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Capacitors for Internal Combustion Engine Starting with Green Technology DLCAP^{TM}

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Abstract

In the past internal combustion engines in commercial trucks, buses, and automobiles were often allowed to idle during stops, whether short or extended. This practice mitigated engine non-starts but increased fuel usage along with air emissions and accelerated engine wear. Engine starting can be performed more reliability by electrochemical capacitors rather than by batteries, especially at low temperatures. Capacitor modules are now available to start engines of all sizes. This paper will discuss the starting requirements of large diesel engines and present low-temperature engine cranking results using Nippon Chemi-Con DLCAP non-toxic-electrolyte electrochemical capacitor.

Keywords: Electrochemical capacitor, Low temperature, Engine starting, Capacitor modules, Non-toxic-electrolyte, Ultracapacitor, Supercapacitor, Double layer capacitor

1 Introduction

Over the past few years electrochemical capacitors (ECs) or, as they are so often referred to today, super- or ultra-capacitors, have become increasingly interesting for internal combustion engine starting. Reasons include: 1) they offer exceptional cranking power compared to batteries, especially at very low temperatures, 2) ECs offer essentially unlimited cycle life when compared to batteries, 3) once installed, ECs are completely maintenance free, 4) ECs provide exceptional power performance and often allow a reduction in the number of batteries needed in a vehicle, thereby reducing the starting system weight, and 5) adding an EC to the starting system can often reduce life-cycle costs of vehicle components. Now capacitors are generating considerable interest in engine cranking for a broad range of vehicles, from heavy trucks to buses to automobiles.
Capacitors have, in fact, been used for almost twenty years to start internal combustion engines, particularly large diesel engines at low temperatures.

This application originated in Russia in the early ‘90s, owing largely to the extremely high power performance of electrochemical capacitors, a performance that does not degrade significantly when they are cooled to temperatures as low as, for example, -40°C. Such is not true of batteries, whose performance degrades significantly as they become colder, to the point where they may have very little power to crank an engine that has itself become correspondingly stiffer in the increasing cold.

2 Engine Starting

The starting process for a modern internal combustion, compression-ignition engine entails a run-up of engine speed to some minimum value where the engine controller will allow a start and continue to function. The power profile of the cranking motor of a heavy diesel truck has very high levels, especially at low temperatures. When the key is turned the energized power immediately goes to the maximum level, often with currents of 1500-2500 A or higher being drawn from the battery system, depending on engine size and type, temperature, and lubrication package. The event lasts on the order of 50 ms, after which current might drop down to 400-600 A, lasting for as long as 1.5-2 seconds, until the rotation rate peaks and the engine can start. An engine-starting application has, therefore, a very high current spike at the moment the starter is engaged and attempts to rotate the static engine. Much of

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this has to do, of course, with the static friction on an engine. It has to do as well, however, with the fact that the starter motor appears like a short circuit when power is first applied, there being very little internal resistance when it is not moving.
The very high current involved in this process is something not much favoured by batteries, which often appear to suffer excessive stress or incur damage under high current levels. Batteries simply operate best at constant power levels. Reducing this spike from the battery in a starting circuit can increase the life of the battery, because the stress on it will be less as the starter is first engaged.
The time for reaching the minimum number of RPMs for engine starting is generally on the order of one second. All of today's engines, from the small ones used in automobiles to the largest ones in use in over-the-road trucks, are for the most part started within one to two seconds. The power needed for such starts is very high, but especially for large engines at low temperatures. Capacitors are well suited for precisely this application. Provided the capacitor has sufficient power, it will accelerate the engine to the minimum RPMs for a start, after which the engine speed will continue to increase. Batteries are usually underpowered and unable to achieve this performance. The engine will accelerate, but only to a level of RPMs somewhat below the level needed to sustain continuing engine operation. It will then crank at that sub-maintenance RPM value, often for many seconds, before a start takes place. The primary feature of such a delayed start is the heating of the engine parts to a point where the number of RPMs needed for the start may be reduced owing to the warmer engine.
Delayed starts are often characteristic of battery systems, because they do not have sufficient power to accelerate the engine to a point where it can start immediately. This is one very major difference between batteries and capacitors with regard to engine cranking at particularly low temperatures. A capacitor can be designed to provide a direct and immediate start. Batteries, on the other hand, generally are unable to do this and must be sized to provide many numbers of seconds of cranking to get the engine started.

