Design of Fretting Test Machines and Instruments

A G Plint at the Institute of Materials

Synopsis

Regardless of the tribological tests we wish to perform, the mass, stiffness, method of actuation and load application all have significant influence on the results produced by a given design of test machine. Friction and wear are system properties and thus have influence on the performance and control of the machine.

The design of fretting test machines presents a number of special problems in particular in respect of precise control of amplitude and mid-stoke position. Designs for high temperature applications or for hostile environments present challenges in respect of material selection. High frequency applications require considerable care in the design and selection of instrumentation and signal conditioning in order to avoid frequency response and phase angle errors.

The presentation will explore these issues with a view to identifying the strengths and weaknesses of a number of different design solutions.

Methods of Actuation

Electro-mechanical Actuation

Electro-mechanical systems of actuation (a motor driven mechanism) can provide a simple and perhaps nominally cost effective means of stroke actuation. However, such systems suffer from a number of serious limitations.

It is very hard to devise a system that allows control and adjustment of the stroke length while the machine is running.

It is very hard to devise a system that will allow precise adjustment of the mid-stroke position to compensate for thermal expansion while the machine is running.

Mechanical drive systems, involving bearings, lack the necessary stiffness.

Mechanical systems are subject to fretting and fatigue failure.

Piezo Actuation

Piezo actuation can provide a cost effective means of actuation for low load applications, with the benefit that the inertia of moving components is very low, hence minimising out of balance forces and the requirement for a high mass machine.

Actuators are readily available with stroke lengths in the fretting range and with driving forces of up to 300 N (in tension) and 1500 N (in compression).

There are a number of limitations that should be considered:

The stroke of a piezo actuator is directly proportional to applied voltage.

The achievable frequency is a function both on the mechanical natural frequency of the actuator and associated tooling and the electronic frequency response of the actuator and associated power amplifier. Typical performance for an actuator with a 140 micron maximum stroke is as follows:

At 100 Hz: Maximum stroke: 40 microns (+/- 20 microns)

At 50 Hz: Maximum stroke: 80 microns (+/- 40 microns)

At 20 Hz: Maximum stroke: 140 microns (+/- 70 microns)

The fatigue life of a piezo actuator is directly related to the total applied current. For the 140 micron actuator, we have the following:

At 40 microns stroke: 10^9 cycles

At 80 microns stroke: 5×10^8 cycles

At 140 microns stroke: 2×10^6 cycles

Electro-magnetic Oscillator

We have used electro-magnetic oscillators in the past, but have never achieved entirely satisfactory results. The key problem with this type of a device is that it is a force as opposed to a displacement generator. The resistance to motion of the machine in pure sliding is of course the friction in the test contact, and in fretting, a combination of friction and elastic deformation.

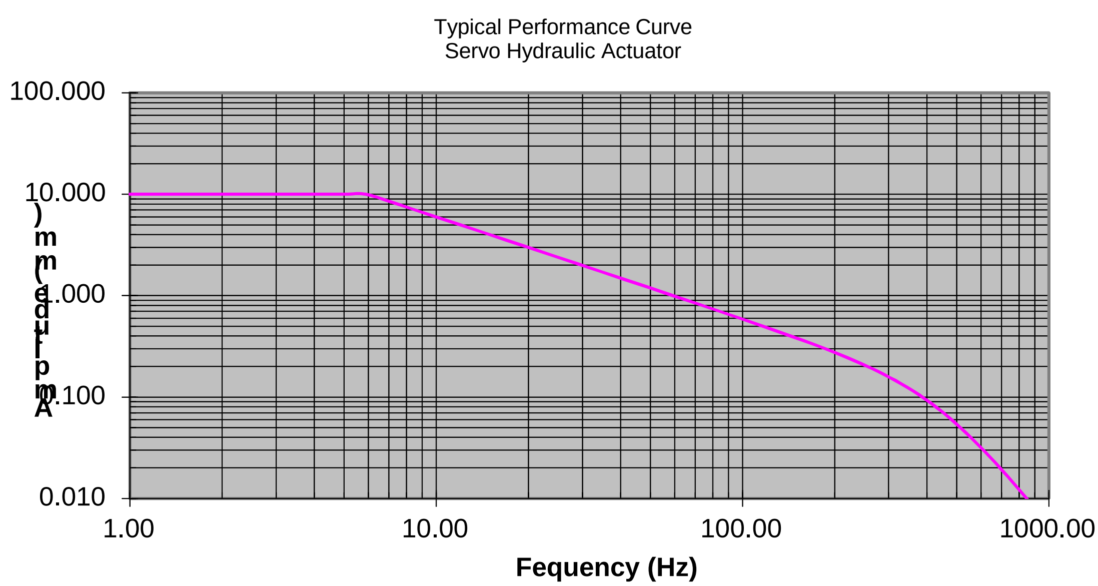
Because the resisting force changes as the test progresses, the loop gain of the system varies thus altering the system response. Even though the actuator will be operated with positional feedback, the positional control loop is still in cascade with the primary force loop. Controlling amplitude and stroke mid position is extremely difficult.

