Real-time estimation of the temperature distribution and expansion of a ball screw system using an observer

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Abstract: Thermal deformations of ball screws directly affect the positioning errors of machine tools. In order to calibrate the thermal deformations of ball screws, an accurate estimation of the whole temperature field of the screws is required. However, it is extremely inefficient and almost impossible to acquire the whole temperature distribution by measuring the temperatures of every point. Therefore, a temperature estimator, which can estimate the whole temperature field from temperatures of just a few points, is required. In this paper, one-dimensional heat transfer problems are formulated under concepts of modal analysis and state-space design. Then an observer is designed to estimate the intensity of a heat source and the whole temperature field in real time. The reliability of the estimator is confirmed through comparisons between solutions from the proposed method and those of exact solutions. The proposed method is applied to the estimation of the intensity of the heat source and the temperature distribution of a ball screw system. It is confirmed that the proposed method estimates the whole temperature distribution of a ball screw system well without noise and time delay.

Keywords: ball screw system, modal analysis, observer, real-time estimation, state-space design, temperature distribution, thermal deformation

NOTATION

- A: cross-sectional area (m²)
- A: system matrix in the state equation
- B: linear homogeneous differential operators
- B_left, B_right: input matrix in the state equation
- C: output matrix in the output equation
- h: convection heat transfer coefficient (W/m²°C)
- H_e: heat generated at x = x_H (W)
- H_f: heat generated at the front bearing of a ball screw system (W)
- H_m: heat generated at the nut of a ball screw system (W)
- H_r: heat generated at the rear bearing of a ball screw system (W)
- H_x: heat generated at x_H < x < x_H2 (W)
- I: identity matrix
- k: thermal conductivity (W/m°C)
- k_o: gain of the heat source observer
- L: length of a ball screw (m)
- L_conv: differential operator of the one-dimensional heat transfer problem
- L: gain matrix of the state observer
- M: weight for generalized orthonormality
- MSE: mean square of the estimated error of the heat source
- MSE_T: mean square of the estimated error of the temperature distribution
- N: number of modes used in the modelling
- N_\theta(t): generalized heat source related to the \theta mode
- P: perimeter of the one-dimensional heat problem (m)
- g_e(t): heat generated per unit area at x = x_H (W/m²)
- q_e(t): heat generated per unit volume (W/m³)
- q(t): heat generated per unit area at the front bearing of a ball screw system (W/m²)
- q_unit(t): heat generated per unit volume at the travelling zone of a ball screw system (W/m³)

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