**Review on Mechanical Issues and Driver Solutions of Industrial PMAC Servo Systems: Parameter Estimation and Auto-tuning Concepts**

**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 loads. In this context, on the driver and control side, there are several approach and solution methods for mentioned mechanical issues. In this paper, problematic issues and offered solutions in the current literature for servo drive systems are defined and systematized.**

**Keywords: Servo Drive Mechanics, Mechanical Servo Issues, Filtering in Servo, Servo Control**

**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. 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 manner, tuning of the whole system can be done by controller-driver via motor with reflection 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 of the system for starting the tuning process. In this manner, there are two strategies for operating the tuning process as known Off-line and On-line. Off-line tuning the servo system means that defining process is done under the zero or no-load (dummy) motions []. This type tuning can be done by using some previous information (commision) or without any information (self-commision) about any part of the system. The other type 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 []. Both strategies are shown in flowcharts as in figure1.**

**Figure 1.**

**Possible useful methods are demonstrated for each step. Detection of the unwanted situations (disturbances) is the first step of both strategies. In real servo systems, these disturbances act as vibration, friction and mismatch []. These disturbances create detectable mechanical characteristics effects on the motor shaft that can appear as position, torque, speed, voltage or current error from controller/driver side indirectly []. Also, some of them can be detect by observation (manually or algorithmic) or using some model state variables []. After detection of the disturbance process, *off-line tuning process* halt or pause the system (motion is stopped) or system is unloaded (dummy motions). Then the system tries to understand the disturbances with using pre-defined routines that can be voltage/current injections, to try specific motion profiles, torque measurements, movements pushing the boundaries, specific position tracking or regular movements as same as loaded condition []. After this process system calculates or estimates the critical parameters, which are electrical, mechanical, model based or state variables, with using measured data from pre-defined routines. New parameters are integrated the controller/driver system and if need controller/driver parameters are updated with respect to new dynamics. System is reactivated []. When we look the On-line tuning process, it keeps going the regular motion (with load) with 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 under load signals are used for calculation or estimation. Because of this challenge, as a parallel process, Fast Fourrier Transform (FFT) based signal process, iteration algorithms or model based state variables ... are used for determining the disturbance properties []. Also, there are some filter based (band-pass) scanning approaches for detecting the disturbance with characteristics []. 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 detected disturbance during regular operation (under load) of servo systems. Some of the designers try to combine detection of the properties of the disturbance and suppression operation in same step. In this case, one of the approaches is observer/estimator strategy. In this approach an observer/estimator 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 past data with using trajectory. Kalman Filter based estimators are commonly used for this approach []. Another commonly used approach, which is known as Model Referenced Adaptive System (MRAS) is creating and controlling/driving a model in parallel with the actual system and comparing or evaluating the data from model and actual system for tuning the system []. MRAS based other adaptive systems also derived []. Some of the systems contain Fuzzy logic, Artificial Intelligent (AI) based structures, Neural Network (NN) strategies and Swarm Intelligence (SI) based self-organized systems but they need much more computing capability and have implementation hardness [].**

**Off-Line Tuning** Start

Position error

Torque error

Speed error

Voltage/Current error

Model based error

Manual observation

Detection of the disturbance

Halt/Pause the system or

Deactivate the load

Start pre-defined routine

Calculate/Estimate parameters

Set the controller/driver

Reactivate the system

**Offline (self commission or commision)**

**1. detection of the disturbance of the system**

**From speed error, torque error, position error etc. or manual observation**

**2. stop or halt or pause the system**

**3. Start pre defined routine**

**4. calculate parameters**

**5. reactivate the load again**

**Online**

**1. detection of the disturbance of the system**

**From speed error, torque error, position error etc.**

**2. detection of the frequency of the disturbance**

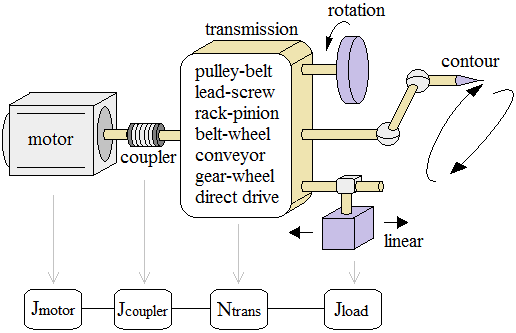
**Fft, iteration, state variables, ..**

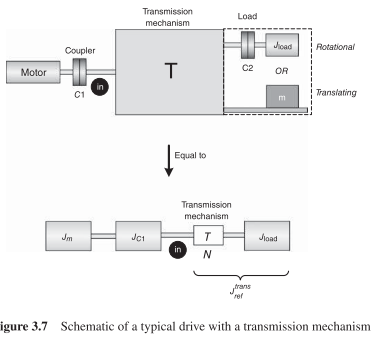
**3. detection of the amplitude and bandwidth of the disturbance**

