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**HOW TO REDUCE 3rd HARMONICS WITH  
ST6200C MOTOR CONTROL SOFTWARE**

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by Microcontroller Division Application Team

**INTRODUCTION**

Universal motors are widely used in home appliances such as vacuum cleaners, washing machines, power tools and food processors. However, universal motors produce a strong 3rd harmonic current. When the TRIAC conduction is not in full wave mode, the motor current contains high amplitude 3rd harmonics which may not comply with the 3rd harmonics limits set by the IEC61000-3-2 standard. In practice, it is very difficult to comply with the harmonics standard when driving universal motors with a power of more than 1200W .

This application note presents an innovative, cost-saving solution for suppressing 3rd harmonic current in the power line. The control principle is based on modulation of the phase angle delay times and is easily implemented in software using a low cost ST6200C microcontroller. The output motor current waveform is modulated so as to suppress specified harmonic components. The efficiency of this method has been proven on a 1500W vacuum cleaner under various load conditions. The measurement of harmonic components and motor power was done with a digital power meter (WT1030). The results show much better harmonic performance than symmetrical phase control methods.

### 1 IEC61000-3-2 STANDARD

Harmonic disturbances in the power line have increased with spread of electronic equipment into homes and offices. Many household appliances and similar electrical equipment with or without electronic control devices, are liable to introduce disturbances, especially harmonics of the supply frequency, into the systems to which they are connected. The harmonics do not represent any real or active power, but nevertheless they lead to substantial copper or iron losses. The IEC61000-3-2 standard deals with the limitation of harmonic currents injected into the public supply system.

#### 1.1 SCOPE

The IEC61000-3-2 standard is applicable to all electrical and electronic equipment with an input current up to 16A and intended to be connected to public low-voltage distribution systems with a nominal 50Hz or 60Hz frequency and of the following types:

- nominal voltages up to 240V, single-phase, two or three wire;
- nominal voltages up to 415V, three-phase, three or four wire;

#### 1.2 OBJECTIVE

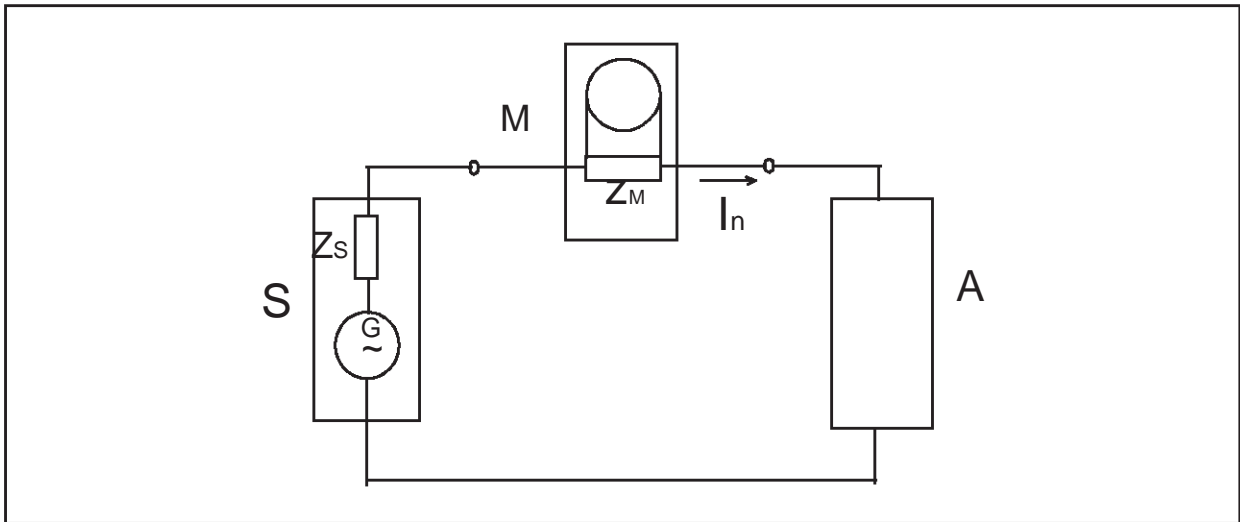
The objective of this standard is to give the general requirements and the maximum permissible values of the harmonic components of the input current which may be produced by a piece of equipment tested individually under specified conditions. It also gives a practical method for testing a prototype.

