Monthly Informative Application Guidelines, with respect to *Motors & Drives* to keep you better INFORMED.

APPLICATION GUIDELINE #40

(DC Bus Capacitor Integrity)

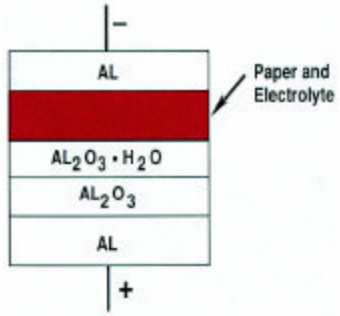
Brought to you by your Motor & Drive Specialists……

TOSHIBA – TOSHIBA INTERNATIONAL CORPORATION – TIC – TOSHIBA – TOSHIBA INTERNATIONAL CORPORATION – TIC

Aluminum electrolytic capacitors are among the most common capacitors used today. These capacitors have become popular because they offer a large capacitance in a small package. This makes them ideal to use as filters in power supplies and couplers in low frequency circuits. However, aluminum electrolytic capacitors have a limited life span, due to the nature of their construction.

An aluminum electrolytic capacitor consists of two aluminum foil plates separated by a porous strip of paper soaked with a conductive solution called the "electrolyte". This moist paper, however, is not the capacitor's dielectric. It serves as a spacer to prevent the two plates from mechanically shorting. The electrolyte conducts the charge from the negative plate, through the paper, and into direct contact with the dielectric. The dielectric is a thin layer of aluminum oxide that is electrochemically formed on the positive foil plate. The key to an electrolytic is the fact that the capacitance increases linearly as the thickness of the dielectric decreases. Therefore, because of their extremely thin dielectric, electrolytics can have a large capacitance within a small package. Figure 1 shows an electrolytic's construction. After the capacitor is formed, it is rolled up and placed in a cylindrical case. The case is then stamped with a manufacturing label. Most capacitors have the manufacturing date printed on the case along with the label. This date is printed in the form of a four digit number. The first two digits represent the year that the capacitor was produced, and the last two numbers signify the week of the year it was produced. For example, a capacitor with a date code of 8318 stamped on its case was manufactured in 1983 during the 18th week.

Figure 1:



Since the electrolyte inside the aluminum electrolytic capacitor is water-based, it will eventually dry out, causing capacitor malfunction. The capacitor is good, or at least re-formable, as long as the electrolyte remains liquid. When the electrolyte dries out, however, or the aluminum oxide dielectric layer deteriorates, the leakage goes up and the capacitor loses capacitance. This can happen to aluminum electrolytics just sitting on the shelf, in fact it's more likely to happen to an electrolytic that sits idle. When an aluminum electrolytic starts this deterioration process, the first symptoms to look for are larger amounts of dielectric absorption and leakage, although Equivalent Series Resistance (ESR) may be present, too. These symptoms do not occur, however, at a linear rate over time. Once the capacitor starts to show these symptoms, the capacitor only has a short life left unless it is reformed quickly.

A large industrial end user recently found out with an unsuspected VFD failure that capacitors have a limited life span. In order to maximize reliability in their other 60 or so VFD systems ranging from 15HP to 300HP, they decided to proceed with capacitor testing on a select few of their VFD's which have been installed for more than 6 years. They decided to purchase a Capacitor tester to get some actual information of 'old' versus 'new' capacitors. The spreadsheet below summarizes some test results they took on a capacitor from a 125HP 460V G3 drive versus a new set of capacitors. They were quite surprised at the difference in the old versus the new test results, it further re-enforced their desire to replace all the capacitors. The readings were taken at a room temperature of 20 deg C, with a nominal voltage of 400VDC: (DC Bus ripple before and after was not tested)

Capacitor Spec: Mfg. Hitachi HCGF5A 3900MFD 400Vdc 450Vdc Surge 5ZB0

Original (OLD) Capacitors

Test Out-of Circuit	1	2	3	4	5	6	7	8	9	10	11	12
Capacitor Value MFD	3705	4059	3890	3666	3839	3850	3963	3843	4035	3844	3905	3841
ESR	0.12	0.03	0.04	0.06	0.07	0.14	0.07	0.03	0.06	0.09	0.06	0.06
Dielectric Absortion	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Capacitor Leakage I	499	682	956	680	990	960	971	985	972	870	915	971
Capacitor Leakage R	728K	571K	408K	574K	394K	406K	402K	396K	401K	448K	426K	402K

New Capacitors

Test Out-of Circuit	1	2	3	4	5	6	7	8	9	10	11	12
Capacitor Value MFD	3688	3765	3775	3743	3714	3730	3681	3766	3750	3779	3774	3791
ESR	0.06	0.03	0.31	0.19	0.09	0.1	0.06	0.07	0.07	0.04	0.05	0.06
Dielectric Absortion	4%	4%	4%	5%	4%	4%	4%	4%	4%	4%	4%	4%
Capacitor Leakage I	3.44	2.94	7.22	3	2.98	2.76	3.52	2.98	3.29	3.44	3.9	3.37
Capacitor Leakage R	113K	133K	54K	130K	131K	141K	111K	131K	118K	113K	100K	116K

ESR: Every capacitor has some ESR. ESR is the electrical resistances in series with the capacitor plates. This includes the resistance of the metal leads and plates and the connections between them. An aluminum electrolytic capacitor also has resistance in the wet electrolyte solution,and in the layer of aluminum oxide which contains high levels of water (called the "hydrated oxide").

