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Research on IGBT junction temperature overload algorithm of servo driver

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Abstract. As the core of industrial control, servo drives have become evident in small volume, multi-spindle integration, acclimatization and energy conservation in recent years. The main domestic and foreign servo drives adopt module temperature detection, thermal accumulation - heat dissipation model or inverse time overload algorithm. The overload multiple and time are relatively fixed, and cannot further improve overload capacity according to the environment temperature or load condition. Due to the low utilization rate of the radiator, the servo drive selection usually amplifies the first gear and increases the cost of the electrical system. Without adding energy feedback cells or capacitors, it's not efficient to recycle the energy produced by braking. This paper mainly studies the overload algorithm which based on junction temperature prediction. The overloading algorithm can increase the overload capacity by 40%. Fanless design can be realized to meet the application of negative conditions such as conductive dust, cutting fluid and cotton. In general, the overload algorithm which based on junction temperature prediction is suit for the application of printing, packaging, semiconductor silicon, forging, laser cutting machines.

Key Words: Servo Drive, IGBT protection, overload algorithm, junction temperature

1. Introduction
As can be seen from the characteristics of servo system in printing and packaging, silicon semiconductor, lithium battery and laser cutting industries, the servo driver's environment temperature is not as bad as the application environment of frequency converter. The continuous operation is rare and generally will not run at full load. Therefore, it is necessary to study an overload protection algorithm based on ambient temperature and load rate.

The overload algorithm of the servo driver is similar to that of the inverter and the motor in principle. Reference [1] is an extension of this model. The inverse time limit protection curve is a set of fixed protection curves based on the maximum ambient temperature design. Literature [2] a kind of suitable for inverter motor thermal protection algorithm research and literature [3] and [4]inverter motor overload protection algorithm and its implementation in detail describes the heating - cooling overload protection model by analyzing the mechanism of heating and cooling, heat accumulation is established and the dynamic mathematical model of heat dissipation, can simulate dynamic change of temperature in a row, can accurate reaction heat accumulation effect caused by the load change.But inverse time overload protection and thermal accumulation overload protection still have several defects as follows:

1.1. Lack of economic benefit

The servo driver of the inverse time overload algorithm and the thermal accumulation overload algorithm cannot be downsized even the ambient temperature is low and the servo driver is running under low load , so it can not save the driver cost and the power cabinet space for the end user in the multi-axis application.

1.2. Productivity cannot be further improved
If the selection of servo driver remains unchanged, the operation speed and cycle of the device cannot be further improved, and the operation efficiency of the device cannot be improved for the end user.

1.3. The quality of disadvantage
The inverse time overload protection algorithm and thermal accumulation overload protection algorithm cannot protect IGBT according to the junction temperature in real time, so the IGBT failure rate of the servo driver in the terminal application scenario is high.
To avoid the above defects,this paper mainly studies the overload algorithm which based on junction temperature prediction. In literature [5], the simulation model of junction temperature of insulated gate bipolar transistor and its application research analyzed that the peak of junction temperature and steady-state fluctuation value were the most direct factors affecting IGBT reliability, and proposed the IGBT junction temperature prediction model based on loss model and heat transfer network model. Literature[5]provides characterization of high-voltage IGBT module degradations uder PWM power cycling test at high ambient temperature while Literature[6] and [7] provide a comparative study on IGBT junction temperature simulation and detection method. Literature[8]solves the problem of thermal resistance extraction. Literature[9] and [10] provide the control method of servo driver which support for the analysis of junction temperature overload.

2. Overload protection algorithm based on junction temperature estimation
The key points of junction temperature overload protection are as follows
- Real-time estimation of IGBT and diode junction temperature, through junction temperature protection to achieve overload protection.
- The IGBT junction temperature is estimated by the ambient temperature and the real-time loss of the radiator temperature.
- Through the internal NTC (or external NTC on the radiator) temperature of IGBT module combined with the real-time loss of the radiator temperature, the IGBT junction temperature is estimated.

The junction temperature estimation model is shown in figure 1.
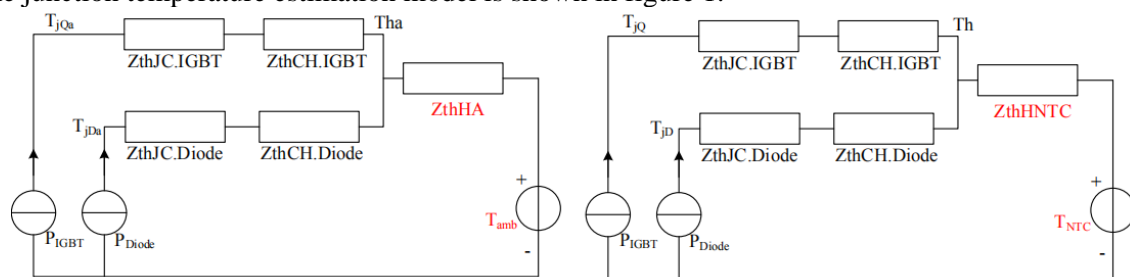
Figure 1. Junction temperature estimation model