3 The separator heats up rapidly

The electrolyte of the tested capacitor is propylene carbonate (PC). The PC-based capacitor usually have higher internal resistance at lower temperature. Figure 1 shows the example of the temperature characteristic of the internal resistance and Figure2 shows the basic capacitor structure with corresponding resistance elements.

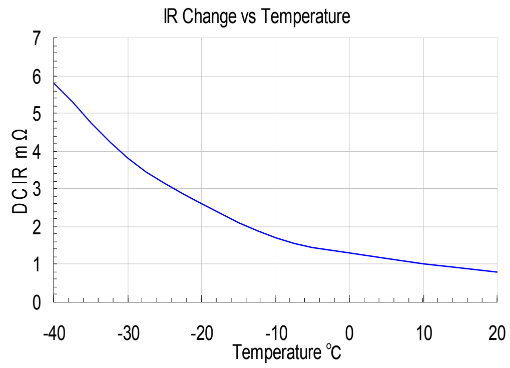

Figure1: Temperature characteristic

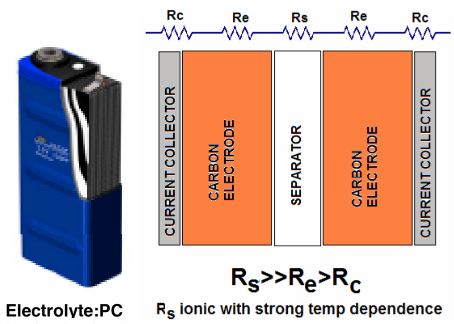

Figure 2: The basic elements forming the capacitor.

The cranking peak current is increased 1000 A at room temperature to 3,500 A at -30 degree C –mostly in the separator and the internal resistance go up to approximately four times from the room temperature value. The heat power (I^2R) in the separator will be 4 x 3.5^2=50 times greater than at room temperature. The internal temperature will increase very quickly and the resistance will drop because of this. Figure3 shows the internal temperature rise at -30 degree C.

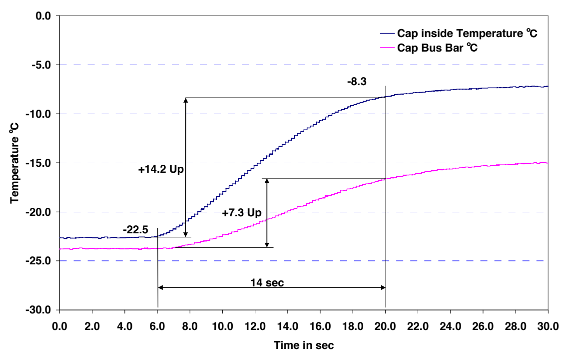

Figure 3: Temperature rise during engine cranking at -30 degree C.

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4 Cold Engine Cranking Tests

- Engine cranking tests were performed on a 6 cylinder, 15 liter displacement diesel engine that had been cold-soaked at various low temperatures, from 0 to -30 .
- Fuel was not supplied, engine RPM, capacitor voltage, starter motor current, capacitor temperature, were recorded every 0.002 seconds.
- Capacitor module was 3 parallel strings of 6 series-connected, 2400 F, 2.5 V DLCAP^{TM} capacitors (non-toxic electrolyte).
- Engine cranked was without fuel, reaching a rotation speed of 100 RPM defined as an engine start.
- Capacitor recharge to various voltages was performed using a 30 A charger.

Figure 4 shows mounting location of capacitor module in Caterpillar diesel engine C-15 for this test.

