Implementation of Food Processor Application Using Brushless DC Motor Control

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Abstract- Food processor requires wide range of variable speed response. Going on the trend of energy saving and carbon reduction, household and commercial using of food processor operation efficiency be much more paid attention to. At the present stage, food processor is mainly with UM and IM. While the operating efficiency and noise cause users must find new solution. Energy conservation, high efficiency SRM and BLDCM become to the market's rising star. Current technology shows that the efficiency of BLDCM is higher than that of the SRM. Analysis and experiment for BLDCM required motion behavior control on the instant speed up, switching forward / reverse and braking in the food processor operation are discussed in this paper. The most suitable food processor required motion behavior control methods are provided. Experimental results proved that the proposed methods in fast dynamic response of food processor do never cause the system voltage and current unstable or over load condition.

Keywords: Food processor, BLDCM, Reverse power braking.

I. INTRODUCTION

In today's busy society, the population of eating out is increasing, while Health maxim "the fresh fruit and vegetables, five a day keeps illness away" also with the people further away, thus people demand for the food processor that were much more vigorous. In accordance with food processor requirement follow different food using different features and speed. Food processor usually used to processing massive or muddy food needs to crush process, thus food processor requires wide range of variable speed. On the market, food processor in accordance with food ingredients can be divided into the following:

1) Blender: Often used in the make of fruit juices, smoothies and nut food. Operation speed is about 6500–37000 RPM
2) Juice extractor: Often used for the separation juice and residues. Operation speed is about 1500–6500 RPM
3) Kitchen mixer: Often used on vegetables, soups, sauces and milkshakes etc. Operation speed is about 50–1500 RPM

Going on the trend of energy saving and carbon reduction, household and commercial using of food processor operation efficiency be much more paid attention to. Currently food processors in market are mainly with Universal Motor (UM) and Induction Motor (IM). UM features with large torque and fast dynamic response, but brush friction generation arcing and sparking causes Electro Magnetic Compatibility (EMC) problem to influence other electronic devices. The brush also needs to be regularly maintained. IM has no brush, no such problem, but its mechanical and electrical properties are poor; such as start-up torque is small, efficiency is low and speed response is bad. To improve these drawbacks, Switched-reluctance motor (SRM) and Brushless DC Motor (BLDCM) are being to be widely used in food processors recently [1]. Both SRM and BLDCM, without brush, commutated by electronic control method, have higher efficiency and better speed response. Efficiency is an important indicator of energy saving and carbon reduction. Current technology shows that the efficiency of BLDCM is higher than that of the SRM. There are two types of permanent magnet configuration used in the BLDCM structure, named Surface permanent magnet (SPM) and Interior Permanent Magnet (IPM). SPM BLDCM puts magnets on the rotor surface, while the IPM BLDCM puts magnets inside the rotor. Obviously, due to the high speed requirement, the IPM structure is selected to be used in the food processor. Analysis and experiment for BLDCM required motion behavior control on the instant speed up, switching forward / reverse and braking in the food processor operation are detailed description in this paper. And the most suitable food processor required motion behavior control methods is proposed.

II. FOOD PROCESSOR SYSTEM ARCHITECTURE

The block diagram of a food processor driver system is depicted in Fig.1. The motor is configured with four poles IPM BLDCM which is embedded with three hall sensor output to provide the rotor position information. Since the DC converter input voltage is designed in range of AC 85~230V, the line voltage can be either AC110V or AC220V. The converter is also designed three DC voltage outputs; (1) DC15V for Intelligent Power Module, (2) 5V and 3.3V for microprocessor system. System control is implemented upon a high performance low cost Micro Control Unit (MCU), HOLTEK-32-bit ARM Cortex-M3, HT32F2652. The Intelligent Power Module (IPM, PS21965-4S, 600V/20A) from Mitsubishi is used as the motor power stage.