There are two common causes of high ESR: 1) Bad electrical connections, and 2) Drying of the electrolyte solution. Electrical connection problems can happen in old or new capacitors, while drying is usually only a problem in old ones.

Connection problems happen because the leads coming into the capacitor cannot be made of aluminum, since aluminum cannot be soldered. The electrical connection between the aluminum plates and the copper leads calls for a weld or a mechanical crimp. Problems with either method produces high series resistance.

Drying problems occur because of the importance of water in the electrolyte solution. The solution soaks the paper spacer between the two aluminum plates. The water carries the electrical charge from the negative aluminum plate to the surface of the insulating oxide on the positive plate. The oxide forms the capacitor's dielectric and the negative charge on the surface of the oxide forms the negative capacitor plate. As the water evaporates, the electrical resistance increases.

Dielectric Absorption: Dielectric absorption (D/A) is the inability of a capacitor to release all its stored energy, even if a dead short is applied across its leads. Some circuits are directly affected by the effects of D/A. The biggest effects are in circuits that use a capacitor to hold a precise DC voltage level. However, a power supply capacitor may tolerate more than 15% before the circuit is affected. Then, filtering may reduce because the capacitor cannot dump all its charge back into the load fast enough to smooth the ripple.

Capacitor Leakage I: Capacitors are supposed to block DC while passing an AC signal. When a capacitor develops leakage, it allows DC current to pass through in large amounts. This causes bias voltages to become incorrect and power supplies to load down. While a leaky capacitor acts like a resistor, you cannot find a leaky cap with an ohmmeter or even a voltmeter. *Leakage in a capacitor is not linear; it depends on the voltage applied to it.* The only way to determine if a capacitor has acceptable leakage or not is to measure the current through it with its rated voltage applied. ESR is not responsible for leakage. Leakage is a PARALLEL resistance path which connects the two plates. ESR is just the opposite, since it's all the resistance EXCEPT for the leakage path . If ESR is large enough, it can reduce the leakage current.

TOSHIBA – TOSHIBA INTERNATIONAL CORPORATION – TIC - TOSHIBA – TOSHIBA INTERNATIONAL CORPORATION – TIC

TOSHIBA – TOSHIBA INTERNATIONAL CORPORATION – TIC – TOSHIBA – TOSHIBA INTERNATIONAL CORPORATION – TIC

Questions asked to Toshiba included:

1. *Does Toshiba see a lot of capacitor failures in the marketplace for their population of drives out there and at what age intervals would these occur.* **Answer:** No, those that do fail are much older than the 5 year service lifetime published in the G3 Operation Manual. Furthermore, the drive that failed at the above end user location was not a Toshiba VFD, but none the less, the end user determined that the investment to replace the capacitors to improve reliability was worth the replacement costs involved.

2. *The probability of failures occurring on the 460V G3 drive capacitors.* **Answer:** There are so many variables that may affect the life time of the capacitor. It's hard to answer this question with out physically testing the capacitors. There are MANY drives that are 15 years old that are still running with the same set of capacitors.

3. *What is the life usage time on the capacitors or the MTBF calculations.* **Answer:** Page 10-2 of the Toshiba G3 Operation Manual states the service lifetime of the capacitors at 5 years. When Toshiba designs VFD's, there are engineering goals for a 40,000 hour (5 years) MTBF on electronic components. The above statement needs clarification. It may be confused as a statement of drive life. Indirectly, this is true. During development, temperature rises of all electronic components are calculated and confirmed by testing. Manufacturers of these components give specifications for reliability based on operating at an ambient temperature. Our goal in drive development is to ensure there are no failures of these components if subjected to the highest ambient in our specifications for 40,000 hours. Except in rare cases, extreme ambient conditions are temporary or part time. For instance, an outdoor drive with a 50°C maximum ambient specification can tolerate this ambient for five years without any expected breakdowns. Between night and day, the ambient fluctuates and for an accumulated five years at this elevated ambient, it would take more than 15 years for the expected failure not counting normal maintenance such as cooling fan inspection and replacement. MTBF is important, but other factors become more significant for breakdowns when drives are running for long intervals. Corrosion and power quality are two major areas that can impact drive life. These generally have no meaning when related to MTBF. Toshiba uses 1600V rectifiers for its diode front end. Some manufacturers use 1200V. This lower voltage device is perfectly fine if the power line has no fluctuations or surges. In the case of MTBF calculations, both devices would result in the same number. Of course the 1600V device is better. The same is true of output power devices. The latest products by Toshiba for 480V ASD's have 1200 Vce ratings on it's IGBT's. Again some manufacturers will utilize 1000V. Toshiba 600V drives utilize 1700V Vce while some manufacturers utilize 1200 or 1400V devices. This is acceptable as long as there are ideal conditions. You may see some claims of 100,000 hours MTBF. It is important to understand this statement and realize this can be a marketing game rather than a true indication of drive reliability. Good engineering practices use MTBF calculations only as a starting point for drive development.

4. *Would a change out of the capacitors on all drives provide them with increased reliability of the drives.* **Answer:** Yes, replacing all capacitors will increase the reliability of the drive

TOSHIBA – TOSHIBA INTERNATIONAL CORPORATION – TIC - TOSHIBA – TOSHIBA INTERNATIONAL CORPORATION – TIC

TOSHIBA – TOSHIBA INTERNATIONAL CORPORATION – TIC – TOSHIBA – TOSHIBA INTERNATIONAL CORPORATION – TIC