#### 1.3 MEASUREMENT CIRCUIT FOR SINGLE PHASE EQUIPMENT

The equipment under test is supplied in series with shunts  $Z_M$  (see Figure 1.) or current transformers from a source with the same nominal voltage and frequency as the rated voltage and frequency of the equipment under test.

The measurement circuit for single phase equipment is show in Figure 1..

Figure 1. Measurement circuit for single phase equipment



**Legend:**

S = Supply source

M = Measurement equipment

A = Equipment under test

$Z_M$  = Input impedance of measurement equipment

$Z_s$  = Internal impedance of the supply source

$I_n$  = Harmonic component of order n of the line current

### 1.4 GENERAL REQUIREMENTS AND LIMITS FOR EQUIPMENT

For Class A equipment (including universal motors), the harmonics of the input current shall not exceed the absolute values given in Table 1. The limits are given as absolute values which are independent of the equipment input power.

**Table 1. Limit of harmonic currents for Class A equipment**

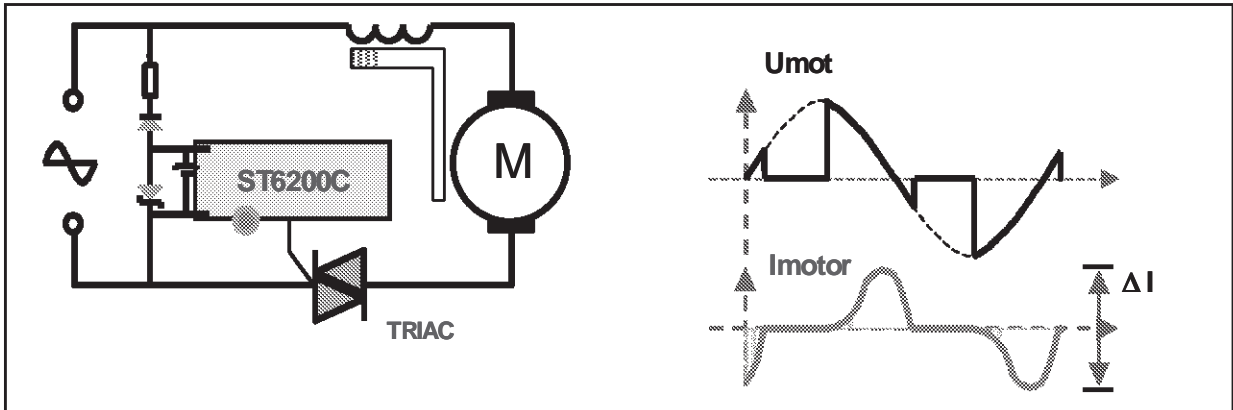
	Harmonic order	Maximum permissible harmonic current(A)
Odd harmonics	3	2.30
	5	1.14
	7	0.77
	9	0.40
	11	0.33
	13	0.21
	$15 \leq n \leq 39$	$0.15 * 15 / n$
Even harmonics	2	1.08
	4	0.43
	6	0.30
	$8 \leq n \leq 40$	$0.23 * 8 / n$

## 2 CONTROL PRINCIPLE

### 2.1 SYMMETRICAL PHASE CONTROL METHOD

In AC power system applications, the amount of power delivered to the system load can be varied by controlling the phase delay time through a TRIAC. The delay time is referred to the zero voltage crossing on the power line. This method is widely used in universal motor control applications. The motor speed can be easily controlled by changing the firing angle. Power delivered is equal to the integration of the power from fire angle to pie (180 degrees). The TRIAC will conduct power after the firing angle and turn off power at the zero crossing point. The system block diagram and waveform are shown in Figure 2..

Figure 2. Topology of universal motor symmetrical phase angle control method



A universal motor operating at reduced speed (i.e firing angle at around 90 degree) produces very high level of odd harmonics. In experiments with a 1500kW vacuum cleaner at 230V/ 50Hz with the same load, harmonic currents were found to be outside the limits when running at reduced power levels from 470W to 1200W. Practical experience shows that 3rd harmonic currents are determined not only by the motor current amplitude, but also by the conduction time.

