Current frequency based identification scheme for resonance detection in Hybrid Stepper Motor.

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ABSTRACT

Stepper motors suffer with skipped steps due to the occurrence of resonance and instability, under certain load conditions. Unlike in other machines, variation of torque is not reflected in the current. Hence the current measurement based position estimation techniques fail. Experimental investigations reveal that high frequency variations are present in the current dynamics during the resonating periods. This paper proposes an identification technique which works based on frequency content during the transient period of the current rise. It is shown that resonance can be identified and with suitable compensation, current measurement based identification technique provide accurate speed & position estimation.

Keyword : - *Skip step, resonance, identification, compensation.*

1. Introduction

Hybrid stepper motor are used in positioning applications due to their durability, high efficiency and small step angle. Its applications include position control of solar array antenna and robotics, etc. The stepping rate normally follows the excitation rate. However, due to the mechanical constructions, resonance and instability are noted at certain speeds. The behavior of the machine varies with loading condition and needs to be addressed. High frequency operation can be achieved easily with these excitation schemes. For a given stepper motor, prediction of speed at which resonance occurs is determined by rotor inertia and stiffness. Resonance can be identified experimentally, either through mechanical or electrical measurements. Electrical measurements include the phase current and back Electromotive Force (EMF) . Mechanical measurements include rotor position, speed, torque and vibration. In this paper we will deal with electrical based measurement for resonance identification.

Permanent magnet and reluctance machines generally suffer with the problem of torque ripple. Voltage excitation based compensation is provided to reduce the torque ripple. This technique requires measurement of position as well as phase currents. Precise closed loop operation is straight forward with the use of mechanical measurement. However the modern approach is to replace the expensive mechanical measurements with low cost estimations based on electrical measurements. Any technique used for position estimation will fail to estimate the resonance conditions, for two reasons. They are:

1) The model used for simulation represents only sinusoidal flux terms and not any harmonics, which could be present;
2) High frequency oscillations seen in the current and back EMF waveforms are not utilized by the estimation techniques [4].

The former problem is addressed in [2], where static friction and 1st, 2nd and 3rd harmonic terms are added in the torque expression. This leads to new damping model. Oscillations are dampened out through current control and direct position measurement with appropriately chosen current commands (with harmonics included). This technique is effective with sinusoidal phase currents. The second problem is addressed in [3], where the presences of high frequency contents are identified.

The main objective of this paper is to clearly delineate the difference in current frequency between resonance and non resonance conditions under full step excitation schemes. Resonance conditions are created in the motor and experimentation is carried out on no loads for full step excitation scheme.

2. Existing Methods to tackle resonance

1. Micro step mode of excitation.
2. Change in phase current.
3. Shifting the step frequency
4. Increasing the friction.
5. Dampers.

Above techniques are available to reduce resonance and vibration as discussed by Kenjo [5] (1984) & Acarnely [6](2002). Each technique has its advantages and disadvantages. The key to eliminate its effects lies in either controlling where the resonant point falls or in reducing its severity.

1. Micro step mode of excitation.

Due to the smaller step angle, the oscillation is reduced and the system has less resonance points. The major disadvantage of the mini-step drive motor windings is the cost of implementation due to the need for partial excitation of the motor windings at many current levels, using a chopper drive circuit in which the reference current level for each phase is changed every mini-step. If no current compensation is provided in the micro step driver, a torque reduction of the motor may occur which is disadvantages in some applications. However, even if the motor is driven with sinusoidal pulse, vibration and resonance still exist due to the motor inherent characteristics.

2. Change in Phase Current

Resonance excitation is strongest during no-load operation and therefore, brings problems during testing. The phase current reduction also minimizes the stiffness and must be taken into account while positioning accuracy.

3. Shifting the Step Frequency

Resonance occurs during no-load operation using full step mode at approximate 70-100 Hz and appears at multiples or harmonics of the resonance. It is easier to avoid the resonant frequency by choosing a frequency that is somewhat higher or lower. Small deviations from the critical step frequencies reduce the resonance.

4. Increasing the friction

Friction generally has a damping effect on the system and oscillation becomes smaller. However, the torque is reduced by this and the motor efficiency also reduces.

5. Dampers

Damper reduces the oscillation and absorbs the vibration energy. The resonant frequencies are very much reduced because of the speed difference between the oscillating rotor and the external mass. Although this results in the significant reduction of overshoot, the use of dampers is unsatisfactory during high frequencies as it is limited by the friction torque.

Above techniques are either for reducing the resonance or for avoiding the resonant frequency. The solution to operate the motor during resonance conditions is left undiscussed.

3. Literature Survey

Points of Comparison	[1]	[2]	[3]	[4]	Proposed Method
Change in the motor model	No need	Required	No need	No need	No need
Resonance Identification	--	High freq extraction from I_{ph}	High freq extraction from I_{ph}	No identification	Transient behaviour of I_{ph}
Measure of Resonance	--	Estimated value of freq & magnitude	Magnitude of high pass filtered current is fixed as a threshold	Estimated results are calibrated to match with experimenta-tion	Depend on load torque
Measured variable	Position & I	Position, Speed & I	Current (I)	Current	Current

Table 1:-Literature survey .

4. Hardware Set-up

Fig 1 represents block diagram of driver circuit to Stepper Motor (Hybrid type).PIC controller is used to provide input speed to the motor by setting particular switching frequency in form of pulses via driver circuit and switching circuit. Fig 2 represents actual hardware based on the block diagram. Four switches are present at the bottom right corner on the board (3 switches for achieving 3 different speeds and 1 extra for reset).The input of the switches are given to PIC microcontroller which generates pulses according to selected input, to be fed to the motor. Two step down transformers are used in the hardware (1^{st} is tap changing transformer which provides 5V dc input after rectification and filtering to the PIC controller and 12V to the driver circuit and the 2^{nd} is 230V/12V for providing power to the motor that is 12V DC after rectification and filtering. Bridge Rectifier has been used as rectifiers.

