Review on Industrial Permanent Magnet Synchronous Machine Servo Systems: Embedded Parameter Estimation and Auto-tuning Concepts

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***Abstract*— One of the result of the advanced industrial technology, industrial servo drive systems need advanced skills for managing the system and motion. Industrial servo systems have challenging mechanical characteristic for sensitive control and accurate stability of driver systems. These mechanical issues occur with respect to drive train of servo systems such as mechanical assembly, motion elements, motion types and load characteristics. In this context, on the driver and control side, there are several approaches and embedded solutions of parameter estimation and tuning methods for mentioned mechanical issues and system deviations. In this paper, problematic issues and offered solutions about parameter estimation and auto-tune process in the current literature for servo drive systems are defined and systematized with considering embedded concepts.**

***Index Terms*—Servo Drive Mechanics, Mechanical Servo Issues, Filtering in Servo, Servo Control**

I. An Overview Introduction

A WELL tuned servo system is robust and has the fastest possible response with (negligible or) no overshoot and steady state error. But, a well tuned servo system can lose its accurate response with disturbances that come from the mechanical dynamics of operated drive train or environmental effects. Drive train of a servo system contains controller-driver, motor and load. Controller-driver can be defined as white box, motor can be defined as grey box and load can be defined as black box. In this concept, tuning of the whole system can be done by controller-driver via motor with using reflections from load to motor shaft. The main principle in tuning a servo system is detecting the unwanted situations from motor and controller side and to suppress them. For this purpose, we have to define the unwanted situations with using mathematical models and their effects on the parameters (both electrical and mechanical) of the system for starting the tuning process. After defining the mathematical model, the system must overcome the situations that will cause problems in the parameter estimation process described below [1]–[3].

A. Rank Deficient Problem

In one operation step, the parameters can be calculated as much as the number of rank of the math equation set. In state-space representation of a servo system, the parameter matrices are multiplicand of the states of system. If one of the state and input are zero with relevant row, the rank of the system will be decreased by one. This means that, one of the parameter is also missed in the analysis. To overcome this problem, the system must be observable and controllable.

B. Persistent/Insufficient Excitation Problem

Input and output signals, which provide information to the parameter estimation and tuning process, must contain sufficient data and must be fast enough to ensure continuity. In order not to fall into this problem in servo systems, the speeds of the loops (or bandwidths) in the system should be designed from small to large while moving from the outer to the inside. Also, analog to digital conversions, speed of sensor measurements and feedback lines should be fast enough with respect to purposed operation.

C. Rotor Position and Nonlinearity Problem

Aligning the magnetic axes of magnets with phases in PMSM-based systems (rotor position information in the software) is critical for the correct operation of the dynamic equations of the machine. In addition, nonlinear current or voltage characteristics caused by the inverter on the driver side should be taken into account in processes.

D. Literature Summary

There are two strategies for operating the parameter estimation and tuning process as known off-line and on-line. Off-line tuning the servo system means that defining process is done under the zero, no-load or dummy (dysfunctional) motions

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[4]. This type tuning can be done by using some previous information (commission) or without any information (self-commission) about any part of the system. On-line tuning the servo system means that defining process is done during the loaded motions. This type tuning is more complicated than off-line tuning because it needs dynamic measurements and decision mechanism in parallel with the work done by servo system [5], [6]. The generalized flow charts of both strategies are shown in fig 1. [7].

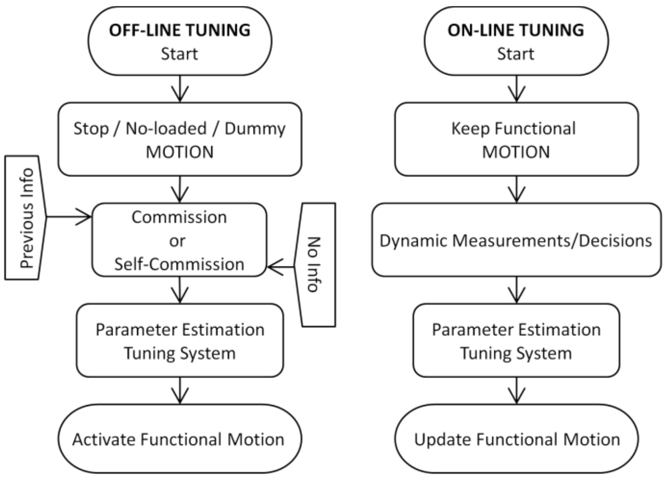


Fig. 1. Off-Line and On-Line auto-tuning flowcharts.