Our experience is that these types of device are only satisfactory if an actuator with a capacity far in excess of the anticipated resisting force is used. Such large actuators invariably have high mass moving parts with the potential to give rise to problems with parasitic vibrations.

Servo Hydraulic Actuation

Servo hydraulic actuators provide a very stiff driving system with precise control of displacement and mid-stroke position over a wide range of frequencies. A conventional high mass and high stiffness test machine frame, typically used for servo hydraulic dynamic testing of materials, provides an excellent base for a fretting test machine. What is more, such machines are readily available in most materials test laboratories.

With a high quality short stroke (say 10 mm maximum stroke) servo hydraulic actuator and appropriate control system, it is possible to achieve precise and continuously variable control of stroke length in the range +/- 1 micron to 10 mm with a control resolution of +/-0.2 microns and frequencies up to 500 Hz. The actuator should of course be fitted with hydrostatic bearings to avoid fretting.



Mechanical Design Consideration

Loading System Inertia Effects

Dead weight loading systems produce more severe conditions than low mass loading systems (for example spring or pneumatic actuation). This is because with dynamic conditions inertia gives rise to shock loading.

Thermal Expansion

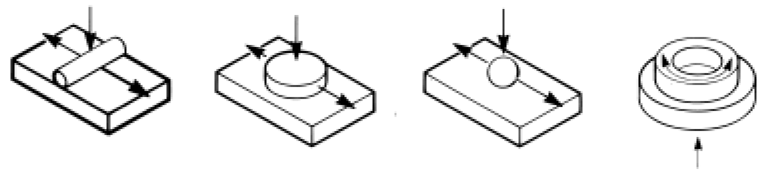
There is one caveat with all designs of fretting test machine. At the fretting stroke lengths it is normal to use a capacitance probe, LVDT or similar displacement-measuring device mounted on the fixed specimen carrier and targeted on the reciprocating specimen carrier, measuring and controlling the displacement of the moving sample with respect to the fixed sample. At very short stroke lengths, this measurement is of course influenced by any thermal expansion of the components within the measuring loop. Thermal expansion or contraction can thus give rise to drift in the measurement and hence the mean position of the moving specimen with reference to the fixed specimen. At very short stroke lengths this can become significant.

The solution is to ensure that tests are run at very stable fixed temperatures and that some form of baffling is provided to prevent differential cooling of key components. The use of low expansion alloys obviously helps, but it is of course worth noting that the mechanical properties of an alloy such as Invar 36 is not much different from those for mild steel. A draft free and temperature controlled laboratory is thus a good idea - and remember not to blow on the test assembly!

