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Research paper

Design of Robust-Performance Compensators for Control Speed of A Double-Sided Linear Induction Motor With Ladder-Secondary

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Abstract

This paper proposes an inovative linear speed robust-controller design. The uncertainty model is developed in combination between multiplicative and addotive structures. The robust controller is referred on feedforward and feedback strategies. For speed controller is employed a error quadratic approximation for calculation of robust digital algorithm using the interpolation metjod. A discontinue-Secondary Double-Sided Linear Motor (DSLIM) as drive was modelled using magnetic path approximation. Especially, the error quadratc method will be employed in finding of unstructured discrete controller for a double-sided linear induction motors with ladder-secondary to obtain position tracking precisely. A decouple process is aimed to linearization of nonlinear mathematic model of DSLIM, so that it can make a simplification of controller design algorithm. Additionally, the inherent characteristic of linear induction motor: longitudinal end effect is also considered and is taken in account for arranging the controller design algorithm. Also, the digital r simulations are built for demonstrating the performance of closed loop speed control with various parameters of DSLIM (robustness). The vector control algorithm will be for achieving the controller in stand still condition.

Keywords: *Double-Sided Linear Induction Motor, 2DOF Robust Controller.*

1. Introduction

A digital controller algorithm of a position control system has a objectives for solving two problems which should be achieved : following set-up command problem and rejecting the disturbance effects. Those problems are solved with using the formulation of the Sensitivity and Complementary Sensitivity - closed loop transfer functions. The decreasing of disturbance effects is overcomed by implementation of a feedforward-controller structures (unknown disturbances can only be decreased by the use of feedforward strategies), on the other side the set-up command problem and stability conditions are based on to the closed-loop system performance. Normally two controllers can be found easily by separated concept for controller design. However for disturbance rejecting in periodically form (cogging force) , it is possible to face a problem for calculating both controllers simultaneously. It would be better to calculate both controllers are solved simultaneous and it might be got a solution by employing 2-DOF configuration strategies. [1].

In order to have a fast and precise motion control performance, it can be done by expending bandwidth of the closed loop control of a closed loop control system. If the position closed loop control system have a wider bandwidth, its characteristic will be able to guarante to avoid the variation of parameters in system and internal variation of system. However the variation parameter in mechanical side, pahse difference in systems, and nonlinearities normally need the narrower bandwidth for overcoming the un-stable system [3].

The existence of contrary aims in arrangement of controllers in a control position system, the combination of feedback- feedforward configuration should be an important method for providing the overcome conflict between both objectives for the bandwidth expansion in the closed loop control system. For dimensioning of parameters of the feed-forward structure, the identification of mathematical model of the DSLIM drive precisely should be be indispensable. It might be stated that a more precise DSLIM-model will produce a good compensation in the existence of the feed-forward paths as well as a more enlightened algortihm in the closed loop controller.

Commonly, for an uncertain nonlinear of mathematical model of a plant, there are three control method approximation which can be implemented: l) self-tuning control, 2) Lyapunov equation -based control, 3) variation in structure control. The first one is used to systems with variations in parameters uncertainties but the other two then allow unstructured ncertainty. Specially, Lyapunov-equation approximations [6] based on an extensions of a Lyapunov equation referred to which a state control is synthesized by the limitation on the uncertainty". To reach the aim of either stabilization or following reference inputs, however, some estimation were introduced related to the forms of the uncertainty. Those situation are called as proper condition.

Design of robust controllers can be obtained in the some steps: 1). Obtaining the nominal plant by the input-output linearization; 2) formulation of a robust control law based on bound of uncertainties for providing compensation of uncertainty effects; 3) Robustness analysus by investigation of the expected extrem limitations on the effect due to error model uncertainties. 4) Closed loop robust stability can be done using internal stability concept.

The implementation of feedback control ways for getting a precision movement of a moving part of linear induction motor is not new, however the robust-algorithm with the matching error approximation (MEA) with considering the cogging forces as external disturbances variables for a double sided linear induction motor with ladder secondary was not still be conducted. The novelty of this paper is design of Robust-performance algorithm using MEA method for a double-sided linear induction motor with ladder secondary for periodic disturbance - cogging forces.

