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基于直升机/涡轴发动机综合仿真平台的发动机非线性模型预测控制

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Nonlinear Model Predictive Control for the Engine Based on an Integrated Helicopter/Turbo-shaft Engine Simulation Platform

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摘要 基于具有可靠置信度的直升机/涡轴发动机综合仿真平台,研究了涡轴发动机带约束优化的非线性模型预测控制(NMPC)技术。首先通过设计多输出迭代约简最小二乘支持向量回归机(RRLSSVR),训练具有较好实时性、精度及泛化能力的内嵌式预测模型,在高度0~5 km、前飞速度0~75 m/s范围内模型精度达5‰。其次,考虑了扭矩、燃油流量、动力涡轮转速、燃气涡轮转速等综合信息及相关约束对控制效果的影响,利用在线序列二次规划(SQP)算法实现滚动优化控制,而后加入目标转速偏差的积分项以消除静差,保证输出恒定。最后,通过对直升机进行机动飞行大扰动仿真验证了该预测控制器对扰动的抑制能力,相比传统串级PID控制,能够显著降低动力涡轮转速下垂/超调量,达到更好的控制品质。

关键词: 直升机 涡轴发动机 非线性模型预测控制 支持向量回归机 序列二次规划 串级PID控制

Abstract: Constrained nonlinear model predictive control (NMPC) is applied to a turbo-shaft engine based on a nonlinear integrated helicopter/turbo-shaft engine simulation system with a reliable confidence level. First, a new method called multiple-output recursive reduced least square support vector regression (RRLSSVR) is proposed to build an engine dynamic predictive model. In the flight envelope of altitude 0-5 km and forward speed 0-75 m/s, the predictive model has a satisfying accuracy within 5‰. Subsequently, considering the comprehensive influences of rotor torque, engine fuel flow, gas turbine rotor speed, power turbine rotor speed and their constraint conditions, a rolling optimizer is designed with the sequential quadratic programming (SQP) algorithm. Then, in order to track the constant reference signal with no error, a correcting step is utilized by adding a deviation integral to the output of the predictive controller. Finally, in comparison with the cascade PID controller, the proposed predictive controller can decrease the droop or overshoot of power turbine rotor speed remarkably during the maneuver flight simulations of the helicopter.

Keywords: helicopter turbo-shaft engine nonlinear model predictive control support vector regression sequential quadratic programming cascade PID control

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