The control functions are implemented by using HT32F2652 MCU as shown in Fig.2. Three Hall Sensor signals outputted from motor provides input signals to MCU for both commutation information and speed estimation. Protecting functions such as: hall sensor error protection, blocked rotor protection and over current protecting, are implemented. Two
signals, named IPM fault output (FO) signal and phase current signal, will trigger MCU interrupt mechanism and activate A/D function to do over current protection. A friendly human interface directs driver system to do different modes of operation to show the unique features of the food processor, such as: Instant forward / reverse switch, fast brake, and pulsed operation. The general electrical specifications of the food processor are listed in Table I.

### Table I

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
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<tbody>
<tr>
<td>Operation Voltage(V)</td>
<td>AC220V</td>
</tr>
<tr>
<td>Max. Input Current(I)</td>
<td>7.6A @ 15000RPM</td>
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<tr>
<td>Blocked Rotor Protecting (Sec)</td>
<td>1s @ 3000RPM; 0.5s @ 6000RPM</td>
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<tr>
<td>Over Current Protecting (A)</td>
<td>8A @ AC220V</td>
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<tr>
<td>Temperature Protecting(°C)</td>
<td>125°C</td>
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<tr>
<td>Output Power Rate(W)</td>
<td>1700W</td>
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<tr>
<td>Operation Direction</td>
<td>Forward(CW)/Reverse(CCW)</td>
</tr>
</tbody>
</table>

### III. SYSTEM CONTROL METHOD

To process food as fast as possible is the most important requirement of food processor, thus, the actions such as instant speedup, instant stop and instant change rotation direction are the general tasks of motor driver, and these motion requirements are the headache problems for all motor control engineering. Three main control strategies will be discussed in this section.

1. **Modified PI control:**
   Generally, Proportional-Integral (PI) is the method used in close loop control. An optimal PI with Anti-Windup flow chart is shown in Fig.3 [2]. Because of wide range of load variation often cause overshoot of PI without Anti-Windup for start-up control, if want to smooth start-up the driver needs to spend too much time to find $K_P$, $K_I$ and $K$. Since the load varying factor during the full speed control of the food processor is too much to find the suitable parameters of $K_P$, $K_I$ and $K$, the PI controller is caused to becoming unstable or generating too large current to shutdown the processor. In order to overcome this problem, the conventional PI is been divided into two stages: start up stage and stable speed control stage. The start-up close loop control flow chart is shown in Fig.4. From this flow chart, we can see that the acceleration is kept constant by linearly increasing constant PWM duty cycle. In this way, the stable start-up can be kept until the rated RPM is been reached, then, the control strategy is passed to the normal PI controller as shown in Fig.5. Examining this method, we found that not only the system stability is increased, but also no over current is detected.

2. **Instant braking control:**
   Another important issue of food processor speed control is instant braking. The response time from full speed to stop is asked as short as possible to let next work been started quickly. The shorter the response time taken, the more regenerated current induced. The induced regenerated current will cause the DC BUS over voltage and destroy the power stage of the motor driver [3],[4]. To avoid these drawbacks, a
reverse braking technique of inverter is proposed. When motor is in normal running, motor rotor and rotating magnet field must be with the same direction, as shown in Fig.6. The principle of reverse braking is that upon the driver receives a stop or reverse rotation direction command, the driver changes rotating magnet field to the opposite direction immediately, as shown in Fig.7. In these two figures; time window is 250usec; channel 1 is colored in yellow color, denotes for HALL A signal; channel 2 is colored in blue color, denotes for braking signal; channel 3 is colored in pink color, denotes for phase A voltage; channel 4 is colored in green color, denotes for phase A current, with scale of 2A/div. Obviously, the reversed electromagnetic torque becomes braking torque. The Back-Electromotive Force (Back-EMF, BEMF) superimposition with DC Bus voltage generates braking current, which can be written as (1):

$$I = \frac{E - U}{R}$$

where, \(I\) = Braking current; \(E\) = Back-EMF; \(U\) = DC Bus Voltage; \(R\) = shunt resistor.

