A Gain Scheduling Controller for Friction Compensation

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1 Introduction

Friction in mechanical systems can show a very complex behaviour. In addition to its non-linear dependence on the velocity, friction is also function of the position. In the vicinity of motion reversal points, i.e. in the pre-rolling/pre-sliding regime, the position dependence dominates and appears in the form of a rate-independent hysteresis with nonlocal memory. One of the ways of treating this complex behaviour is through the use of the Describing Function (D.F.) method. This approach yields equivalent dynamic parameters, which are function of the amplitude of motion.

Machines using conventional, plain or rolling-element guideways will often suffer the adverse effects of friction on motion control: stick-slip, limit-cycling, quadrant glitch errors,… are common problems in such systems. Thus, in systems such as pick-and-place or spot-welding robots, the requirement of fast and accurate positioning is often difficult to realise owing to the presence of friction.

In this work, we present an application of the gain scheduling method to realise an effective controller in the presence of friction. The criterion for scheduling is based on equivalent dynamic parameters obtained from the D.F. formulation.

2 Control Strategy

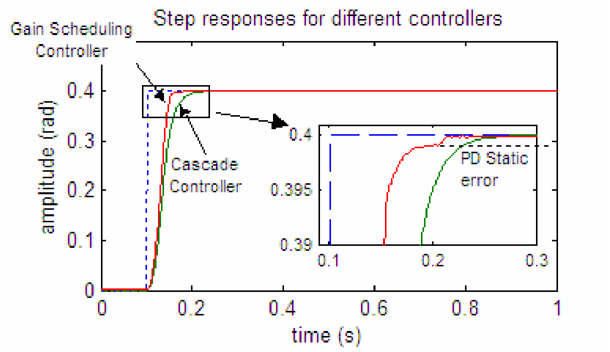
Experimental verification of the proposed control scheme was carried out on a simple ABB DC-motor type M19-S, where the input is the current and the output is the angular position. An incremental angular encoder was connected to the shaft to allow position and velocity measurement. The friction source in the test set-up is attributed to the rolling and sliding elements of the shaft and the bearings.

Identification of the friction in the test set-up was carried out utilising the (novel) Generalised Maxwell-Slip (GMS) model. This model formulation employs the original Maxwell-Slip elements, but replaces the simple Coulomb law by a rate-state equation to account for the sliding dynamics. The results showed, however, that owing to the nearly constant gross-rolling force, the conventional Maxwell-Slip model could account satisfactorily for the friction dynamics. This fact simplifies the control problem, since the equivalent dynamic parameters can then be derived as reported by Al-Bender et al. [1].

The equivalent parameters are the instantaneous stiffness and damping of the system, which are correlated to the amplitude of the motion. Based on these parameters the proposed controller is designed with two modes. The first mode deals with the gross-rolling (/sliding) friction, i.e. when the distance to the desired position is larger than the pre-rolling ('sticking') distance. In this mode, the system uses a linear compensation scheme together with equivalent Coulomb friction compensation. When the motion is reversed, with the distance to the desired position being within the sticking limit, a second mode of the controller is activated until the motion leaves the sticking region. In this mode, the controller uses scheduled PID gains, which are designed beforehand by optimisation based on the known equivalent dynamic properties.

3 Results

The step response to a 0.4 rad step input of the system with gain scheduling controller, as compared to that using a cascade controller, is shown in the adjoining figure. The steady state errors of the cascade and the gain-scheduling controllers are similar: they both lie below the sensitivity of the output encoder, i.e. below 10^{-4} radian. However, the gain scheduling controller offers an important advantage. Since it does not contain an integrator part, it can have a higher gain margin than that of the cascade controller. As a consequence, this controller results in a significantly faster response (shorter settling time, up to factor of 175%).



References

1. F. Al-Bender, W. Symens, J. Swevers, H. Van Brussel, "Theoretical analysis of the dynamic behavior of hysteresis elements in mechanical systems", Int. J. of Non-Linear Mechanics 39, pp. 1721-1735, 2004.