**4. Filter setting with respect to detected f, q, BW**

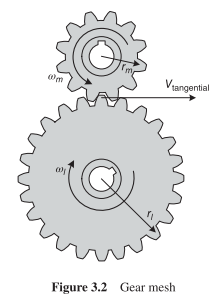
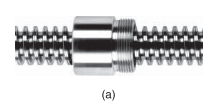
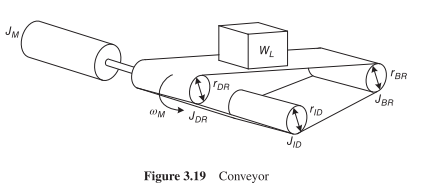
**MECHANICAL ISSUES**

**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, conveyor and gear-wheel structures (fig xx).**



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**These structure contains some mechanical part are listed as rolling mill, long shafts, large inertia, bearings, elastic couplings, rail, damping elements and belt, that return vibration (resonance or randomly), friction or sliding 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).**

** **  **elastic coupling yay, long shaft burulma, askıda hareket eden kütle.**

**These type mechanical issues must be compensated as possible as by controller/driver structure with using a detection-filtering method. For this purpose electrical and mechanical parameters of the system and auxiliary variables, which are used for modelling or defining the reflections must be defined in controller side as shown in fig.xx.**

**Parameters**

**Electrical Parameter (PMSM)**

|  |
| --- |
| **Electrical Parameters:** |
| : Series resistance |
| : d-axis inductance |
| : q-axis inductance |
| : Back EMF constant |
| : Rotor PM flux linkage |

**Mechanical Parameter**

|  |
| --- |
| **Mechanical Parameters:** |
| : Electromechanical torque |
| : Disturbance load torque |
| : Torque constant |
| : Rotor and load inertia |
| : Viscous friction coeff. |

|  |
| --- |
| **Variables:** |
| : rotor pole number |
| : rotor electrical speed |
| : rotor mechanical speed |
| : Laplace operator |
| : Back EMF+Cross coupling |

**Definitions (with figures), Sourced what**

**Reflection to motor and driver side (speed error, torque ripple, current error, phase difference ...)**

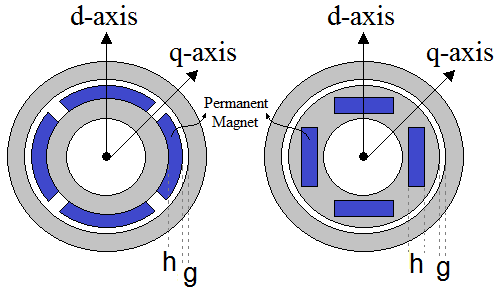
**Characterized of issue – frequency, peak and width definition of disturbances, shapes in time and freq domain.**

**1 periodic characteristic**

**2 non periodic characteristic**

**MODELLING**

**Modelling of the servo drive train have critical role in tuning operation because the real system behaviour have to run in the controller side. Modelling can be categorized in three main parts as mechanical model, machine model, controller/driver model. For this purpose, PMSM machine mathematical model with respect to** stationary α-β frame and rotating d-q frame **is given in fig.xx .**

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**DYNAMIC MODEL OF PMSM - IPMSM (SPMSM : )**

SPMSM vs IPMSM (g: gap length, h: PM width)

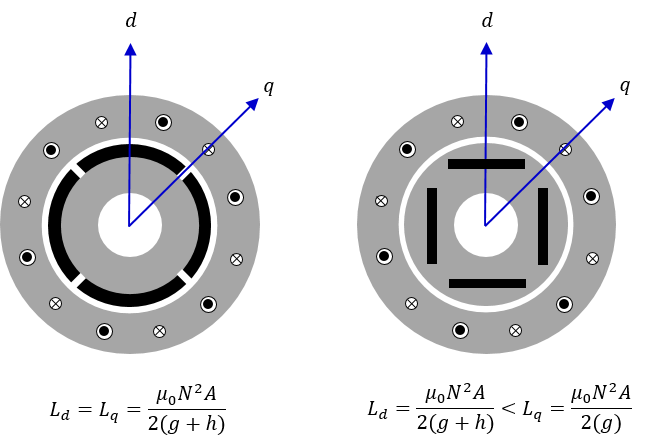


Fig. 2: PMSM Machine models and inductance, torque expressions

Rotating reference frame d-q currents, rotor speed and torque expressions are given below:

PMSM model with respect to stationary α-β and rotating d-q frame for d-q voltages and flux estimation are given below:

[Review and evaluation of some position and speed estimation methods for PMSM sensorless drives, Yousfi, D., Halelfad, A., El Kard, M.]