Back-EMF voltage is propositioned to RPM speed which is then added with DC Bus \((U)\) to obtain just enough braking torque to generate a deceleration force to let motor stop immediately.

$$PWM\ Duty = \left(\frac{STEP}{2}\right) \cdot \left(\frac{Current\ PWM}{MAX\ RPM/STEP - 1}\right)$$

where, \(STEP\) = decelerate step.

3. Fast reversing control:

   The switching logic of the normal operation and reverse braking operation of the motor driver is listed in Table II. The upper six steps is denoted the clockwise direction (CW) and the lower six is for counter clockwise direction (CCW). The upper six steps is for normal running (in CW direction) and the lower six steps is for reverse braking (in CCW direction). In the normal running, the PWM signal is applied on the high side MOSFET, AT, BT, and CT, while in the reverse braking, the PWM signal is applied to both high side and low side MOSFET. In normal running, the low side MOSFET is always on to reduce switching loss, while in braking period the low side MOSFET is been applied PWM signal to control the regenerating current used to stop motor immediately. In this situation, if there is any unsuitable control applied to the duty of PWM, then the dangerous of over current or over voltage caused by electric regeneration on DC BUS will be happened. Examining the relationship of the regenerated current and the running speed, we can calculate the suitable duty value of the PWM to brake motor smoothly follow the (2). To simplified brake operation and consider backward rotation, we use the flow chart of braking or backward rotation procedure is shown in Fig.8. In the figure we can find the relationship of PWM value and the rotation speed. In fast forward/backward direction switching applications, increasing the calculated PWM value a little bit, will help the motion control made easily and smoothly.

   ![Diagram](image)

   Fig. 6. Normal operation.

   ![Diagram](image)

   Fig. 7. Reverse braking.

   ![Diagram](image)

   Fig. 8. Procedure of braking, or backward rotation.

<table>
<thead>
<tr>
<th><em>CS</em></th>
<th><em>Hall</em></th>
<th>AT</th>
<th>AB</th>
<th>BT</th>
<th>BB</th>
<th>CT</th>
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<td>6</td>
<td>PWM</td>
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<tr>
<td>3</td>
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<td>ON</td>
<td>PWM</td>
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<tr>
<td>5</td>
<td>PWM</td>
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<tr>
<td>4</td>
<td>PWM</td>
<td></td>
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</tbody>
</table>

   | 6    | PWM   |    |    |    |    |    |    |
   | 2    | PWM   |    |    |    |    |    |    |
   | 3    | PWM   |    |    |    |    |    |    |
   | 1    | PWM   |    |    |    |    |    |    |
   | 5    | PWM   |    |    |    |    |    |    |

   | 4    | PWM   |    |    |    |    |    |    |

   *CS = Commutation Switching.
   *Hall = Combine HC, HB & HA, such as 0, 0, 1 equal 1.
Since the time period for doing stop motor is been asked to as short as possible. To monitor the increased regenerated current also becomes very important and needs some artwork skill. We use PWM interrupt function to trigger A/D to read current. By this way, we can correctly monitor the phase current and precisely protect the control system.

IV. EXPERIMENTS AND FUNCTION VERIFICATION

To verify the function of food processor, we designed five experiments that can help us to understand how much better the function will be:

1) Load and no-load testing: We measured food processor system no-load power consumption at rated speed 15000 RPM which is 550W, with input line voltage 220V/60Hz and consumed current is three amperes. With the same testing conditions as no-load, but adding the food processor with load of 800g carrot and 1200ml water, the carrot was cut roughly into 25mm*25mm cubes, we found a recorded peak power consumed of 1100W at start, the consumed current is seven amperes. After carrot cubes were broken up and mashed, the consumed power is down to 880W (consumed current 5.5A).

2) Test speed-up response time: This experiment is to check the acceleration and deceleration response time that is the time elapsed between 0 RPM and 15000 RPM. The first speed-up method using conventional close loop PI controller, as mentioned in the previous section. The motor state was recorded by Logic Analyzer (LA) as shown in Fig.9. The elapsed time is the time period between mark A and mark B which is equal to 557.417msec. An active low I/O pin is used as flag for mark A and B.

