Improving Reliability of Servo Motors and VFD with Servo Motor Filters

OnFILTER' family of SF series servo motor filters (Figure 1) prolongs life of servo motors and variable frequency drives (VFD) by reducing damage to their bearings. The filters also reduce overall EMI in equipment as well as electrical overstress (EOS) to sensitive components.

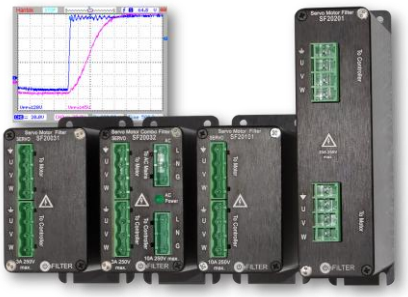

Figure 1. OnFILTER' family of Servo Filters

Almost every equipment with moving parts utilizes either servo or variable frequency motors. They are a workhorse of today's automation. Unfortunately, they are also usually the strongest source of EMI in a tool.

Background

Servo motors and VFD are typically comprised of two parts - the motor itself and a controller (also called "amplifier," "servo pack" or "inverter") which drives the motor and is connected to it by cable. Controller receives power from AC mains: single phase for low-to-medium power drives and three phases for high-power drives. A typical manufacturing and robotic tool may have as little as one and as many as 20 of such drives. Servo motors have a feedback circuit that allows it to maintain specific position with high accuracy. This also means that servo motors work even when they are not moving. Variable frequency drives (VFD) work in a different way - their speed is controlled by the frequency of the drive signal. What is common between these two different types of drives is that both are driven by pulsed signal.

Figure 2. Servo controller and motor

Bearing Damage in Servo Motors and VFD

Servo motors and VFD are driven by three-phase pulses with the repetition frequency ranging typically between 6kHz and 20kHz. Pulses have sharp edges only a few nanoseconds long. Figure 3 shows the leading edges of three phases of a servo motor drive signal. While the drive pulse frequency by itself seldom causes problems, the sharp edges of the pulses do. Sharp edges have very wide spectrum extending into the Megahertz range. Capacitive coupling prevalent in motors and cables presents very low impedance for such signals. The result is significant high frequency voltage on the rotor and subsequent ground currents through bearings (Figures 4 and 5). The particular current shown is ~20mA - a question may be asked how can such seemingly low current do any damage. If this current was one-time occurrence it wouldn't case concern. But these current spikes occur up to 40000 times per second every second - servo motor works even

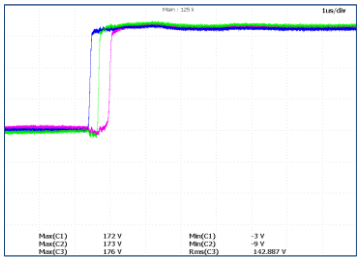

Figure 3. Pulse edges of servo drive signal
(three phases shown)

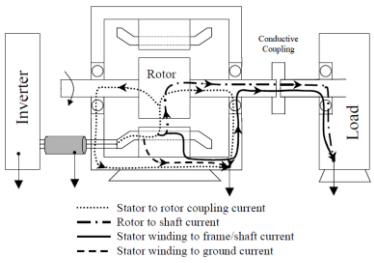

Figure 4. Parasitic current path in a motor
Source: IEEE Proceeds, Shieferl,et. al.

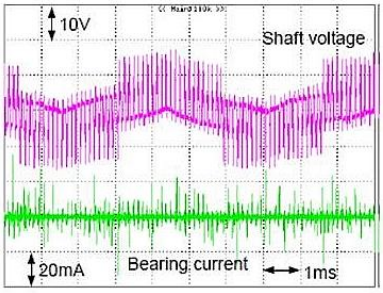

Figure 5. Shaft voltage and bearing current
Source: Control Engineering Magazine

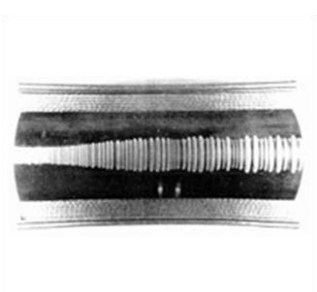

Figure 6. Motor bearing damage
Source: Machine Design Magazine

when it is not moving. Such continuous hammering and chiseling can and does cause deterioration of bearings just like a small stream carves in time a deep path in stone. Figure 6 on the previous page shows typical damage to a bearing from such current - this type of damage is often called "racetrack." This problem worsens with time causing eventual sparking, performance deterioration and eventually catastrophic failure.