Load/Force Interaction and Specimen Inertia Effects

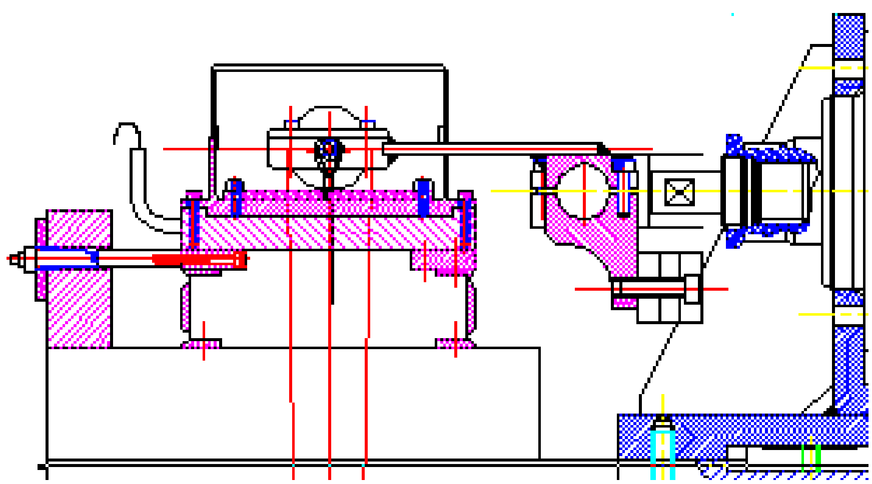
It is clearly unacceptable to have a mechanical design with a geometry in which the resulting friction force interacts with the nominal applied load, either increasing or decreasing the resulting load on the contact. This is a matter of getting the vector geometry right.

Conventional specimen configurations worth considering include the following:

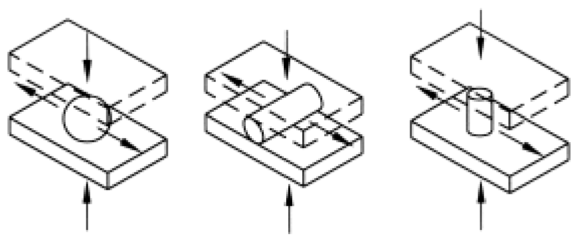


Whereas it is not particularly difficult to ensure that the specimen contact area and line of action of any driving mechanism are coaxial, it is not easy to ensure that the centre of mass of a moving specimen system is on the same axis. Failure to achieve this may, at higher velocities or frequencies, give rise to both additional inertia generated loading on the specimen contact and possible unplanned and unpredictable movement of the specimens.

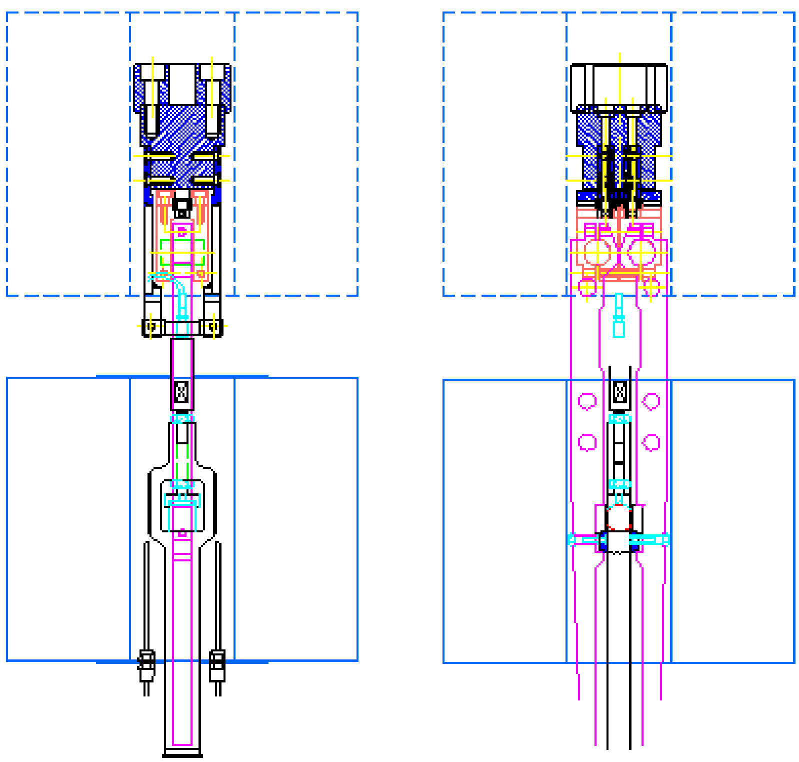
The following drawing, the general arrangement of which will be familiar to anyone with knowledge of a range of different reciprocating tribometers, is the design for fretting assembly for movement of a large diameter ball or cylinder on a flat. In this case, a counter weight is provided both to tare the applied load and to ensure that the centre of mass of the moving assembly is co-planar with the friction surface. This design worked satisfactorily over a wide range of frequencies, but at high loads occasionally suffered from undesirable resonance problems associated with flexing of the specimen arm.