Most of the disturbance effects can be detect by observation (manually or algorithmic) or using a model that contains observable state variables [8]. Conventional way of off-line process to obtain servo system's characteristic is using pre-defined routines that can be voltage/current injections, to apply specific motion profiles, torque measurements, movements pushing the boundaries, specific position tracking or regular movements when system is no-loaded, stand-still or dysfunctional moving condition [9]. After excitation, system calculates the critical parameters, which are electrical, mechanical, model based or state variables, with using measured data from applied pre-defined routines. Determined new parameters of servo system are integrated the controller/driver side and system is updated with respect to new dynamics. When we look the on-line process, it keeps going the functional motion (with load) with detecting and calculating the disturbance properties, which are mainly frequency, amplitude and bandwidth, as a parallel process. In this process, since the under load system is not suitable for injection signal or specific profiles, existing and measured under loaded signals are used for calculations. Because of this challenge, Fourier transform based signal analysis, model based estimator, observer, predictor, iteration algorithms, adaptive mechanism, filtering techniques are used for determining the disturbance properties [10], [11]. Also, there are filter based (band-pass) scanning approaches for detecting the disturbance's characteristics [12]. After detection of disturbance properties, a filtering operation, which is mostly notch filters (in some applications low-pass and high pass topologies are used), is used for suppressing the disturbance during functional motion (under load). Some of the designers try to combine detection of the properties of the disturbance and suppression operation in cascaded step. In this case, common approach is observer/estimator/predictor strategy. In this approach an observer/estimator/predictor structure, which contains state-space equations (position, speed, voltage/current) and time dependent data collected from system, traces the system dynamics and evaluate the near future data from previous data with using trajectory. Kalman filter based observers/estimators/predictors are basically used for this approach [13], [14]. Another useful approach, which is known as Model Referenced Adaptive System (MRAS) is creating and controlling/driving an adjustable model in parallel with the actual system and comparing and iterative evaluating the data from model and actual system for parameter calculation and tuning the system. MRAS based systems can derived with changing measured signal type (speed, torque, current etc.) [15]. Some of the literature works contain Artificial Intelligent (AI) based structures, such as Fuzzy logic, Neural Network (NN) strategies and Swarm Intelligence (SI) based self-organized systems but they need much more computing capability and have implementation hardness as an embedded structure because of the hardware limits (FPGA is one of the solution such designs) [16].

II. MECHANICAL ISSUES AND FRICTION

Most of the servo systems have a specific mechanical architecture and load properties as known drive train. A servo drive train can be characterized three different motion profiles as linear motion, circular motion and contour motion. Providing these motion, there are several mechanical auxiliaries such as, pulley-belt, lead-screw, rack-pinion, belt-wheel, gear-wheel and direct drive structures (fig.2).

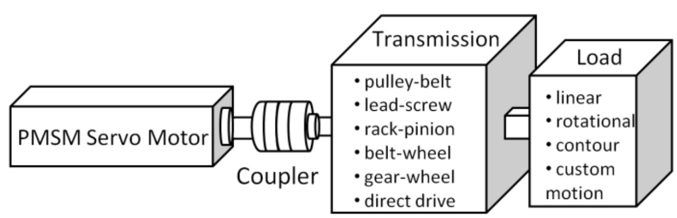


Fig. 2. Industrial servo system drive train.

These structures, which contain some mechanical parts are listed as rolling mill, long shafts, large inertia, bearings, elastic couplings, rail, damping elements, belt, gears (with backlash) [17] etc., return vibration (resonance or randomly) and friction on the transmission and then these effects are seen by motor side as reflected inertia, viscous friction and torque (from controller/driver side as position, speed, voltage/current error) [18]–[21]. Consequently, tuning required issues can be described as more specifically, slow response, noisy operation, oscillation, torque overload, over speed, position errors etc. Some of the critical issues, that cause motion deviation and mechanical distortion, are given in fig. 3.