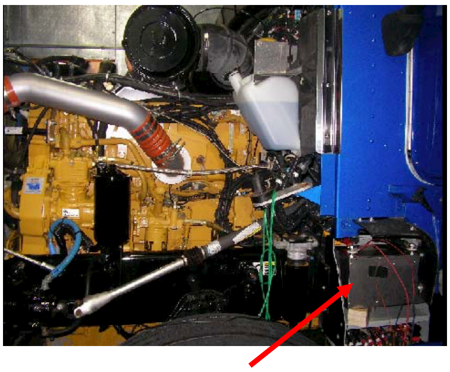

Figure 4: DLCAP module location in C-15 CAT diesel engine

5 Engine Cranking Result

The result were unexpectedly better than anticipated, due in part to electrolyte self-heating at the beginning of the high-power discharge. Figure6 shows 1st cranking at 0℃ greatly exceeded 100 RPMs, Figure7 shows 2nd cranking at -20℃, again with engine RPM greatly exceeding 100 RPMs, Figure8 shows 3rd cranking event at -30℃, again with greater than 100 RPMs achieved, showing how the internal temperature of a capacitor cell instantly increased at -30℃, which demonstrates that PC-based non-toxic electrolyte DLCAP^{TM} performed adequately for cranking large engines at low temperatures.
Figure5 shows the block diagram of this system configuration.

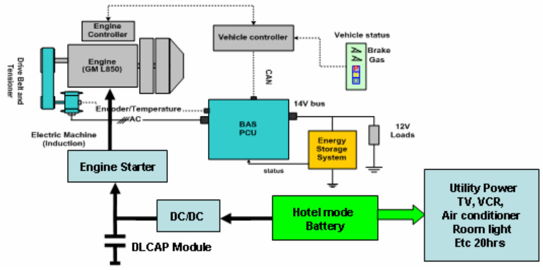

Figure 5: Block diagram of engine with DLCAP capacitor. Portion of diagram provided by AV.Inc

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Figure 6: 1st cranking exceed 100RPM at 0℃ V=15V

Figure 7: 2nd cranking: exceed 100 RPM at -20℃ and with the capacitor module charged at 18V

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Figure 8: 3rd cranking, which exceeded 100 RPM at -30 ℃ with the initial capacitor module charged to21V.

6 Developed DLCAP™ Engine Start Module

Figure 9 shows the developed engine cranking capacitor module. The larger size is for heavy duty vehicle engine and smaller size is for P&D Trucks. Figure 10 shows C-15 CAT diesel engine starter module with mounting bracket for driving test.

Heavy duty vehicle engine
6 cells in series, 3 parallel strings
Energy: 135 kJ
Max power: 90 kW
Size: 173x353x180 mm
Weight: 15 kg
Operating Temperature: -40℃ to + 60℃

P&D Trucks
6 cells in series, 2 parallel strings
Energy: 80 kJ
Max power: 39 kW
Size: 114x353x180 mm
C15 CAT Engine Starter Module
Weight: 12 kg
with mounting bracket for driving test.
Operating Temperature: -40℃ to + 60℃

Figure 9: The engine cranking capacitor modules developed in this work.

Figure 10: C15 CAT diesel engine cranking capacitor module with mounting bracket.

7 Conclusion

- The green technology DLCAP™ performed well in cranking a large, cold diesel engine to starting RPM levels
- Cranking current rapidly increases electrolyte temperature, giving very good cranking power performance at low tempeatures
- DLCAP™ module appears to be sized appropriately if second-attempt starts allowed at very cold temperatures
- Boosting the capacitor voltage clearly improves its cranking performance
- Non-toxic electrolyte capacitors have fully demonstrated their suitability for cranking large compression ignition diesel engines at low temperature.

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Author

Toshihiko Furukawa has electrical engineering degree Tokai University Japan. Technical background is over 20 years experience in power electronics and high frequency amplifier development/design . Currently, focusing on DLCAP technical support and business development in global market. United Chemi-Con/Nippon Chemi-Con Group