MOSFET’s are used as switching devices to the stepper motor and it is seen on brown bread board. Driver circuit for switching the MOSFET is represented on blue PCB (printed circuit board) and it’s diagram is represented in Fig 3. Stepper motor selected is of specification given in Table 2.

Motor Parameter, units	Values
Voltage (Volts)	12
Current (Amp)	0.5
Number of Phases	2
Number of rotor teeth (N_r)	50
Step angle (Deg)	1.8
Number of steps per revolution	200
Torque (Nm)	0.19
Detent Torque (Nm)	0.029

Table 2:-Specification of Hybrid Stepper Motor for Hardware.

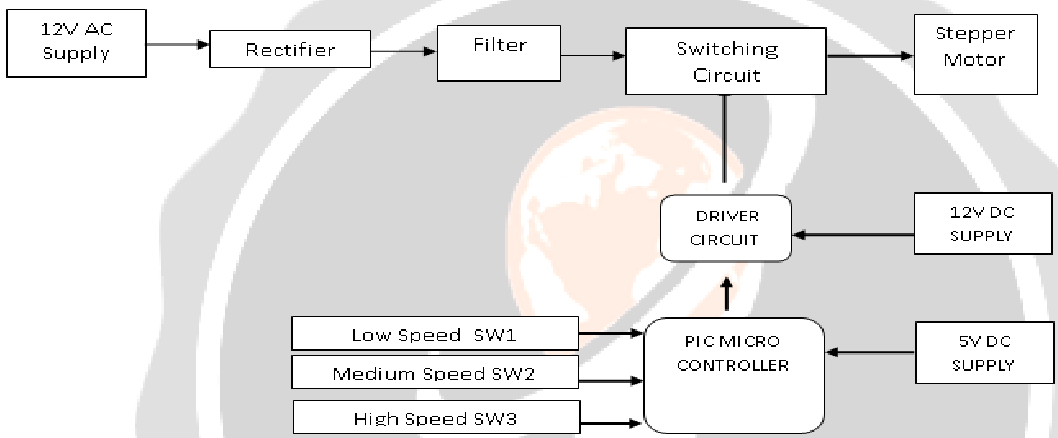

Fig 1:- Block diagram for Driving Hybrid Stepper Motor under no load

Resonance is the oscillatory phenomena which disturbs the normal operation of the stepper motor. In some cases the magnitude of oscillation increases with time and eventually the motor loses synchronism. Resonance and instability may be classified into three categories, namely the low frequency, medium range instability, and higher range oscillation .The oscillation that occurs below 200 Hz is called low frequency resonance. Medium range instability occurs between 500 Hz to 1500 Hz. The higher range oscillation occurs in the range of 2500 Hz to 4000 Hz. When resonance and instability are noted at certain speeds the behavior of the machine varies with loading condition and needs to be addressed. Full step, half step and micro-stepping excitation schemes can be used.. Resonance conditions are created in the motor, under full step excitation schemes Resonance can be identified experimentally. Different excitation scheme can be achieved by programming the PIC microcontroller using MPLAB tool. For a particular excitation scheme and load, variations in frequency of current are noted at the input side of the hybrid stepper motor due to oscillations created during resonance.

Fig 2:-Hardware set-up for driving the Hybrid stepper motor for full step excitation mode under no load.

5. Observations

Sr. no.	Switches (Full step)	Excitation frequency (Hz)	Maximum current frequency variation (Hz)	Load Torque (N-m)
1	**1**	**5**	**19**	**No load**
2	**2**	**10**	**22**	**No load**
3	**3**	**15**	**50**	**No load**

Table 3:-Observation Table

Similarly readings can be taken for half step and micro stepping mode of excitation for different loading conditions. From above table variations in current frequency during resonance can be utilized to compensate well before the stepper motor misses a step.

6. CONCLUSIONS

This paper investigates experimentally variations in current frequency at the input side of the hybrid stepper motor well before the motor misses a step. The variation in current frequency gives an indication of severity of the load torque applied and distinguishes the resonance and non resonance condition on no-load. Different compensation technique can hence be applied for compensation of resonance to avoid skipping or stalling of the steps for sensitive positioning applications.

7. REFERENCES

[1] H. Zhu, X. Xiao, and Y. Dong Li, "Torque ripple reduction of the torque predictive control scheme for permanent-magnet synchronous motors," *IEEE Trans. Ind. Electron.*, vol. 59, no. 2, pp. 871–877, Feb. 2012.

[2] K. W. H. Tsui, N. C. Cheung, and K. C. W. Yuen, "Novel modeling and damping technique for hybrid stepper motor," *IEEE Trans. Ind. Electron.*, vol. 56, no. 1, pp. 202–211, Jan. 2009.

[3] K. Balakrishnan, B. Umamaheswari, and K. Latha, "Estimation of rotor position and speed for hybrid stepper motor under various phase exci-tation schemes and compensated resonance," in *Proc. (POWERENG) Int.*

[4] K. Wonhee and C. Chung Choo, "Novel position detection method for permanent magnet stepper motors using only current feedback," *IEEE Trans. Magn.*, vol. 47, no. 10, pp. 3590–3593, Oct. 2011.

[5] T. Kenjo, *Stepping Motors and Their Microprocessor Controls*. New York: Oxford Univ. Press, 1984.

[6] P. Acarnely, *Stepping Motors: A Guide to Theory and Practice*, 4th ed. London, U. K: Inst. Elect. Eng, 2002

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