Faculty of Manufacturing Engineering

A STATE OBSERVER-BASED TRACKING CONTROLLER FOR SUPPRESSION OF INPUT DISTURBANCE IN MACHINE TOOLS APPLICATION

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DECLARATION

I declare that this thesis entitled "A State Observer-Based Tracking Controller for Suppression of Input Disturbance in Machine Tools Application" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………………

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Date : 1 July 2021

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy in Manufacturing Engineering.

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Date : 1 July 2021

DEDICATION

To my beloved mother and mother-in-law,

my husband and my family,

This humble work is dedicated for all of you who taught me to be patience in completing my work, who never fail to give continous support, du'as and encouragement during difficult time of this journey.

ABSTRACT

In milling process, disturbance forces such as cutting force and friction force act directly on the servo drive system producing unwarranted effect that deteriorates the accuracy of the positioning table. This effect has to be compensated in order to preserve geometrical accuracy and quality of the final product. This thesis focuses on suppression of disturbance force characterise by harmonic frequencies dictating by the spindle speed of the milling table using state observer-based controller for precise tracking performances of the motion drive system. This thesis proposes improvement to control performance of classical cascade P/PI controller via add-on modules to the control structure consisting of state observers named inverse model-based disturbance observer (IMBDO) and disturbance force observer (DFO). The cascade P/PI controller was designed using traditional loop shaping frequency domain method. IMBDO estimates the input disturbance and any unmodeled system dynamics while DFO performs direct estimation of the cutting force using information of harmonic frequencies corresponding to the sinusoidal based input disturbance force. Numerical analysis was performed using MATLAB/Simulink software and experimental analysis was performed on the *x*-axis of an XY milling positioning table ball screw driven system. This thesis compares the performance of cascade P/PI with add-on IMBDO plus DFO with other control configurations; (i) a cascade P/PI stand-alone, (ii) cascade P/PI with IMBDO, and (iii) cascade P/PI with DFO. The control performances of these configurations were analysed using maximum tracking errors (MTE), root mean square (RMSE) of the tracking errors, and magnitudes of the Fast Fourier Transform (FFT) of the tracking errors. Results obtained showed that cascade P/PI with add-on IMBDO plus DFO module produced superior performance against other control configurations. Maximum tracking error results showed that cascade P/PI with IMBDO plus DFO produced the best tracking performances for all harmonic frequencies considered yielding percentage errors reduction of 97.52%, 98.70% and 99.13% for input disturbance of one harmonic, two harmonics, and three harmonics respectively. In term of RMSE values, the experimental results showed that cascade P/PI with IMBDO plus DFO produced the most percentage error reduction with values recorded at 98.80%, 97.75% and 97.97% for the respective input harmonics. In term of FFT results, cascade P/PI with IMBDO plus DFO produced the most reduction in peak amplitudes with values corresponding to 99.78% for the first harmonic, 99.67% and 99.53% for the second harmonics and 99.86%, 99.81% and 99.91% for the third harmonics. The closed loop and sensitivity transfer function of this control configuration confirmed the superiority of cascade P/PI with IMBDO plus DFO in yielding the smallest tracking error thus yielding the most efficient positioning control system.

PENGAWAL PENJEJAKAN BERASASKAN PEMERHATI KEADAAN UNTUK PENINDASAN GANGGUAN INPUT DALAM APLIKASI PERKAKAS MESIN

ABSTRAK

Dalam proses pengisaran, daya gangguan seperti daya pemotongan dan daya geseran yang bertindak secara langsung terhadap permukaan kerja menghasilkan impak luaran kepada sistem pemacu meja kedudukan. Kesan ini mesti dikurangkan untuk memelihara ketepatan geometri dan kualiti produk. Tesis ini memberi tumpuan kepada penekanan daya gangguan, diklasifikasikan oleh frekuensi harmonik yang ditentukan oleh kelajuan gelendong meja pengisaran menggunakan pengawal berdasarkan anggaran untuk pengesanan prestasi yang tepat dalam sistem pemacu gerakan. Tesis ini mencadangkan penambahbaikkan bagi mengawal prestasi kawalan dengan menggunakan penganggar yang dinamakan pemerhati gangguan berdasarkan model terbalik (IMBDO) dan daya gangguan pemerhati (DFO) sebagai modul tambahan kepada pengawal konvensional lata P/PI. Pengawal konvensional lata P/PI telah direka menggunakan kaedah domain frekuensi membentuk gelung tradisional. IMBDO menganggarkan gangguan input dan dinamik sistem yang tidak dimodifikasi manakala, DFO melakukan anggaran terus dari daya pemotongan menggunakan maklumat dari frekuensi harmonik yang sesuai dengan daya gangguan berasaskan masukkan sinusoidal. Analisis berangka dilaksanakan dengan menggunakan perisian MATLAB/Simulink dan analisis eksperimen dilaksanakan pada paksi-x sistem pemacu skru bola pemutar XY. Tesis ini membandingkan prestasi pengawal lata P/PI berserta tambahan IMBDO tambah DFO dengan konfigurasi pengawal yang lain iaitu; (i) pengawal lata P/PI, (ii) pengawal lata P/PI dengan IMBDO, dan (iii) pengawal lata P/PI dengan DFO. Prestasi kawalan konfigurasi ini dianalisis menggunakan ralat trajektori maksimum (MTE), ralat purata punca kuasa dua (RMSE) dan magnitud tranformasi fourier pantas (FFT). Hasil yang diperoleh menunjukkan pengawal lata P/PI berserta tambahan IMBDO tambah DFO menghasilkan prestasi unggul berbanding konfigurasi pengawal lain. Keputusan MTE menunjukkan pengawal lata P/PI dengan IMBDO tambah DFO menghasilkan prestasi penjejakan terbaik, memandangkan gangguan input satu, dua, dan tiga harmonik masing-masing menghasilkan penurunan peratusan ralat sebanyak 97.52%, 98.70% dan 99.13%. Dari segi nilai RMSE, hasil eksperimen menunjukkan pengawal lata P/PI dengan IMBDO tambah DFO menghasilkan pengurangan ralat peratusan terbanyak masing-masing dengan nilai direkodkan pada 98.80%, 97.75% dan 97.97% input harmonik. Dari segi keputusan FFT menunjukkan pengawal lata P/PI dengan IMBDO tambah DFO menghasilkan penurunan amplitud puncak dengan nilai 99.78% untuk harmonik pertama, 99.67% dan 99.53% untuk harmonik kedua dan 99.86%, 99.81% dan 99.91% untuk harmonik ketiga. Fungsi gelung tertutup dan sensitiviti kawalan bagi konfigurasi pengawal ini mengesahkan keunggulan pengawal lata P/PI dengan IMBDO tambah DFO dalam menghasilkan ralat penjejakan terkecil dan secara tidak langsung menghasilkan sistem kawalan kedudukan yang paling efisien.

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