**Table 2. 1500W vacuum cleaner harmonic currents measurement at fixed load with symmetrical phase angle control method**

Power	Delay time	Harmonic order & Harmonic Currents (A)			
P (W)	t (ms)	3	5	7	9
250	6.9	1.918	0.92	0.275	0.2
320	6.5	2.122	0.931	0.322	0.213
535	5.75	<b>2.474</b>	0.92	0.453	0.175
590	5.55	<b>2.513</b>	0.923	0.478	0.156
780	5.0	<b>2.601</b>	0.883	0.502	0.127
900	4.5	<b>2.576</b>	0.859	0.44	0.162
1000	4.2	<b>2.515</b>	0.834	0.357	0.196
1050	4.0	<b>2.448</b>	0.82	0.306	0.194
1090	3.75	<b>2.406</b>	0.806	0.27	0.188
1130	3.6	<b>2.331</b>	0.793	0.232	0.182
1200	3.5	2.193	0.743	0.188	0.142
1300	3.0	1.892	0.612	0.196	0.06
1400	2.25	1.386	0.33	0.2	0.116
1450	1.6	1.11	0.138	0.13	0.111
1480	0.3	0.77	0.107	0.022	0.01
Harmonic current limit (A)		<b>2.30</b>	<b>1.14</b>	<b>0.77</b>	<b>0.4</b>

In Table 2., the figures in bold are outside the harmonic current limit specifications.

### 2.2 ASYMMETRICAL PHASE CONTROL METHOD (KURZ PATENT)

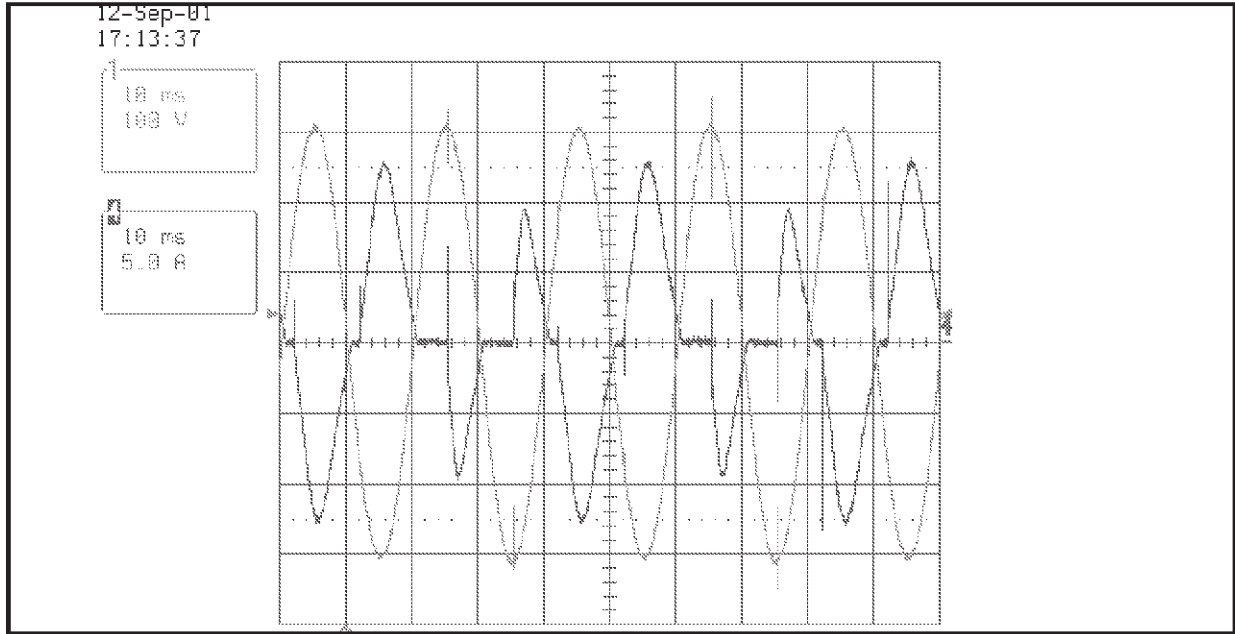
The experiment results in Table 2. indicates that universal motors produce the maximum 3rd harmonic currents at the middle power range. This makes it possible to reduce the harmonic current with the asymmetrical phase control method.