High-Frequency Noise in Equipment

Sharp pulse edges and resulting ground current not only cause problems for the bearings, they also pollute the entire machine, especially its ground, by strong sharp transients with the repetition rate of that of drive pulses. The resulting signals can be high enough to cause interference with the equipment's electronics and electrical overstress (EOS) to sensitive components. Figure 7 shows AC power line ground current spikes occurring every time there is a drive pulse edge. With the sensitivity of current probe of 5mA/mV (Tektronix CT1 probe) this voltage translates to ~1.8A of high-frequency noise current in power line ground.

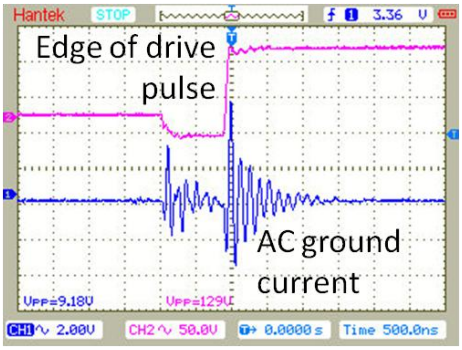

Figure 7. AC ground current caused by operation of a servo motor

Interference with Operation of Equipment

High-frequency electrical noise (often called EMI - electromagnetic interference) raises overall noise level in equipment. This causes random undesirable equipment behavior, data errors and outright equipment lockups as illustrated in Figure 8. It is not uncommon to find noise levels in equipment of the same magnitude or higher than the legitimate data signals. This affects normal operation of computerized equipment and alters sensor readings. Once noise gets into the equipment' circuits it is very difficult to remove it - a much better option is not to let motor operation to pollute the equipment with EMI to begin with.

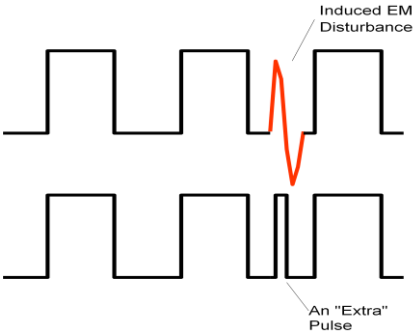

Figure 8. Illustration of how EMI corrupts data

Electrical Overstress (EOS)

Equipment handling sensitive components, such as pick-and-place tools in electronic assembly, IC handlers and wire bonders in semiconductor manufacturing and other similar tools handle components that can be damaged by the levels as low as a fraction of a volt per IPC-A-610 standard for electronic assembly.

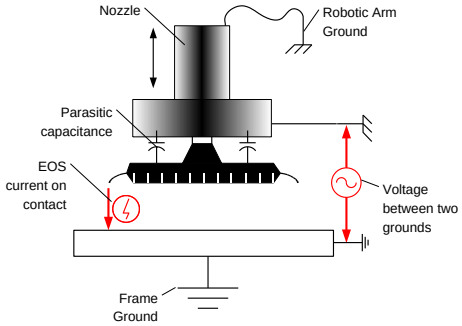

Figure 9. Unwanted current through IC in a handler

Figure 9 illustrates how high level of noise in the tool causes difference in voltage between various ground points which results in unwanted current through the IC. This current is synchronized with drive pulses of the motor as shown in Figure 10 (current pulses that appear out of sync with the pulses are actually well-synchronized with operation of other drives in the IC handler).