For stationary α-β frame :

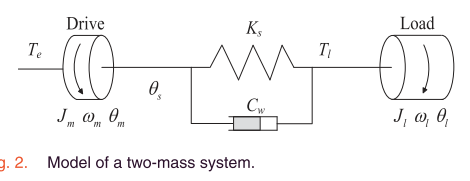
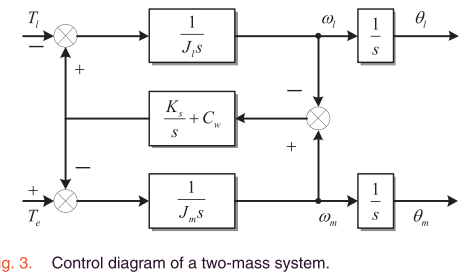
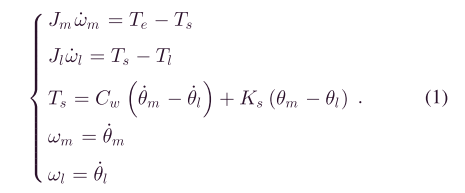
For rotating d-q frame :

Where,

Non-salient PMSM :

**MECHANICAL MODELLING**

**Mechanical models of the servo systems are created by using two ways as using flywheels [] or two or three mechanically coupled motor system (one of them represent motor, other one acts as load). In general, they are called two-mass, three-mass systems [] as shown in fig xx.**

** ** 

**Controller/Driver Model**

**In controller side, servo drive systems use Field Oriented Control (FOC) in rotating d-q frame. Position, speed and current/voltage control loops are located sequentially and they are controlled by PID []. Some specific applications use Direct Torque Control (DTC) technique if there is no need any sensitive speed or position control need []. Another control action for these systems is Model based control systems. These type controller works with a mathematical model of a plant (motor or motor with load) and a predictor, estimator or adaptive structure [].**

**Figure: foc,dtc,mras**

**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.**

**Motor types (DC, Induction Machine, PMAC) math model**

**Model of 2 and 3 mass system**

**Matlab models – real models (conveyor belt, gear wheel, fly wheel, robotic arms motions)**

**Nonlinear mechanical models and mathematical expressions**

**Controller and drivers**

**Current Controller**

**Speed Controller**

**Position Controller**

**DETECTION METHODS**

**How to find disturbance time duration and peak value ? (disturbance freq detection system)**

**-Adaptive approach : Adaptive notch filter ANF Regalia’s algorithm, MRAS**

**-Prior knowledge required: Disturbance observer, Inertial model control**

**-FFT, shifted discrete Fourier translations (SDFT), discrete wavelet transform (DWT), frequency weighting functions**

**-Kalman Filter (EKF)**

**++freq, amplitude, damping coeff**

**--Require appropriate model, computational requirement (real time implement difficult)**

**-Dissipative control + fitering techniques**

**ESTIMATORS & OBSERVERS**

**Kalman Filter based estimators**

**Extended kalman filter (EKF)**

**Reduced order kalman filters**

**Model referenced observers estimators (MRAS)**

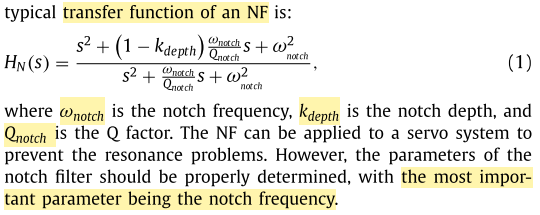
**Measured signals based estimators**

**Others**

**AI, Neural Network, Particle Swarm, Fuzzy Logic**

**FILTERs**

**Notch filter (adaptive notch, robust adaptive notch)**

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**Biquad Filter (easy digital implementation)**

**Low pass in which conditions**

**Band pass in which conditions**

**SYSTEM MANAGEMENT**

**Detection algoritmaları nasıl çalışıyor, hangi donanımda hangi yazılım koşuyor, Implementasyona uygun methodlar, ne kadar İşlem gücü gerekli?**

**DSP + FPGA**

**DSP: Speed loop, position loop, Robust Adaptive Notch Filter**

**FPGA: Current control loop, FFT, EKF**

**CONCLUSION**

**A servo system has unique and non-unique mechanical issues.**