The same condition was applied to our proposed method whose LA diagram is shown in Fig.10. We can see that the elapsed time is only 142.999 msec between mark A and B in Fig.10.

3) Test speed-up system stability: The system stability is to check the current variation. The current variation of conventional close loop PI controller is recorded by four channels oscilloscope as shown in Fig.11. In the figure: channel 1 is colored in yellow color, denotes for HALL A state, with scale of 5V/div; channel 2 is colored in blue color, denotes for DC BUS voltage, with scale of 50V/div; channel 3 is colored in pink color, denotes for Phase A shunt resistor voltage, with scale of 2V/div; channel 4 is colored in green color, denotes for phase A current, with scale of 3.5A/div. An inrush current which causes DC Bus voltage sag is found inside the elliptic mark in Fig.11.

The same condition was applied to our proposed method as shown in Fig.12. We can see that the DC BUS is very stable in the start-up acceleration and the current is also under control. After smoothly start-up, the conventional PI method is invoked as the white triangle indicated in Fig.12.

Obviously, the system stability is guaranteed by two stages start-up acceleration control as mentioned in the previous section.
4) Fast motor braking: To examine the effect upon using reverse braking to stop motor, non-braking method and reverse braking method were tested comparatively. Non-braking means all inverters are switched off, and only friction force let rotor freely stopped. A no load non-braking motor stopping process is recorded using LA as shown in Fig.13. The time from receiving stop command to standstill is 626msec. The same condition was applied to no load reverse braking method as shown in Fig.14. We can see that the time from receiving stop command to standstill is only 364msec. The same tests with full load were also conducted and recorded as shown in Fig.15 and 16. The time from receiving stop command to standstill is 194msec in Fig.15 which is the case of non-braking method, while in reverse braking case the time is 103msec in Fig.16. Thus by using the reverse method, the time can be greatly reduced (almost the half time).

The current and system bus response were recorded by using oscilloscope as shown in Fig.17, 18, 19, 20, for no load non-braking, with load non-braking, no load reverse braking, and with load reverse braking, respectively. In these figures: channel 1 is colored in yellow color, denotes for HALL A state, with scale of 5V/div; channel 2 is colored in blue color, denotes for brake command (low active), with scale of 5V/div; channel 3 is colored in pink color, denotes for DC Bus voltage, with scale of 50V/div; channel 4 is colored in green color, denotes for phase A current, with scale of 3.5A/div.
Compare Fig.17 to Fig.19 and also Fig.18 to Fig.20, we can find that both system voltage and phase current are all stable there is no regenerated BEMF recharge back to the system bus, but the used time of reverse braking is only half of the time of non-braking.

5) Fast forward/backward: Take the advantages of reverse braking, we can smoothly switching fast forward to fast backward rotation. A fast reverse rotation control process, from high speed CW to CCW, with full load is recorded using LA as shown in Fig.21. The elapsed time is the time period between mark A and mark B which is equal to 636msec. The reverse rotating command is pushed at time mark T, and reversed high speed is reached at mark A and mark B. The current and system bus response were recorded by using oscilloscope as shown in Fig.22. In the figure: channel 1 is colored in yellow color, denotes for HALL A state, with scale of 5V/div; channel 2 is colored in blue color, denotes for check 15000RPM signal, with scale of 5V/div; channel 3 is colored in pink color, denotes for DC Bus voltage, with scale of 50V/div; channel 4 is colored in green color, denotes for phase A current, with scale of 3.5A/div. There is no any inrush current or any bus unstable (caused by regenerated voltage, or recharge current) occurred. The proposed motion control strategy is very good of instant switching forward/backward.

V. CONCLUSION

The optimized control method of the food processor for BLDCM motion response is realized. The proposed methods whether fast start-up, acceleration, deceleration, braking, or forward/reverse switching, which are response smoothly and immediately. Experimental results show that the proposed methods in fast motion dynamic control of food processor do never cause the system voltage and current unstable or over load condition.

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