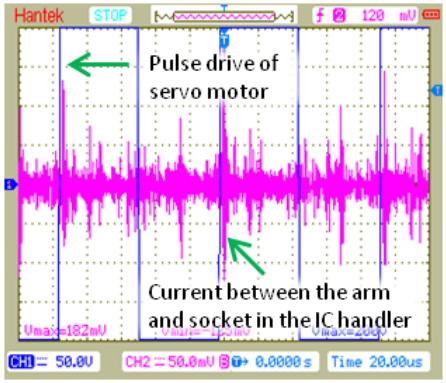

Figure 10. Actual current through device in a handler

According to Intel (Intel® Manufacturing Enabling Guide, 2010, Section 3.2), "EOS is the number one cause of damage to IC components." Reducing high frequency noise caused by servo motors and VFD operation greatly reduces electrical overstress to sensitive devices and resulting damage, including latent damage which is not obvious until the device fails when in actual use.

Mitigation of High-Frequency Noise in Servo Motors and VFD

The problem of bearings damaged by high-frequency ground current is not new - one simply has to search for bearing damage of motors on the web to see how much attention is drawn to this subject over the years and how many technical papers are dedicated to understanding and to solving this problem (the latest count showed around 400000 entries on this subject for VFD motors alone). A number of offerings are available to deal with this problem, none of which truly resolves it completely. Mechanical solutions such as ceramic bearings and bearing protection brush rings do not reduce overall EMI levels in equipment while requiring different physical sizes to fit a particular motor model, and being subject to wear, performance deterioration, inspection and maintenance with its associated on-going cost. Special reactors which are simply inductors connected in line with each phase of the drive signal offer marginal improvements plus they are often bulky and require special installation, both electrical and mechanical.

OnFILTER Solution

Motor Filters

OnFILTER' SF series servo motor/VFD filters provide an effective and a comprehensive solution to the servo motors' and VFD' EMI problems. Using patent-pending technology, SF series filters substantially reduce ground current in motor's bearings and overall high-frequency noise in the tool while offering easy installation, small footprint, and requiring no maintenance.

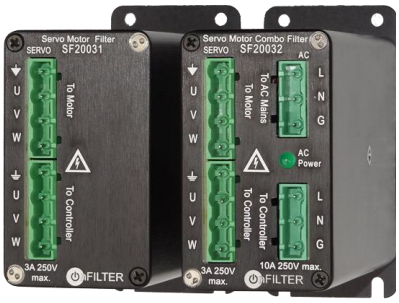

Figure 11. OnFILTER' Servo/VFD Filters

Reduction of Currents through Bearings

OnFILTER SF series filters work with the majority of servo motors and variable frequency drives (VFD). One of the functions the filters perform is modification of the sharp edges of the drive pulses. The reason this reduces ground current is due to frequency dependency of impedance of parasitic capacitive coupling between the rotor and the stator of the motor as illustrated in Figure 4. Sharp edges of the pulses have broad frequency spectrum which thanks to low impedance of this capacitive coupling causes high ground current. "Slowing down" the edges lowers the spectrum of the signal which leads to increased impedance of that capacitive coupling and to reduction of unwanted current.

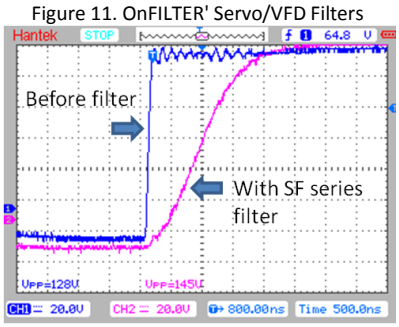

Figure 12. Typical edge modification of servo drive signal by a SF series filter

Figure 12 shows how the edge of the drive pulse looks like before and after a typical OnFILTER' SF series filter. In this example the edge of drive pulse was stretched ~25 times proportionally lowering the frequency spectrum of the drive signal, increasing parasitic capacitive impedance in the motor and reducing ground current. This provides good reduction of EMI while fully preserving operability of the motor.

