (on average 15% larger). This mismatch is probably due to inaccuracies in the normal load measurement in the rigs. In order to account for this experimental uncertainty, it is suggested to run multiple nonlinear dynamic simulations with different μ input values within the 15% in the investigated range.

Conclusion

A round robin test was performed on the high frequency friction rigs at Imperial College London and Politecnico di Torino with the aim to increase the confidence in the measurement of contact interface parameters used as input in nonlinear dynamic analysis. The round robin test consisted of measuring a multitude of hysteresis loops for different loading conditions including varying normal loads and sliding distances. Specimens have been manufactured from the same batch of stainless steel material in order to guarantee a reliable comparison between results from the fretting rigs. Both rigs employed flat-on-flat contacts with nominal contact areas in the range of 1 to 40 mm^2. Preliminary results were shown here of friction coefficient measurements. The findings suggest that the friction coefficient is mostly unaffected by the loading conditions and it has an average value of 0.79 for the stainless steel material used. Results were quite repeatable from the two friction rigs, with differences below the 15%. This relatively low uncertainty increases the confidence in the measured contact parameters used as input for nonlinear dynamic analysis. More results from this round robin test will be published in future, hopefully providing many more insights for the joint mechanics community and more guidelines on the best use of existing high frequency friction rigs. The authors would also very much like to encourage other research groups to participate in this comparison, so that it can become a comprehensive Round-Robin that will add even more value to the community.

References

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