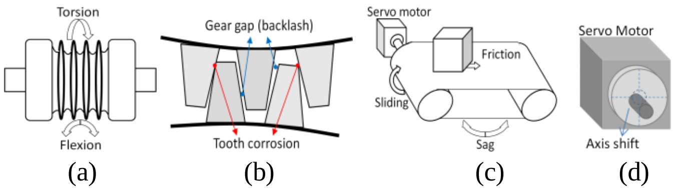


Fig. 3. Vibration and friction sources in servo drive train. (a) Elastic coupling, (b) Gear transmissions, (c) Conveyor transmission, (d) Servo motor shaft.

The compensation of the issues must be solved as possible as by controller/driver structure with using detection-filtering methods according to embedded approach. For this purpose, electrical and mechanical parameters of the system and auxiliary variables, which are used for modeling or defining the reflections must be defined in controller side as shown in Table 1.

TABLE I
SERVO SYSTEM MAIN PARAMETERS AND VARIABLES

Variables	**Electrical Parameters**	**Mechanical Parameters**
P: Pole number	r_s : Series resistance	T_e : Electromech. torque
w_r: Speed elect.	L_d : d-axis inductance	T_L : Load torque
θ_r: Angle elect.	L_q : q-axis inductance	K_t : Torque constant
s: Laplace operator	K_e : Back EMF const.	J : Rotor and load inertia
v_{do}, v_{qo}:Back EMF, Cross coupling volt.	λ_m : PM flux linkage	B: Viscous friction coeff.

Friction is a complex phenomenon that exists in the contact surface among shaft, end caps, pistons, and the cylinder wall. It is highly non-linear and may result in steady-state errors, limit cycles, and poor performance. Generally, friction behavior is divided into two categories namely static friction and dynamic friction. The static friction force occurs when the body is at resting state or stationary object, which unable to avoid in the mechanical systems which limit the performance in precise motion control. Dynamic friction occurs when surfaces are moving over one another. In addition, the Coulomb friction is a constant friction contribution and thereby independent of the velocity. The viscous friction is interrelated to the velocity, while it is expressed as a function of viscous friction coefficient B multiplied with the velocity.

III. MODELING

Modeling of the servo drive train have critical role in parameter estimation and tuning operation because the real system behavior have to run in the controller side. Modeling can be categorized in three main parts as motor model, mechanical model and controller/driver model.

A. Motor Model

PMSM machine (there are two types as SPMSM and IPMSM) [22] mathematical model with respect to stationary rotating d-q frame is given in fig.4 and as follows.

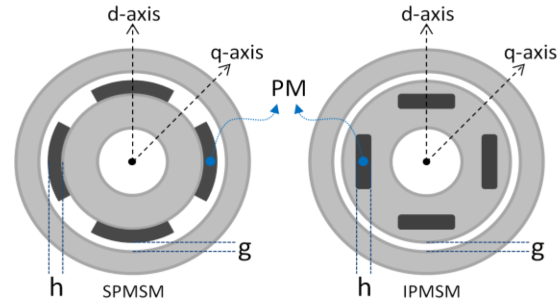


Fig. 4. SPMSM and IPMSM structure and d-q frame axes.

For SPMSM: $$L_d = L_q = \frac{\mu_0 N^2 A}{2(g+h)} \quad (1)$$

For IPMSM: $$L_d = \frac{\mu_0 N^2 A}{2(g+h)}, L_q = \frac{\mu_0 N^2 A}{2(g)} \quad (2)$$

$d-q\ axis$ voltage/current (v_d, i_d, v_q, i_q), speed and torque expressions with respect to rotating $d-q$ frame are given below in (3-6) referred to the variables in Table 1.

$$\frac{di_q}{dt} = \frac{1}{L_q}\left(v_q - r_s i_q - \frac{P}{2}\lambda_m w_r - L_d w_r i_d\right) \quad (3)$$

$$\frac{di_d}{dt} = \frac{1}{L_d}\left(v_d - r_s i_d + L_q w_r i_q\right) \quad (4)$$

$$\frac{dw_r}{dt} = \frac{P}{2J}\left(T_e - \frac{2B}{P} w_r - T_L\right) \quad (5)$$

$$T_e = \frac{3}{2}\frac{P}{2}\left(\lambda_m i_q + \left(L_d - L_q\right) i_d i_q\right) \quad (6)$$

For the field oriented control (FOC), i_d current is kept zero to provide stator current vector kept along $q-axis$ direction (T_e is linearly proportional to the $q-axis$ current in closed loop control). Also, for the simplicity we can select SPMSM ($L = L_d = L_q$). With these simplifications, we can describe the state-space representation of the SPMSM as shown eqs. (7-9).