In order to overcome this particular problem, we came up with a design in which a single moving specimen is reciprocated in contact with two fixed test surfaces. The centre of mass of the moving components is equidistant between the two friction surfaces, thus ensure no out of effect from inertia forces and, providing the friction coefficients on both test surfaces are approximately equal, we end up with no net turning moment on the moving specimen. Contact geometries are as follows:

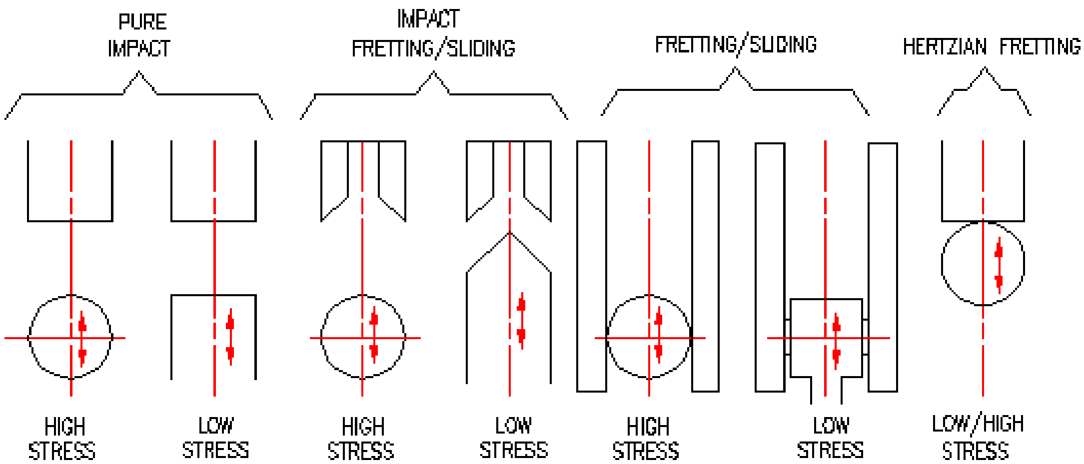


The design was implemented on a standard servo hydraulic test machine, with the moving specimen carried on the actuator rod extension. Each fixed specimen was carried on an articulated arm suspended from a piezo force transducer for friction force measurement. The unit was designed for tests at temperatures up to 800 deg C within a furnace. Specimen loading was provided by extending the specimen forks bellow the furnace and applying a load by squeezing the end of the forks together with a pneumatic loading arrangement.



The test assembly was fitted to a standard servo hydraulic test machine frame.

Originally designed for sliding fretting tests, minor modifications to the tooling can provide the capability for a number of other, in some cases potential more interesting, test geometries.



Resonant Frequencies

The higher the stiffness and the lower the mass of system components, the higher the natural frequency and the frequency response of associated measuring systems. Hence, stiff, light weight designs, with low inertia will be required for all but very low speed applications, in order to avoid resonant frequencies problems.

With high moving mass systems such as servo hydraulic actuators and large electro-magnetic vibrators, there is a requirement for the overall test machine to have a high mass in order to minimize machine vibrations. Force measuring systems with associated tooling act as very effective accelerometers with the risk that the true friction signal will be swamped by parasitic vibrations.

Frequency Response

The information content available in the signal channels of a dynamic testing machine is directly related to the signal bandwidth. The fundamental limitation in most measuring systems is the bandwidth of the transducer itself.