2. Physical designed DSLIM

Authors have been designed and manufactured a ladder-secondary DSLIM [6,7]. Figure 1 shows schematic of the designed a ladder secondary DSLIM which are having 9 stationary ladder-bars and 10 winding spaces on moving part. The physical design of stationary part is shown by figure 2.

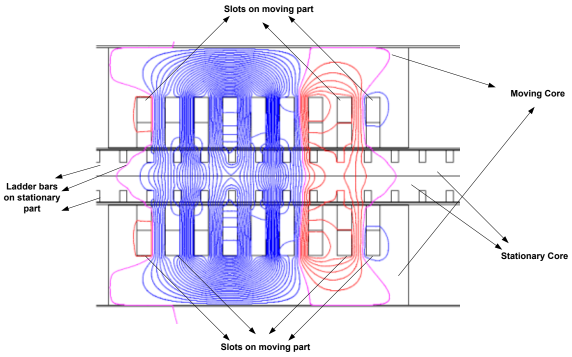

Figure 1 Magnetic Model of Designed DSLIM

The length of unmoving (stationary) part of designed DSLIM is 600 mm length. The stationary bars are made of mild steel and slots of stationary part consist of copper metal. The coils were inserted into spaces of moving parts. The three-phases of power sources are flowed within winding on slots (space) on moving part with symmetry form between right and left side of moving parts.

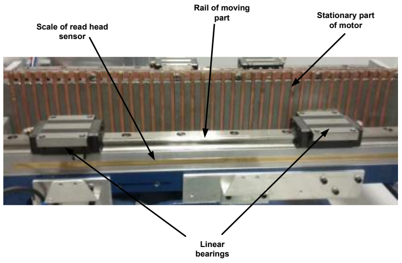

Figure 2 A Physical Designed DSLIM

3. Mathematical Model of Plant

A plant model was based on the DSLIM connected to the load of motor – machine tool. The flexibility of DSLIM when motor's load is linked to the primary part of motor. At first, the motor with load was modelled as ideal linear motor with the air gap width was keep constant. For every flexible mode of plant, it can be represented into series equation with above parameters and is conected to the motor's load. Therefore the mode of real plant can be formulated P into the equation 1.

$$P_r(s)=\sum_{i=0}^{m}\frac{c_i}{s^2+2\xi\omega_i s+\omega_i^2} \tag{1}$$

For parameter i=0, then plant model shown by equation 2 is

$$\frac{C_0}{s^2} \tag{2}$$

coresponds to the un-flexible body slewing motion respect to the end position of DSLIM. The second term is therefore,

$$\frac{C_1}{s^2+2\xi\omega_1 s+\omega_1^2} \tag{3}$$

Corespond to the first non-rigid mode, and so on. The move of moving part of motor was defined as the first four non-rigid modes. The damping ratio and natural frequency was determined by experiment. The meaurement of thrust of DSLIM can be shown in figure 3. Finally, the power amplifier, motor and sensor are linked into the microcontroller.

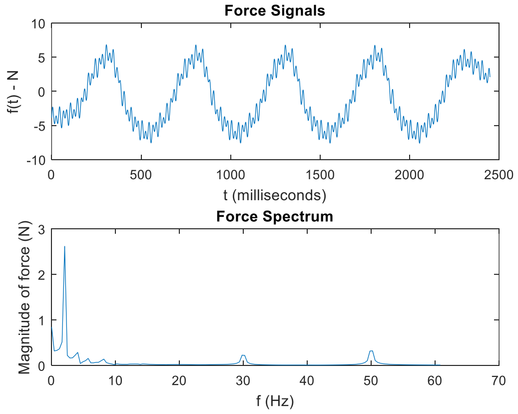

Figure 3 Spectrum of Quadrature Current of Signals

Based on the experiments results, the parameters of equation 3 can be made an asssumptions that the first two poles represent standard body motion, the one at S=-0.0008, and was experience pertubation which stay away from origin, is caused by the back EMF in the linear induction motor with ladder stationary.