$$\dot{x} = Ax + Bu + Ee \quad (7)$$

$$y = Cx \quad (8)$$

$$A = \begin{bmatrix} -\frac{r_s}{L} & -\frac{\lambda_m P}{2L} & 0 \\ \frac{\frac{3}{2}P\lambda_m}{J} & -\frac{B}{J} & 0 \\ 0 & 1 & 0 \end{bmatrix} B = \begin{bmatrix} \frac{1}{L} \\ 0 \\ 0 \end{bmatrix} E = \begin{bmatrix} 0 \\ -\frac{P}{2J} \\ 0 \end{bmatrix} C = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}^T \quad (9)$$

Where, the states are $x = [i_q \quad w_r \quad \theta_r]^T$, input $u = v_q$ and disturbance $e = T_L$. In this case, the rank of the system is equal to 2. This means that, 2 parameters can be calculated in each operating cycle (Rank Deficient Problem). Systems operated with i_d current, that is slightly larger than zero, it is to make the rank number 3 and solve 3 parameters in one process step [23]–[25].

B. Mechanical Model

Mechanical implementation of the servo systems are created by using two ways as using flywheels ($T_L = 0, J_L \neq 0$) or two mechanically coupled mass system (one of them represent motor, other one acts as load). In general, they are called two-mass (motor-load) or multi-mass model as shown in fig 5. In two mass model approach, there are two sides, that are connected with a coupling (elastic or rigid) has two critical parameters as stiffness (K_s) and damping (C_w). Each sides (driver and load) have dependent torque (T), inertia (J), speed (w) and position (θ) [11], [26], [27].

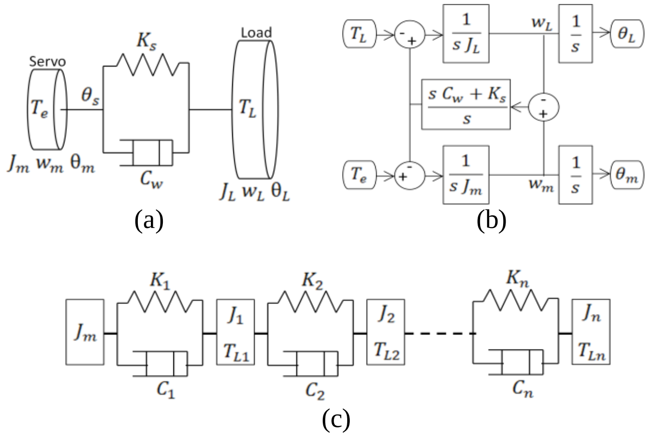


Fig. 5. Mechanical model, (a) two-mass system physical model (b) two-mass system mathematical block model (c) multi-mass model

C. Controller/Driver Model

In controller side, most of the servo systems use Field Oriented Control (FOC) in rotating d-q frame. Position, speed and torque control loops are located sequentially with respect to band width (The slowest position control loop is outermost) and they are controlled by PIDs. Some specific applications (torque dominant) use Direct Torque Control (DTC) technique if there is no need any sensitive speed or position control need [28]. Parameter estimation and tuning control actions are run model based structures. These type controller works with a mathematical model of a plant (only motor or motor with load) and observer, predictor, estimator or adaptive structure. In driver side, three phase inverter with sine PWM or space vector PWM techniques are commonly used. Also, specific vector tables for DTC or look-up tables for model based control systems are used. Generic structure about control strategies are given in fig.6 [29]–[31].

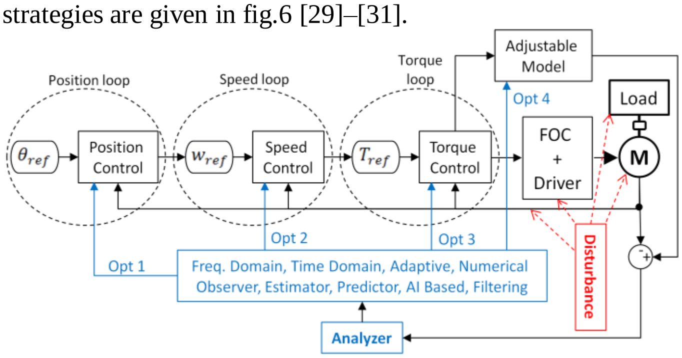


Fig. 6. Generic controller/driver approach for auto-tuning and parameter estimation in servo systems.