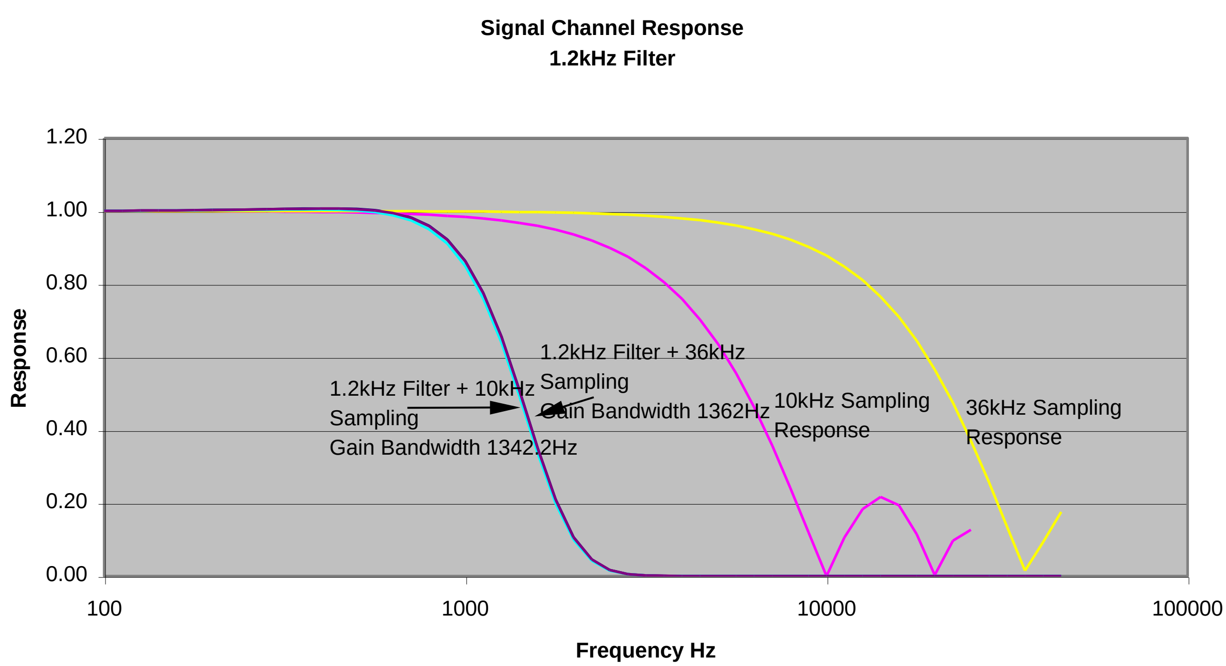
In most testing machines it is the load cell that will be the limiting factor in the form of its mechanical resonance. Most low profile strain gauge load cells will have a natural resonant frequency in the range 4000 Hz to 5000 Hz with an internal effective mass typically in the region of 0.5 kg. When typical external specimen adapters are added we can expect this resonance to fall to about 3 to 3.5 kHz. It is generally accepted that, in order to keep measuring errors low, a load cell should not be used at frequencies above about 0.3 of its resonance, therefore input filtering is imposed to limit the signal bandwidth accordingly.

We normally apply a 6-pole 1.2 kHz filter on both the displacement and force measuring channels in order to eliminate higher frequency signal noise and aliasing. The same characteristic filter should be used on both channels, especially in high frequency systems, to ensure that force information and displacement information can be directly correlated and are not subject to differing time delays.

When sampling the signals processed by such a filter it is important to sample at high enough a rate to preserve the information in original signal. The Nyquist Sampling Theory indicates that the minimum acceptable sampling rate is twice the maximum frequency of interest. The measured amplitudes of signals at half the sampling rate are attenuated to 64% of their true value and it is good practice to sample at higher rates wherever possible. With a systems usually sampling at 10 kHz, a 1 kHz signal, which would have suffered 36% attenuation with 2 kHz sampling, only suffers 2% attenuation. The graph shows the differences between the combined effects of a 1.2kHz input filter and the attenuation effects of 10 kHz sampling and 36 kHz sampling. The differences are barely noticeable.