According to Table 2., when a 1500W vacuum cleaner works at 780W, the 3rd harmonic current is outside the limit. But when it works at 1200W and 320W, the 3rd harmonic current is within the limit. If it works at 1200W and 320W in alternate full wave cycles (2 long plus 2 short), the 3rd harmonic current should not be outside the limits due to phase considerations and the average power should be around 760W. The motor speed will be still quite stable due to the rotor momentum. The experiment results in Table 3 prove this hypothesis.

It is very simple to try out this control method with a simple experiment. During the testing period, two potentiometers can be used to set two independent phase angle delay times. In this way, the motor power can be changed with different combinations of the two potentiometers. The motor power and 3rd harmonic current can be measured at the same time. The best harmonic performance can be achieved by finely adjusting the two phase angle delay times. From this, it is easy to build a look up table (t1 and t2 corresponding to the motor power).

The current waveform is shown in Table 3. Channel 1 is the AC mains voltage waveform, channel 4 is the motor current waveform.

**Figure 3. . Motor current waveform of asymmetrical phase control method**



Based on the simple experiment with two potentiometers, the two phase angle delay time could be optimized at different motor power rates. From this, the look up table for the two phase angle delay times can be created . With this innovative solution, the 3rd harmonic currents at middle power range have been reduced dramatically without any additional cost. Table 3 gives the harmonic currents test results with the same universal motor under the same test conditions.

**Table 3. . 1500W vacuum cleaner harmonic currents measurement at fixed load with asymmetrical phase angle control method (Kurz patent)**

Power P (Watt)	Delay time		Harmonic order & Harmonic Currents (A)			
	t <sub>1</sub> (ms)	t <sub>2</sub> (ms)	3	5	7	9
535W	6.8	5.25	2.13	0.536	0.18	0.059
580W	6.8	5.0	2.033	0.38	0.151	0.104
780W	6.6	4.1	1.745	0.165	0.164	0.21
940W	6.0	3.4	1.557	0.18	0.252	0.134
1000W	6.0	2.9	1.241	0.327	0.29	0.083
1050W	5.55	2.05	0.86	0.388	0.207	0.146
1100W	5.25	2.05	1.01	0.342	0.261	0.106
1120W	4.75	2.05	1.267	0.25	0.316	0.015
Harmonic current limit (A)			<b>2.30</b>	<b>1.14</b>	<b>0.77</b>	<b>0.4</b>

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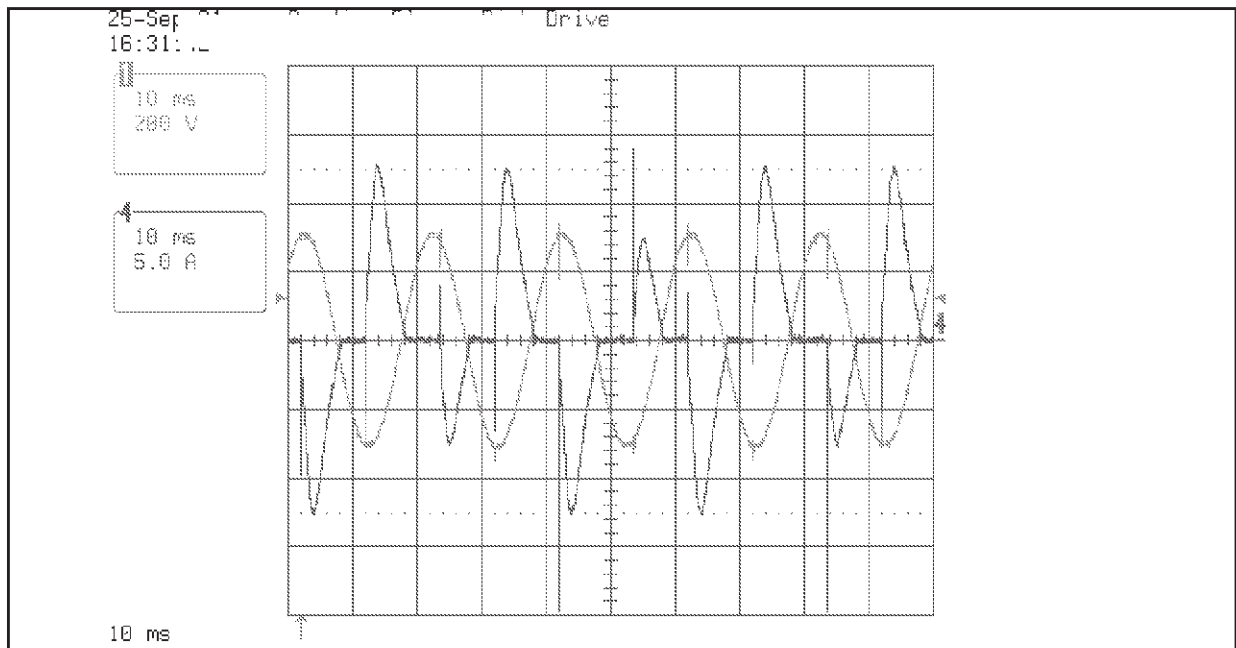
This method has already been patented by KURZ. The patent number is DE19705907A1 (German Patent) and EP0859452A1 (European Patent). With the KURZ patented method, the motor current is modulated by two long half waves and two short half waves. In short, this method can be called the “two long plus two short” method.