IV. Disturbance Detection

A disturbance signal has three main characteristic such as frequency, amplitude and bandwidth (or duration of disturbance). Also another critical data about disturbance is formation, which can be form of specific function, periodic or non-periodic. In addition, non-periodic formations can be categorized as follows, pure random, limited random, changing in certain order or dependent to any system's variable (electrical or mechanical).

A. Frequency Domain Analysis Based Techniques

The main works of frequency analysis techniques concentrate around Frequency Response Function (FRF) with using Fourier based analysis. In Fourier transformation based techniques, detection system contains two main parts as signal analyzer in frequency domain and filter (both detection and compensation).

1) Direct Fourier Transform Methods

The work flow of this method contains three basic processes. The first one is collecting the position, speed, current/voltage or torque error data (whichever has functional data) and these data is saved in a memory and Fourier analysis is applied [32]–[34]. At this step classical FFT or DFT computation takes much more time in real time systems. Overcome this challenge, designers determine a resolution for FFT computing according to overall servo system needs. For this purpose, shifted DFT (SDFT) (DFT computing is done when the frequency window is shifted with fixed length) or DWT techniques are in use. Similar approach is used in sweep frequency response analysis (SFRA). In this approach, plant (servo motor and load) is excited by sine wave with consecutive frequency intervals (generally, 5-10 Hz increment is selected and plant is excited after that, results are evaluates in frequency domain with DFT analysis) [20]. The aim is decreasing the computing time with decreasing the detection frequency resolution of system (i.e. 2048 point data with Advantech 610H industrial control computer takes 3ms for traditional DFT, 0.1ms for SDFT) [7]. The second step is, collected and transformed data are sorted (or grouped) with respect to amplitude and center frequency. In this stage, it is known that controlled variables (position speed, current/voltage, torque) are oscillating at several different resonance frequencies. So, in sorted data, the most dominant frequency (or the biggest amplitude) refers to resonance frequency, which is sourced by mismatch, distortion or disturbance, of the system and other ones are vibrations or frictions sourced. The last step is filtering the significant frequencies with side lobes (details in section V). Fig. 7 shows that generic block diagram of detection [35].

2) Transfer Function Estimation with Fourier Transform

Another useful approach in same manner is obtaining transfer function (TF) of the plant in frequency domain with using DFT and the most basic methods are empirical transfer function estimate (ETFE), Welch's averaged periodogram TF estimation, impulse response TF estimation and time-frequency decomposition [36]. Stable results are obtained with this technique, but there is a need for hardware that can work with microprocessors and memory units with high processing capability. The parameters obtained in the frequency domain can be used directly in digital filters and can be integrated with look-up tables.

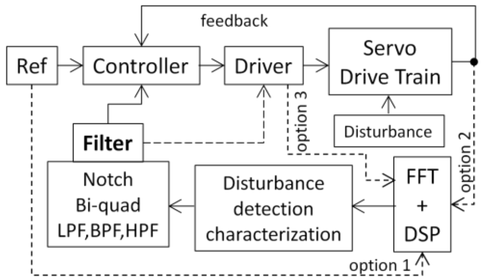


Fig. 7. FFT based disturbance detection system generic block diagram.

B. Model Based Estimator/Observer/Predictor

The main aim for this technique is to calculate the system parameters or control variables with using linear or nonlinear mathematical model of the plant (motor and load) in time or frequency domain. For this purpose, servo system dynamic behavior must be modeled and executed in the software. Estimator, observer or predictor uses measured data from physical plant and model data and evaluates with statistical methods and system specific calculations. The basic difference between estimators and predictors is feature of input and produced data.

1) MRAS

MRAS can be evaluated in a separate category. An adjustable model (model with unknown parameters), which is running parallel to the reference model (real system or real system model with known parameters), is updated iteratively. This process performs parameter calculation by using the difference (error) of the signals coming from the reference model and the signals produced by the adjustable model through an adaptive process block. It tries to compare and equalize these parameters with the reference system via minimizing the error.

2) Observers

In observers, the operation is based on data or error tracking or comparison of model data and real data with parallel process [37]. The main purpose is to calculate parameters, which cannot be measured or accessed in the real system, through the model of the system. If the disturbances effects are defined previously and inserted model, the accurate of the observer increases. While reduced order observers are used for calculation such basic mechanical parameters J, T_e, T_L (or K_t) [38], [39], generally, conventional observers work with an estimator or predictor block (i.e. Kalman filter) [40]. Also, adaptive, sliding-mode, disturbance observers are basic embeddable techniques for parameter estimation and tuning process [41], [42].