Estimating the gain bandwidth product (an estimate of the information carrying ability of the system) shows that the 36 kHz sampled system is only 1% better than the 10kHz system. In other words sampling faster than necessary may produce more data but no more information! We could obtain the same amount of data by using a lower sampling rate and simply interpolating between the samples.

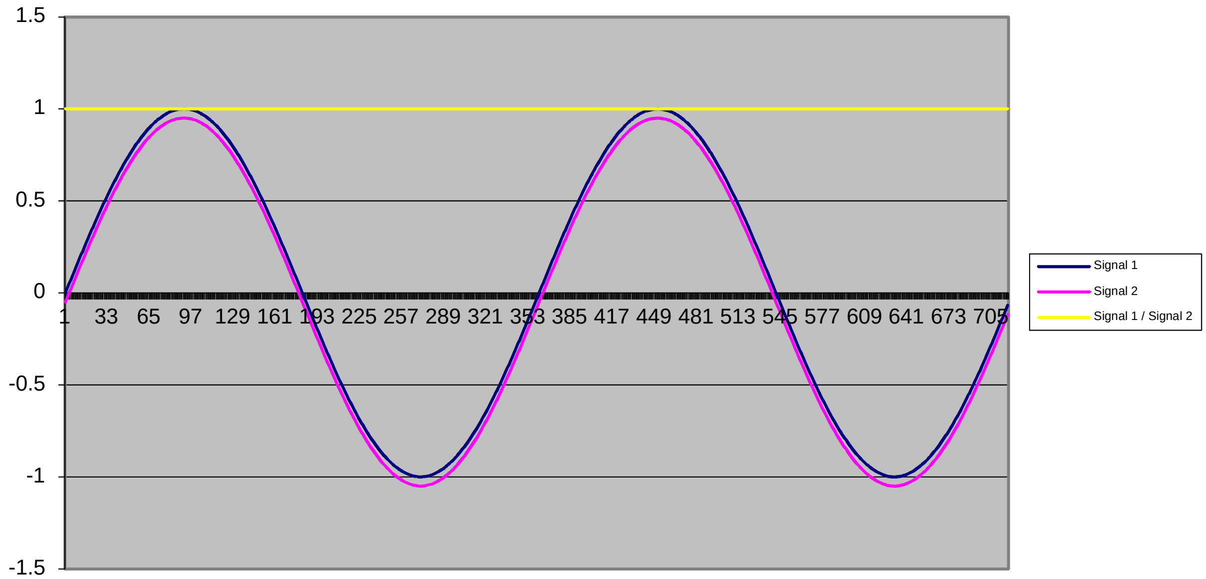
To conclude, the Sampling rate of the system should be well matched to its signal bandwidth in order to preserve information content. Furthermore the signal bandwidth should be well matched to typical measuring transducers.