### 2.3 ASYMMETRICAL PHASE CONTROL METHOD (ALTERNATIVE SOLUTION)

This new asymmetrical phase control method introduced here, modulates the motor current as 2 long half waves and 1 short half wave. This reduces 3rd harmonic current at reduced speed and with careful modulation, keeps it within the limits of the IEC61000-3-2 standard. Compared with the previous method, it generates lower flicker and torque ripple.

The current waveform is shown in Table 4. Channel 1 is the AC mains voltage waveform, channel 4 is the motor current waveform.

**Figure 4. . Motor current waveform in asymmetrical phase control method**



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Table 4 gives the harmonic current test results with the same vacuum cleaner under the same test conditions.

**Table 4. 1500W vacuum cleaner harmonic current measurements at fixed load with asymmetrical phase angle control method (Alternative Solution)**

Power P (Watt)	Delay time		Harmonic order & Harmonic Currents (A)			
	t <sub>1</sub> (ms)	t <sub>2</sub> (ms)	3	5	7	9
535W	6.90	5.48	2.22	0.634	0.281	0.041
580W	6.90	5.13	2.170	0.532	0.280	0.072
700W	6.85	4.74	2.115	0.451	0.251	0.157
780W	6.85	4.36	1.974	0.437	0.241	0.185
940W	6.13	3.75	1.799	0.371	0.182	0.174
1000W	6.04	3.37	1.595	0.364	0.219	0.105
1050W	6.08	2.91	1.362	0.389	0.234	0.049
1100W	5.19	2.90	1.658	0.204	0.245	0.084
1150W	5.20	2.47	1.349	0.121	0.293	0.052
Harmonic current limit (A)			<b>2.30</b>	<b>1.14</b>	<b>0.77</b>	<b>0.4</b>

### 3 CONCLUSIONS

#### 3.1 BUILT-IN ST62 FEATURES YIELD THE LOWEST TOTAL SYSTEM COST

The use of MCU-driven motor control system in home appliances is becoming more and more popular with the availability of flexible, reliable and low cost microcontrollers.

The STMicroelectronics ST62 microcontroller family is ideal for home appliances because it offers many powerful on-chip peripherals and resources, a wide range of operating voltages, built-in ruggedness and excellent noise immunity to enable designers to achieve the lowest possible system cost.

#### 3.2 A SOFTWARE APPROACH PROVIDES A VERY COST EFFECTIVE SOLUTION

The design presented proposes a cost effective solution for reducing the 3rd harmonic currents for vacuum cleaner applications. The results given by the experiments prove the efficiency of this method.

The source code of the software (filename vacuum.st6) is supplied with the UMC01EVAL board. Please contact your local STMicroelectronics sales office for information about ordering this kit.

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