The two not reel poles corespond to the first vibration phenomena, the damping factor being 0.0775. The null are located on -5.8081 and 4.7709. Because of the zero at S=4.63 the plant is clasified as phase with non minimum structured model. Therefore the plant-model was experiencing perturbation, and can be formulated into an equation:

$$P(s) = \frac{-6.4s^2 + 4.03s + 175.77}{s(5s^3 + 3.5s^2 + 139.5s + 0.09)} \tag{4}$$

4. Expected Closed Loop Performance

Fig.4 shows the design schema for robust controller. The diagram block consist of robust controller and the perturbed plant. Designing the robust controller in this case, desired closed loop system should be defined. A common method to define expected closed loop system characteristic is by step-test. For this case, the specification is based on that a step. The equation 11 shows an expected closed loop performance.

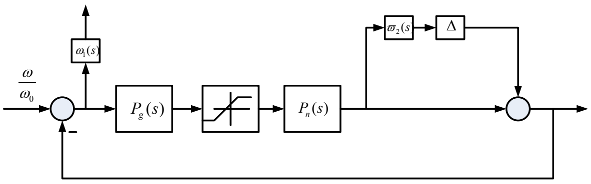

Figure 4 Closed Loop System

Responses system corespond to specification design in which that error model should be satisfy: settling time ≈ 2 s. And overshoot less than 2%. Based on those spec, the closed loop performance can be formulated into the common second orde equation as shown by equation 5.

$$T_i(S) = \frac{\omega_n^2}{S^2 + 2\xi\omega_n S + \omega_n^2} \tag{5}$$

For A settling time of 8 s. Requires:

$$t_s = \frac{4.6}{\xi\omega_n} \approx 2 \tag{6}$$

The spec for overshoot level should be not more than 10%, therefore the equation can be defined into:

$$\exp\left(\frac{-\xi\pi}{\sqrt{1-\xi^2}}\right) \approx 0.1 \tag{7}$$

From two equaions 6 and 7, the expected parameter can be estimated in value of $\xi \approx 0.6$ and $\omega_n \approx 1$, so that the expected performance can be formulated into an equation 8.

$$T_i(s) = \frac{1}{s^2 + 2.2s + 2} \tag{8}$$

Then an sensitivity equation of closed loop system is defined as:

$$S_i(s) = 1 - T_i(s) = \frac{s(s+2.2)}{s^2 + 2.2s + 2} \tag{9}$$

The weighting function is formed by $S_i^{-1}(s)$:

$$W_1(s) = \frac{s^2 + 2.2s + 2}{s(s+2.2)} \tag{10}$$

The MEA method is to minimize $\|W_1(1 - Q_i J)\|_\infty$. In order to obtain the youle parameter $Q_i(s)$, the norm of below equation should be less than one.

$$\|W_1(1 - Q_i J)\|_\infty < 1 \tag{11}$$

Where:

$$J(s) = \frac{1}{(\tau s + 1)^3} \tag{12}$$

Because P has one right half-plane zero, at s=5.6308, so that the minimal value of

$$\min\|W_1(1 - PQ_i)\|_\infty = |W_1(5.5308)| = 1.0210 \tag{13}$$

Therefore the spec $\|W_1 S\|_\infty < 1$ is not achievable for this transfer function of plant and weight function, so it is required the normalization of weighting function. If it is assumed that the new weight function is scaled as in below equation:

$$W_1 \leftarrow \frac{0.9}{1.0210} W_1(before) \tag{14}$$

So that $\|W_1(5.5308)\| = 0.9$ and the optimal

$$Q_i(s) = \frac{W_{1-0.9}}{W_1 P} \tag{15}$$

Therefore

$$Q_i(s) = \frac{s(0.0009s^5 + 0.0421s^4 0.1868s^3 + 0.8008s^2 + 4.8910s + 0.0038)}{s^3 + 8.1081s^2 + 4.8897s + 6.8801} \tag{16}$$

The equation 16 shows that youla parameter $Q_i(s)$ is unproper, so that controller robust is calculated by subtitution of a third order low pass filter $J(s)$.

$$J(s)=\frac{1}{(\tau s+1)^3} \tag{17}$$

Parameter τ in equation 17 is decreased, in order to that NORM of matching problem is less than the value of one, which is shown in equation 18.

$$\left\|W_1(1-PQ_iJ)\right\|_\infty<1 \tag{18}$$

The calculation result of NORM-finction is shown on table 1.