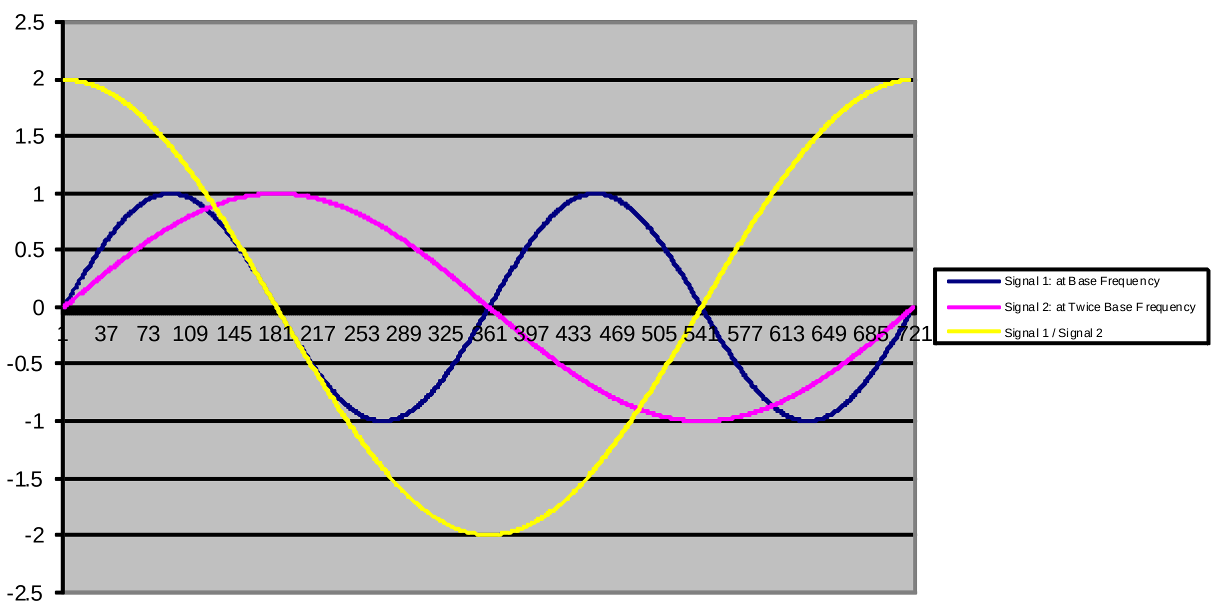
Phase Angle Errors

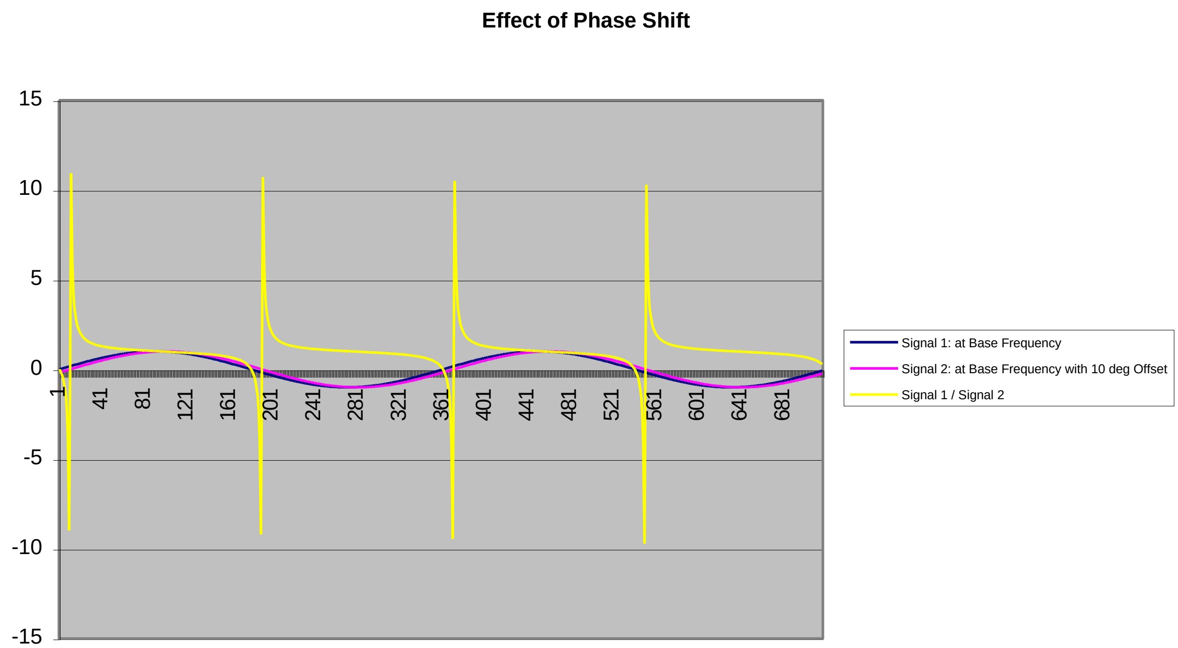
Ignoring the effects of frequency response can lead to some interesting errors, which can, for the uninitiated give rise to some spectacular errors. This is especially the case where one dynamic signal is divided by another in order to give, for example, a friction coefficient reading. The following provides a graphical illustration of this point:

