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Design of Control Loop for Smooth Automatic Steering of Atomic Clocks

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Time keeping systems contain a lot of control loops on different levels: from internal structure of atomic clocks and other instruments to the level of interaction between the systems, and it is worth to note that nowadays almost all control loops are digital. In this paper timescale steering problem is considered. It is assumed that auxiliary crystal oscillator is used to generate output timescale signals (i.e. 5, 10 MHz and 1 PPS) of some atomic clocks system. The oscillator is synchronized by means of frequency locked loop to highly stable reference signal, which is usually produced by H-maser. Additional phase and frequency shifts of the output signals can be achieved by frequency steps entered manually or automatically according with some predefined algorithm. The actuator applying discrete frequency steps for timescale steering seems to be fairly common, this and the other types of actuators are considered in [1]. Depending on the task, auxiliary oscillator (timescale signals) can be steered to different references: local, e.g. paper clock timescale of local atomic clock ensemble [2] or external, e.g. coordinated universal time (UTC) using GNSS receivers or two-way satellite time and frequency transfer (TWSTFT). Both, steered and reference signals represent stochastic processes, for which frequency stability (Allan variance or deviation – AVAR/ADEV) is considered to be crucially important characteristic. The particular case analyzed in this work assumes that frequency stability plots of a reference signal and a signal of steered oscillator (if control is off) have a crossing point in the interested interval of averaging times. Automatic control should make frequency stability of steered oscillator following the frequency stability of master for $\tau > \tau_X$, and worsening of frequency stability of steered oscillator should be minimized for $\tau < \tau_X$. The technique for calculation of control loop parameters to achieve such steering is the goal of this work. To minimize degradation of steered oscillator frequency stability, smooth control under the noise level is used. Linear Quadratic Gaussian (LQG) control is one of the methods, which can be applied for smooth steering of timescale signals [3, 4]. LQG controller is a combination of a Kalman filter (i.e. Linear Quadratic Estimator) and a Linear Quadratic Regulator (LQR). Kalman filter allows to get benefits from a-priori information about noise parameters of a reference and steered signals, which can be extracted from frequency stability plots. In contrast to Kalman filter, LQR does not assume using any information about statistical properties of the signals. In LQR a cost function – weighted sum of integral phase and frequency squared errors and integral control effort is minimized. Weight matrices of the cost function, which determine as a result transient time of the control loop, should be set manually. This is the difficulty of LQG method, because for particular noise properties of master and slave signals computer simulation of LQG control is required to find appropriate weight matrices. In this work the algorithm of weight matrices calculation for considered steering problem is described. Only one parameter should be known for this – the averaging time τ_X, corresponding to the crossing point of master and slave signals. The problem is divided into two tasks: analysis of the relationship between transient time (or time constant) and the weight matrices, and analysis of the relationship between τ_X and appropriate time constant of the control loop. The procedure obtained from the results of the analysis significantly simplifies the design of LQG-based control loop.

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