3) Estimators

Estimators create the output data with respect to created trajectory from background information (which is called in models as regression vector). In servo system dynamics, estimators are heavily used because most of the servo systems are used in industrial applications with known limited motion profiles. Recursive Least Square (RLS) estimation and modified versions [43], maximum likelihood, Kalman based estimators are the basic embedded applications.

4) Predictors

Predictors use data that may contain limited randomness, system specific assumptions and background data for calculating the parameters. It covers the process in two main steps such as prediction and update. In prediction step, measured and background data is used for parameter calculation after that if there exist any system specific assumptions or probabilities (i.e. Gaussian distributed noises, constant mean and covariance noises, characterized disturbances etc.), it adds these randomness data to the calculation and tries to find the best result with update stage. Predictors are preferable for advanced servo systems (i.e. underwater systems, military purposed usage) contain observer with predictor controller. The single structures of the mentioned parameter determination techniques are given in fig. 8 [44], [45].

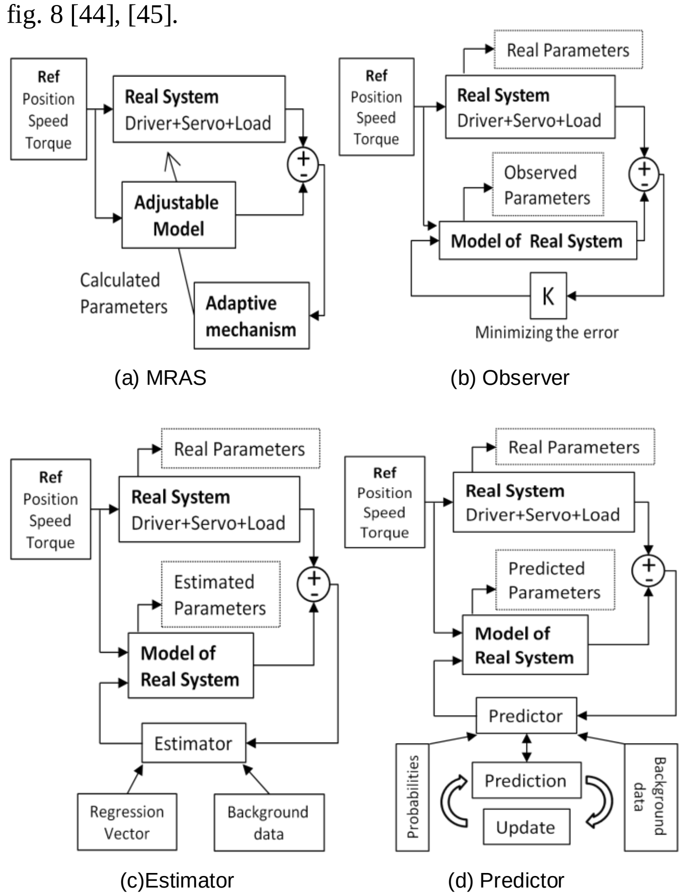


Fig. 8. The control blocks for determining the parameters in servo systems (a) MRAS (b) Observer (c) Estimator (d) Predictor.

C. Input Configured Excitation Methods

Predefined routines are applied to the system in these parameter estimation and auto-tuning operations that are based on excitation. The applied signal sets are selected according to the dynamics of the system (servo motor type, controller, mechanical load characteristic). The aim is to determine as many parameters of the system as possible at each excitation.

Generally, this technique is used in off-line parameter estimation and tuning because the system is idle.

1) Basic Signal Injection

The most basic application (simple single or two mass systems) is to obtain (basic signals) step, pulse, sine, ramp or square responses with relevant excitations. This simple method is often used to tune PID controller coefficients or to calculate the series resistance (r_s) and inductance values (L_d, L_q) of the motor windings [46]. Also, combinations of these basic signals can be used for calculating more specific parameters such as K_e, K_t, J, B [47] with PID controller coefficients. These excitation types can be physical references such as speed, torque, position, or phase current/voltage (or in the alpha-beta/d-q reference frames). As the structure of the servo system becomes more complex, non-linear effects [3] and delays in the system increase. This situation makes it difficult to estimate parameters with simple signal injection processes.