Equal Frequency Response & Zero Phase Shift



Effect of Frequency Response



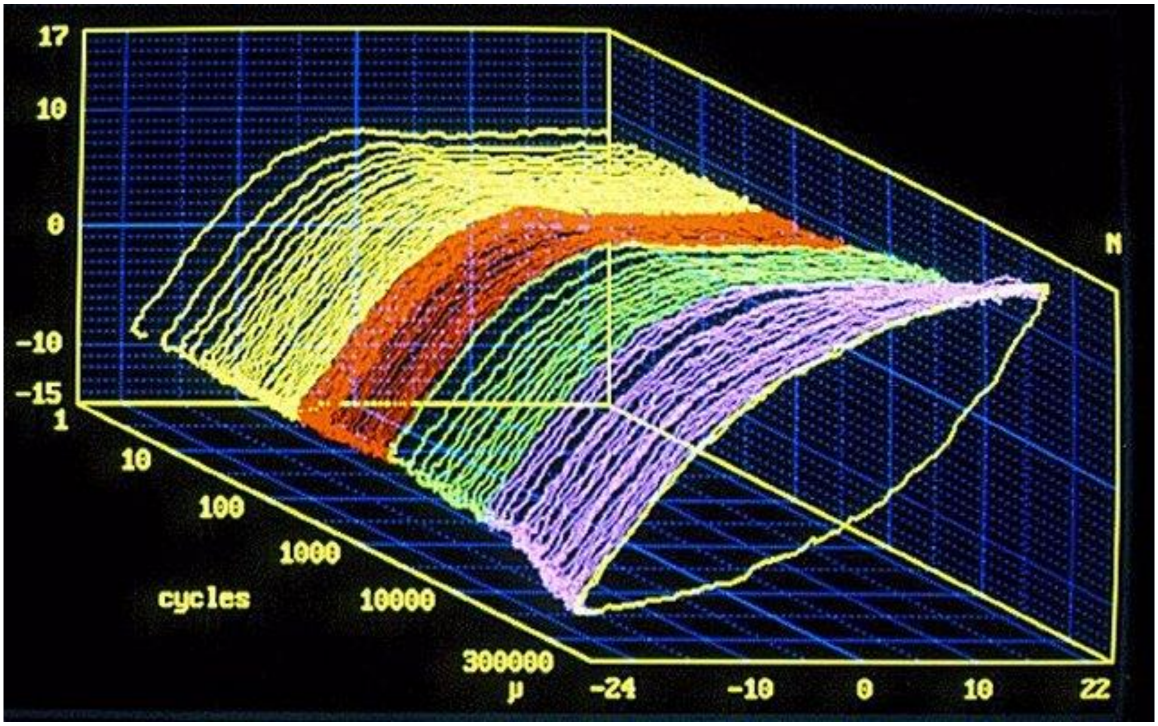


Clearly, if presented with a friction coefficient graph of the above form, alarm bells should start ringing.

Output Data

The most commonly used real time output for fretting tests is the force displacement curve. The transition from a hysteresis type curve to a trapezoidal curve is usually identified as the point of transition between combined elastic deformation and micro-slip to gross slip, the latter condition being typically associated with the generation of third bodies (oxide debris) in the contact.

A number of researchers have presented data in which filtering techniques are used to “clean up” unsatisfactory force displacement curves. It is difficult not to treat “corrected” post-processed data with anything other than suspicion. High quality data, which records what is happening in the tribological contact, free of machine vibrations and signal processing errors, should be the target and is readily achievable with the right engineering design.



Conclusion

Most of our work in fretting and fretting corrosion has been carried out for French customers. It appears that the French, with active interest in the development of nuclear power, advanced rail transport systems and the aviation and space industries, are prepared to commit resources to the investigation of fretting and fretting corrosion, in particular in respect of the application of hard coatings to tribological contacts. We are waiting to see whether anyone in the UK will develop a similar interest.