According to the junction temperature estimation model and electrical parameters in figure 1, the average loss of IGBT module in one cycle can be calculated in real time.The junction temperature of IGBT and continuous diode can be calculated by combining ambient temperature or NTC temperature and various thermal resistance parameters. The radiator temperature and junction temperature are expressed as follows:

$$\begin{cases} T_{jQ} = T_h + \Delta T_{jhQ} = T_h + \sum_{k=1}^{n} \Delta T_{jhQ(k)} \\[2mm] T_{jD} = T_h + \Delta T_{jhD} = T_h + \sum_{k=1}^{n} \Delta T_{jhD(k)} \\[2mm] T_h = T_a + \Delta T_{ha} = T_a + \sum_{k=1}^{n} \Delta T_{ha(k)} \\[2mm] T_h = T_{NTC} + \Delta T_{hNTC} = T_{NTC} + \sum_{k=1}^{n} \Delta T_{hNTC(k)} \end{cases}$$

$$\begin{cases} \Delta T_{jhQ(k)(i+1)} = P_{lossQ}R_{thjhQ(k)} + (\Delta T_{jhQ(k)(i)} - P_{lossQ}R_{thjhQ(k)})e^{-\frac{T_{SW}}{\tau_{thjhQ(k)}}} \\[3mm] \Delta T_{jhD(k)(i+1)} = P_{lossD}R_{thjhD(k)} + (\Delta T_{jhD(k)(i)} - P_{lossD}R_{thjhD(k)})e^{-\frac{T_{SW}}{\tau_{thjhD(k)}}} \\[3mm] \Delta T_{ha(k)(i+1)} = P_{loss}R_{thha(k)} + (\Delta T_{ha(k)(i)} - P_{loss}R_{thha(k)})e^{-\frac{T_{SW}}{\tau_{thha(k)}}} \\[3mm] \Delta T_{hNTC(k)(i+1)} = P_{loss}R_{thhNTC(k)} + (\Delta T_{hNTC(k)(i)} - P_{loss}R_{thhNTC(k)})e^{-\frac{T_{SW}}{\tau_{thhNTC(k)}}} \end{cases}$$

Where n represents the thermal resistance order, i represents the temperature appreciation of the last beat, and i +1 represents the current beat. Tsw represents the temperature calculation period.
The flow chart of the temperature estimation function is shown in figure 2:
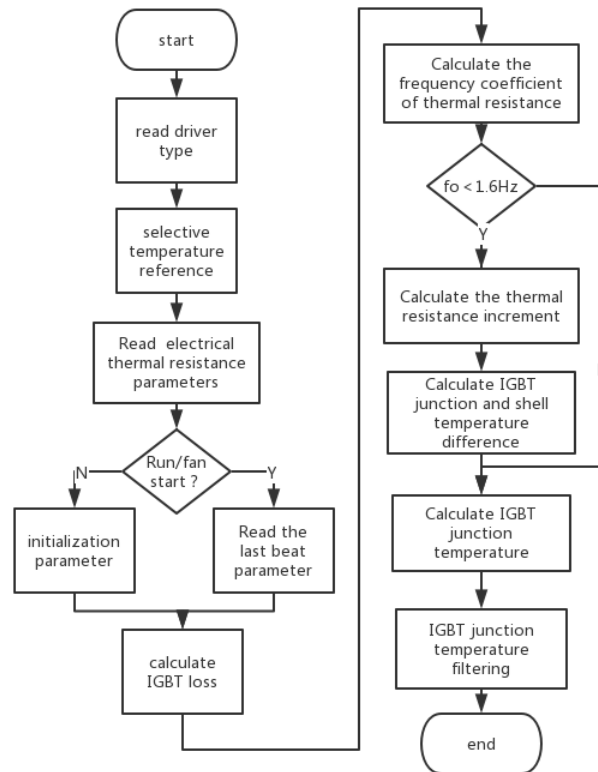

Figure 2. Flow chart of temperature estimation function

First read the model, temperature and current heating parameters.Second selects the initialization parameters including ambient temperature, radiator temperature, thermal resistance between junction and shell, thermal resistance between shell and radiator or reads the parameters of the previous beat

based on whether the fan is started.The third step is to calculate IGBT loss, thermal resistance frequency and temperature difference.At last, calculate IGBT junction temperature and save global variables.