2) Custom Signal Injection

In more complex cases (such as more than two-mass system, more than two motion transmitter elements in the system, frictions and vibrations, nonlinear effects or mismatches etc.), custom signal injection specific to the characteristics of the servo system can be applied [48], [49]. For example, in a fixed-torque servo system operating in a wide speed band (60 rpm-6000rpm), it is necessary to make several excitations up to the boundary speed values while calculating the parameters of the system. Parameters determined by low (60 rpm) or medium (3000 rpm) speed excitation may cause deviations at high speed values. This logic also is valid for torque, position, voltage/current quantities.

3) PRBS Injection

Another approach is to use a pseudo random binary set (PRBS). This method is often used as disturbance detection (finding the center frequency of disturbance peaks). In this method, the system is stimulated with a PRBS multiplier. The aim is to generate data that helps to estimate system parameters by making random excitations in the entire frequency band. The advantage of PRBS is that it minimizes the motion so that it is convenient for mechanics with limited stroke. PRBS can be applied both, an open loop identification as a random disturbance signal and closed loop identification for unstable plants [50], [51].

D. Other Embeddable Methods

AI based methods are used for online parameter estimation or auto-tuning operations. The most commons are neural network (NN), fuzzy logic, genetic algorithm (GA) and particle swarm (optimization) (PS). They use the information of servo systems such as position, motion, torque and mechanical dynamics and constrain as input. It determines the parameters of the system and tuned motion trajectory using methods such as learning, prediction, filtering and mapping [52]–[54] for embedded applications. In some specific applications, which's thermal sensitivity is important, r_s and L_d, L_q values vary in proportional to temperature. It is possible to adjust these values by monitoring the temperature [53] or vice versa [55]. One of the other different methods is to use the current ripple of the servo motor in parameter estimation. This method is similar to the input configured excitation method mentioned earlier. But in this method there is no excitation, the electrical peaks created during the routine operation of the servo motor are used [56].

V. FILTERS AND COMPENSATORS

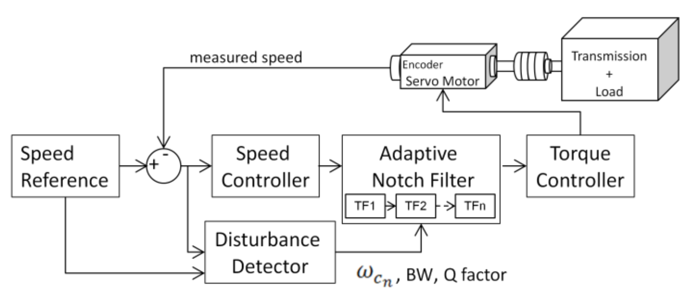
Filters are essential elements in a servo drive system for both detect and compensate the disturbances. Each distortion has specific period, amplitude and duration. Various modifications of filter-based methods are applied to the servo systems. There are two main filter type for operations such as band pass filter for detecting the disturbance signal and band stop (band reject) for eliminating the detected disturbance.

A. Notch Filters and Compensation

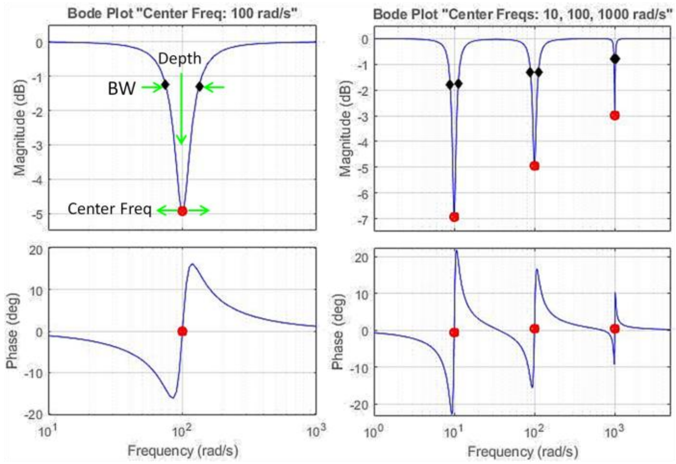
Notch filters (band reject) are the most common topologies that are using basic filtering or adaptive designs. Also, like the disturbance characteristic, there are three critical parameters for the filters as center frequency (ω_c), bandwidth (BW) and depth (Q factor). According to servo system complexity, there can be more than one disturbance (low vibrations, resonance, periodic oscillations etc.) with different frequencies and amplitudes. Online adaptive notch filter (OANF), iterative tuning of notch filter and robust online adaptive notch filter (ROANF) versions are used for such issues [57]–[59]. The general structure of the notch filter in the embedded servo system and 2nd order specific notch filter design example is given in fig. 9.