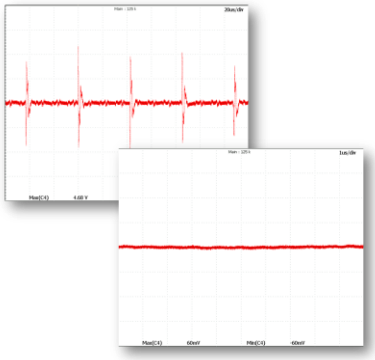

Figure 13. Ground current without and with SF filter

This by itself would offer a significantly better performance - better than other approaches could offer - but SF series filters go further by adding an additional patent-pending filtering section to reduce ground current even more. Figure 13 illustrates reduction of ground current with SF series filter. Typical ground current reduction by a filter of SF series is ~100 times.

Such reduction of ground current offers substantial benefits in reliability and longevity of motor's bearings without any mechanical attachments and requiring no maintenance.

AC Line Filtering: Combo Filters

Servo motors and VFD present another problem - pollution of AC power by the noise from pulse generation that is fed back into a power line. Not only AC lines become noisy, but ground as well, further increasing possibility of ground currents through bearings. Servo and VFD manufacturers recommend to use power line AC filters to reduce this noise. Unique patent-pending combo filter SF20032 combines in one small package two filters - a motor filter and an AC filter which allows complete noise suppression in one small package (Fig. 11). This offers small overall footprint, saves cost, and simplifies wiring.

Reduction of Overall EMI Levels in Equipment

Another significant benefit of utilizing OnFILTER' SF series filters is overall reduction of noise in the equipment. Reduction of spectrum of electrical noise caused by drive pulses not only reduces currents in bearings, it also reduces high-frequency currents and voltages everywhere in equipment. With the SF series filters long cables between the controllers and the motors no longer induce noise in other cables and in ground. Interference with equipment is essentially eliminated. Electrical overstress to sensitive components is also greatly reduced as shown in Figure 14 where implementation of just one servo filter in an IC handler reduced unwanted current through the device down to insignificance.

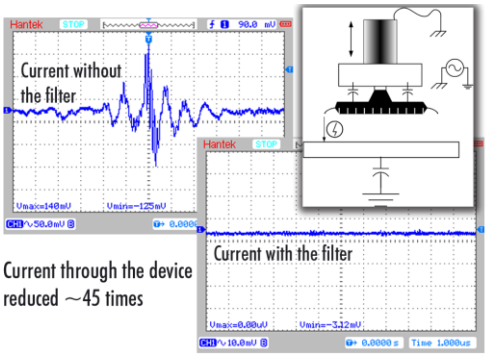

Figure 14. Reduction of EOS current using SF-series filter

Selection of Servo Filter

OnFILTER' SF filter family includes servo motor/VFD filters of different max. current ratings - 3A, 10A and 20A and voltage up to 250V. To select the proper model please look at the ratings of the controller and of the motor. If in doubt, take a photo of the labels and email them to us at info@onfilter.com While the controller may be capable of supplying higher current, the motor consumes no more than what it was rated for - its rating will be the defining one. It is prudent to allow for at least ~15% headroom in current rating because of occasional motor overload. Servo motors may require smaller headroom than VFD since their duty cycle is significantly smaller.

Installation

It is recommended to install servo/VFD filter next to a servo/VFD controller, not to the motor, otherwise the drive cable carrying high frequency currents will continue to pollute the equipment with noise. SF series filters remove high-frequency content from drive pulses thus reducing coupling of noise from the cables to other wires and to ground.

SF series filters can be installed on a back plane with screws or on a DIN rail (with special kit). Mounting dimensions are shown in the datasheet.

Figure 12. Place filter close to the controller, not to the motor

Conclusion

OnFILTER' servo/VFD SF series filters greatly reduce bearing currents in motors as well as overall electrical noise level in equipment. They are easy to install and require no maintenance. Please visit www.onfilter.com for more detailed information. Contact us at info@onfilter.com with any questions.