Table 1 The Calcultaion Results of NORM-function

τ	$\infty-NORM$
0.2	1.23
0.1	1.12
0.05	1.02
0.04	0.988

The value τ -parameter based on table 1 is 0.04. For robust controller calcultaion, the youla parameter $Q_i(s)$ should be modified by multiplication with J-function.

$$Q(s)=\frac{s(0.0009s^5+0.0421s^4 0.1868s^3+0.8008s^2+4.8910s+0.0036)}{(s^3+8.1081s^2+4.8897s+6.9801)(0.08s+1)^3} \tag{19}$$

So that robust controller is defined as the Q-equation, which is shown by equation 20.

$$C=\frac{Q}{1-PQ} \tag{20}$$

For matching problem, in this research is approximated by the ideale Transfer function of second orde system that is shown by equation 14, so that controller can be obtained with simple equation.

$$C(s)=\frac{Q}{1-Q\dfrac{1}{s^2+1.2s+1}}=\frac{Q(s^2+1.2s+1)}{s^2+1.2s+1-Q} \tag{21}$$

5. Results and Discussion

Fig. 5 and 6 show that the linear speed of DSLIM is closed to the speed reference signals precisely. It shows that the analytical results of MEA method can provide a smaller level of precision of linear motor movement The robust performance have been shown by figure 6. Even though parameters of DSLIM experience a variation of magnitude, control system can follow the set-up reference. The response has been compared to control system in which are supported only feedback controller, without feedforward. Application of MEA algorithm has been investigated by comparison results to response of block diagram with only one feedback algorithm.

Investigation of closed loop system using MEA method is already done. The investigation was conducted for reference input of exponential signals. Fig 6 illustrates output signals of system for Robust controller and normal controller. Set-up or refernce signals are the exponential and sinusoidal signals. It illustrates that the normal controller structure results have bigger error in linear movement than using the MEA methodm structure. The MEA method structure generates the linear speed precisely for setpoint exponential is less than common controller structure. The error-transient of trajecctory for feedforward-feedback structure is 0.002%, for normal control is 2.12%.

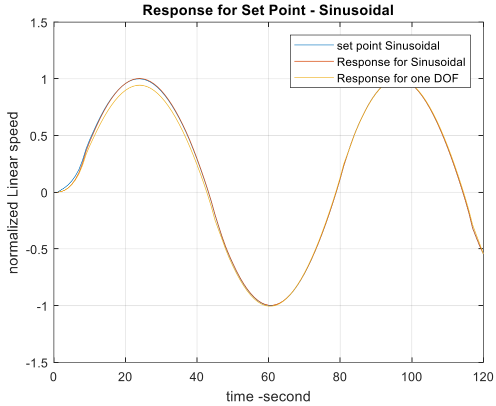

Figure 5 Response of Sinusoidal Reference

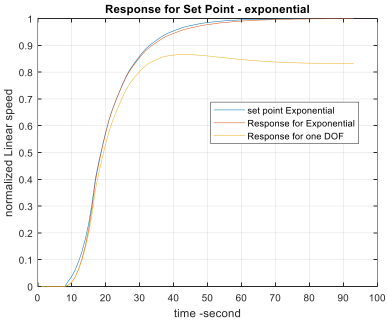

Figure 6 Response of exponential Reference

6. conclusion

This paper illustrates that an improvement of precison level can be achieved very well using MEA method for a Ladder-Secondary DSLIM drive applications. The level of linear movement precision was simulated using MATLAB-software. Then robust-design algorithm was able to make a rejection of the existence of the variety of plant model (Robustness performance). It means the control target is not affected by existtence of parameter variation of linear motor.

It also shows that the expected closed loop system scheme, in which the feedforward strucure can be obtained using directly trajectory information only. It can provide some advantages such as short calculation process, filtered of measurement effect, a separation of robust algorithm design from variation of parameters, and a short time in adaptation process in implementation. When system is given sinusoidal signals as reference functions, and parameters of damping ratio are varied 0.9 to 1.5, the performance of speed closed loop system was still stable and show a good performance. Responses of control system can follow the reference signals, sinusoidal refrence signal, ramp refrence signals and step signals simultaneously.

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