B. Biquad Filters and Compensation

Another filtering approach of the servo system is Biquad filters [60]. This filter type is used for multipurpose operations as it can be made operable like low-pass, high-pass, band-pass, band-reject by changing the filter coefficients. This flexibility generally provides an advantage in disturbance detection and compensation, because scanning and filtering, from very small frequency (0-10 rad/s) to high frequency (10000 rad/s), can be done by setting useful topology (low-pass, band-pass, high -pass). Since the topology remains constant in the notch filter structure, the performance is insufficient in low and high frequency bands [61].



(a) Speed disturbance detection and compensation



(b) Single and three center frequencies notch filter design (for single disturbance compensation filter: $\omega_{c_{single}} = 100\, rad/s$, $depth = -5dB$, $BW = 0.25\, Log$), (three disturbances compensation filter: $\omega_{c_1} = 10\, rad/s$, $depth = -7dB$, $BW = 0.1\, Log$, $\omega_{c_2} = 100\, rad/s$, $depth = -5\, dB$, $BW = 0.1\, Log$, $\omega_{c_3} = 1000\, rad/s$, $depth = -3\, dB$, $BW = 0.02\, Log$), obtained by MATLAB/controlSystemDesigner(1)

Fig. 9. Adaptive notch filter block schematic and example designs

VI. System Management

Control parameter estimation and tune operations of industrial servo systems generally run on a DSP device. The switching frequency of the servo drive and the control method (i.e. V/f, Hysteresis, FOC, DTC with parameter estimation and tuning algorithms) are criteria for selecting the specification of the DSP. While a single core processor is sufficient in simple systems (single motor – load with low level control and tuning), dual core processors run in mechanical systems that require multiple movements and more advanced on-line tuning techniques with estimators/predictors. As the nonlinearities formed in the system (sourced by inverter, gears, couplings etc.) and the complexity on the load side increase (cascaded mechanical contacts), the number of loops in the control and tuning blocks increases and this situation requires FPGA-based solutions. A summarized comparison hardware systems and embedded applications in the literature are given in fig. 10 [20], [29], [62], [63].

120MHz	150MHz	250MHz	340MHz
TI TMS320F28075 32-bit MCU, 120 MHz FPU, TMU, 512 KB Flash, CLA, SDFM **Ex. Process:** 10kHz-SVPWM Direct drive Fuzzy network Inertia identification	**TI TMS320F28335** 32-bit MCU, 150 MHz FPU, 512 KB Flash, EMIF, 12b ADC **Ex. Process:** 5kHz-SVPWM Direct drive Adaptive PI control Estimator	**NXP MPC8240** 64-bit MCU, 250 MHz FPU, 2 x 16KB cache on-chip 32 MB SDRAM, 8MB Flash **Ex. Process 1:** 10kHz-SVPWM Belt drive two mass Speed&Torque Control FOC Parameter identify **Ex. Process 2:** Nonlinear friction analysis DFT, Linearization	**XILINX Virtex-5 FPGA** 64-bit MCU, 550 MHz FIFO, 36-Kbit block RAM 64-bit distributed RAM **Ex. Process :** Position control (FOC) RLS algorithm - Online Parameter identification

CPU

Fig. 10. Classification of hardware specifications and running embedded applications.

VII. Conclusion

In this review study, parameter estimation and auto-tune processes of industrial servo driven mechanical systems were examined. In this context, the models of the components (servo motor, controller/driver and mechanics) were presented and reviewed. Commonly used approaches in the literature are described with examples. Some of the concept confusion found in the literature (Model based, Observer, Estimator and Predictor) are explained and classified. One of the two important questions drawn from this study is how feasible the designed systems are on an embedded hardware, and the other is how well the defined problems describe the real problem. In many studies, the mechanical model (two mass) used in problem definition has similar properties. In the solution part, many studies have been carried out with over specification hardware (computer interface). In future studies, the definition of the problem can be expanded by adding existing non-linear effects coming from driver side or mechanical side, and more compact embedded solutions can be offered at the solution stage.

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