Reducing the Problem of Torsional Resonance in Mechanically Coupled Systems Using Electrical Control

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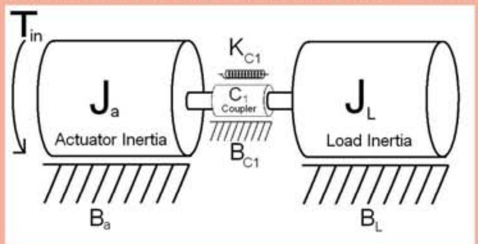
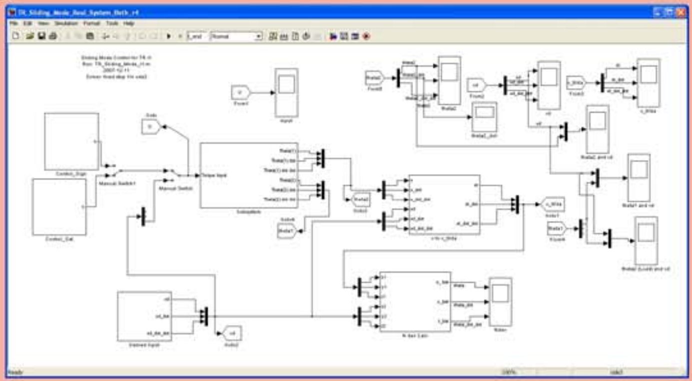
Abstract: Connecting two rotary mechanical devices utilizes a flexible coupler to accommodate various shaft misalignments. Couplers, including belts and gear boxes, exhibit a spring constant and a viscous damping term. The spring constant causes the system to have a resonant frequency while the damping controls its amplitude. In the frequency domain this characteristic is called Torsional Resonance (TR). The TR frequency can not be allowed into the pass band of closed loop servo because it will cause instability. Current workarounds to obtain stable operation include: reduction of the servo's bandwidth below the TR frequency; using stiffer, more expensive, components to increase the TR frequency thus increasing the useable bandwidth; and using notch filters to reduce the resonant peak. It is important to note that notch filters are not robust since the torsional resonance frequency can change due to non-linearities.

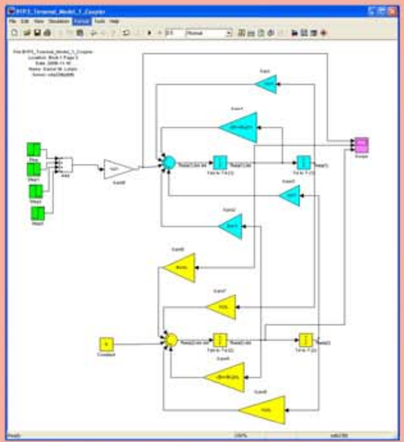


System Modeled by two inertial loads with damping associated with each as well as a coupler which is assumed to have not inertia but does have a spring constant and damping associated with it.

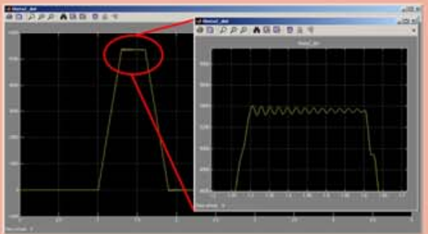


The test rig consists of a brushless DC motor with a 6.75:1 gear box, variable inertial loads as well as a system to change the belt tension. The inertial loads are connected to the motor via a belt. Both the load and the motor is monitored and controlled via a 1Ghz computer running a real time controls operating system.

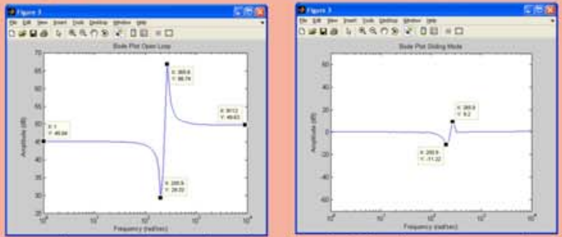
Sliding mode control, a non-linear form of robust control, is used to reduce the problem of torsional resonance. This method allows the system to track a desired profile even when parameters are unknown. In this case the parameter that is unknown is taken as the inertia. This is because the acting inertia changes before and after the resonant frequency from the summation of the motor and load inertia to just the motor inertia.



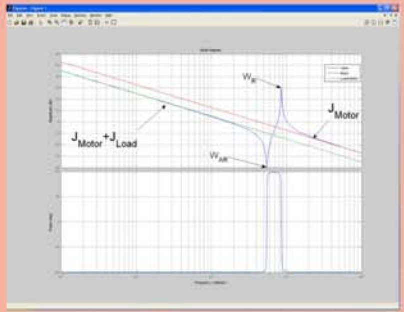
Model of the TR system made in Simulink. This will be used for testing control before implementation on the physical system.



Resonance is prevalent on the plot of velocity vs. time for a velocity ramp command input. This resonance is caused by the flexible coupler



Open loop velocity bode plot (left) shows a peek of 66dB and an offset of the position gain before and after the resonance due to the change in effective inertia. The closed loop bode plot (right), using Sliding Mode Control, shows a peek of 9dB and no offset due to effective inertia.



The slop of the open loop bode plot of the position shows that before the resonant frequency the acting inertia is the sum of the motor's inertia and the loads inertia. After the resonant frequency the motor's inertia is the one acting on the system.

Objective: To provide a control solution to allow systems using elastic parts, including loose belt drives and plastic gears achieve sufficient bandwidth to obtain their desired performance. A model of a commercial application exhibiting the TR characteristic has been made using Matlab and Simulink. A test rig has been constructed with an industry used brushless DC motor and a system able to control the location of the TR frequency. This test rig is controlled by a real time target control system which accepts control through Matlab and Simulink. In simulation non-linear Sliding Mode Control (SMC) has shown to reduce the error at resonance by approximately 50dB. This technique as well as other control methods including the work of Bigley and Rizzo will be modeled and implemented on the physical system. The ability to reduce the effects of TR using electrical control allows mechanical system implementation suing less costly components while achieving the desired bandwidth of a closed loop servo system.