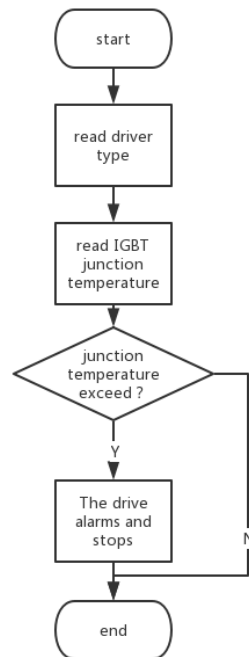The flow chart of overload protection function is shown in figure 3:

Figure 3. Flow chart of overload protection function

First, read the driver type and IGBT junction temperature. Second, judge whether IGBT junction temperature exceeds the set value. Third, determine whether the drive is stopped by alarm.

3. Application of junction temperature overload protection

Table 1. Comparison of junction temperature overload and heat accumulation algorithm.

Type	Overload time when speed over 10r/min				Overload time when speed under 10r/min			
Overload ratio	250%		200%		250%		200%	
Radiator temperature	Junction temperature protection	Thermal accumulation protection	Junction temperature protection	Thermal accumulation protection	Junction temperature protection	Thermal accumulation protection	Junction temperature protection	Thermal accumulation protection
20℃	continuous	2.6S	continuous	18S	32S	0.5S	continuous	4S
30℃	continuous	2.6S	continuous	18S	27S	0.5S	250S	4S
40℃	continuous	2.6S	continuous	18S	15S	0.5S	120S	4S
50℃	250S	2.6S	continuous	18S	9S	0.5S	80S	4S
60℃	120S	2.6S	continuous	18S	5S	0.5S	50S	4S
70℃	50S	2.6S	continuous	18S	2.5S	0.5S	24S	4S
80℃	20S	2.6S	240S	18S	1S	0.5S	10S	4S
90℃	10S	2.6S	80S	18S	0.7S	0.5S	6S	4S

Thermal accumulation overload algorithm is a set of overload time constants based on the maximum application temperature and full load test of the servo driver.The overload multiple and time cannot be adjusted dynamically according to the different environment temperature and average load rate.But the junction temperature overload algorithm can adjust the overload time and multiple dynamically according to the different ambient temperature average load rate, which can give full play to the capacity of radiator and IGBT.As shown in the table, the temperature overload algorithm can achieve the effect of continuous operation at 200~250% operating overload of 20~40℃.The 250% overload time improved by 284% compared with the heat accumulation algorithm at 90℃, and 200% overload time improved by 344%. The time of 200~250% occulting is 29 times higher at 40℃ . The 250% of the blocking time increased by 100% and 200% by 150% at 80℃.The 250% of the plugging time is 40% higher than that of the heat accumulation algorithm at 90℃, and 200% of the plugging time is 50% higher .

Table 2. IGBT shell temperature simulation value and measured value comparison table

Radiator and IGBT	thermal simulation	Actual test results	The relative error
Radiator point 1	68.1℃	68.7℃	0.6
Radiator point 2	83.6℃	82.6℃	-1
Radiator point 3	83.6℃	82.4℃	-1.2
Radiator point 4	81.6℃	85.3℃	3.7
IGBT point 1	95.0℃	92.7℃	0.4
IGBT point 2	95.6℃	94.6℃	-2.2
IGBT point 3	95.6℃	97.8℃	1.0
IGBT point 4	95.0℃	94.6℃	2.3

When the drive reaches steady state with load steps of 70%, 100% and 150% torque and the motor speed is 15 RPM, the radiator temperature and IGBT shell temperature calculated by the software and the following error of the measured value meet the application requirements within 2.8℃ while Radiator temperature within 3.7℃. Therefore, the accuracy of the junction temperature overload protection model meets the application requirements.

Table 1 shows the increase of overload capacity while table 2 indirect verifies the accuracy of junction temperature prediction. However, the junction temperature overload algorithm still has the some disadvantages compared with the heat accumulation overload algorithm. Firstly, the junction temperature overload algorithm depends on the accuracy of IGBT device parameters and loss calculation model. Secondly, the junction temperature overload algorithm takes up more MCU chip resources. Finally, the IGBT compatibility of junction temperature overload algorithm for different manufacturers is poor.

4. Conclusion

- Based on the junction temperature overload protection algorithm, the instantaneous and long-term overload capacity can be increased by at least 40% so that the servo driver can be downsized when the ambient temperature is low and the servo driver is running under low load. It can save the driver cost and the power cabinet space for the end user in the multi-axis application.
- The operation speed and cycle of the device can be further improved, and the operation efficiency of the device can be improved for the end user.
- The junction temperature overload protection algorithm can protect IGBT according to the junction temperature in real time which can reduce the IGBT failure rate of the servo driver in the terminal application scenario.

The junction temperature overload protection algorithm can solve the instantaneous protection problem well. But the long-term reliability estimation of IGBT and power devices combined with servo operating conditions remains to be studied.

5. References

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