Operational Testing of Valve Regulated Lead Acid Batteries in Commercial Aircraft.

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ABSTRACT

Valve regulated lead acid (VRLA) batteries provide electrical performance that is virtually identical to sintered plate nickel-cadmium battery systems. In addition, the VRLA batteries offer the user a no maintenance battery and other enhanced features that make this a very desirable battery for aircraft applications. In field trials, where VRLA batteries were substituted for nickel-cadmium batteries, the VRLA provided the user with a high reliability turbine engine starting battery under a wide variety of climatic conditions.

Introduction

Valve regulated lead acid batteries are seeing increased use in both military and commercial aircraft as a substitute for nickel-cadmium systems. There are several significant benefits which VRLA offer to the aircraft designer and user which are not present in competing systems.

The electrical performance of lead acid batteries has been greatly increased with the introduction of VRLA designs. In particular, the high rate and cold temperature performance has seen a considerable improvement over flooded systems. VRLA batteries are now available which are virtually indistinguishable in turbine starting high rate performance from their nickel-cadmium counterparts. This is true not only at ambient temperature but at temperatures down to -20°F. At lower discharge rates, the performance of the VRLA has also shown superior results. Recent testing at the C rate with a battery cold soaked at -40°F yielded 50% of the nominal rated capacity of the battery.

The VRLA battery requires a very simple charge regime. The ideal charge is a high rate, constant voltage or pulsed charge. The high rate gives a fast recharge and recent research has indicated that this charge regime may greatly extend battery life. Where sufficient charging current is available, it is possible to return 50% of the charge to a fully discharged VRLA battery in under 3 minutes and 80% in under 10 minutes. Recent testing by the Advanced Lead-Acid Battery Consortium (ALABC) has shown this type of charging to increase cycle life by a factor of 4 *(1)*. For aircraft with AC systems, a simple transformer / rectifier may be used to charge the battery while it is often possible to retrofit a VRLA into an application that has a nickel-cadmium battery charger with little or no change in the charger.

The VRLA battery is maintenance free. No periodic maintenance is required. Users have generally adopted one of two courses of action with regard to VRLA. The first is to put the battery on a fixed replacement schedule. In this case, there are no capacity checks or other maintenance. At the end of the replacement interval, the battery is removed and discarded. Alternatively, the user establishes an interval, based on the aircraft and duty cycle, at which the battery is periodically capacity tested. The battery is then discarded when its performance degrades beyond a preset limit.

There is a greatly reduced explosion hazard than with either flooded lead-acid or flooded nickel-cadmium systems. Under normal circumstances, no combustible hydrogen is released.

There is reduced corrosion of surrounding structures and equipment due to acid mist or spray. The battery contains no free electrolyte and will not leak or spill in any attitude.

The reliability of the battery system is greatly increased. VRLA Batteries with severe mechanical damage will continue to function in an emergency.

The battery is convenient for the user in that it may be shipped by air as a non-hazardous item in a fully charged, ready to install condition. This also means that the battery may be fully tested before being shipped from the factory. A fresh battery may be removed from the shipping carton and immediately placed into service.

There is a well established infrastructure for the recycling of all lead-acid batteries.

Finally, the battery has a low “Life Cycle Cost”. The low initial cost of the VRLA combined with the maintenance savings yield a very low cost of ownership when compared with competitive nickel-cadmium systems.

Comparison Testing

In early 1993, Cessna Aircraft Company began a series of comparison tests of various alternate battery types for the C208 series aircraft. The 208 was originally certified with either a nickel-cadmium or a flooded lead-acid battery.

Comparison testing was conducted on the originally approved flooded nickel-cadmium and lead-acid batteries as well as comparable VRLA batteries from two manufacturers. Initial bench testing was conducted to verify that the batteries would accept a charge in order to meet the essential capacity requirements for emergency operations, and confirm the battery’s stability on the aircraft buss at high temperatures. Following the bench tests, all batteries were installed in an instrumented test aircraft for an engine starting test with battery temperatures of -40°F, -20°F, and 0°F.

At 0°F all of the tested batteries were successful in starting the aircraft. In examining the data, it can be seen that the flooded lead-acid is beginning to lag as indicated by the longer start time required and the higher turbine temperature. The NiCd and two VRLA’s show comparable performance.

Table I. Engine starting tests at 0°F.

0°F Starting tests - Results are the average of three successive trials [2]							
Battery Type	Initial voltage under load (V)	End voltage under load (V)	Initial current (A)	Ending current (A)	Start time (sec)	Internal Turbine Temp. (°F)	Charge amps (A)
NiCd	18.2	22.2	650	162	19	703	125
FLA	16.4	20.7	575	163	21	737	112
VRLA-1	16.8	21.0	603	160	19	710	110
VRLA-2	16.5	20.8	568	157	19	713	108

[1] All batteries successfully completed 4 starts at 0°F.

At -20°F, the NiCd and two VRLA’s continue to show comparable performance. The flooded lead-acid is clearly inferior at this temperature and is not able to start the aircraft.

Table II. Engine starting tests at -20°F.

-20°F Starting tests - Results are the average of three successive trials [1]							
Battery Type	Initial voltage under load (V)	End voltage under load (V)	Initial current (A)	Ending current (A)	Start time (sec)	Internal Turbine Temp. (°F)	Charge amps (A)
NiCd	16.6	21.1	615	157	20	753	122
FLA	14.2	13.4	503	247	28	Hot	No start
VRLA-1	16.1	19.8	545	152	22	780	110
VRLA-2[1]	15.7	20.0	537	153	20	758	110

[1] VRLA-2 successfully completed 4 starts at -20°F.

At -40°F none of the batteries were able to start the aircraft. Again, it can be seen that the performance of the VRLA's and NiCd are comparable.

Table III. Engine starting tests at -40°F.

-40°F Starting tests - Results are the average of three successive trials.						
Battery Type	Initial voltage under load (V)	End voltage under load (V)	Initial current (A)	Ending current (A)	Start time (seconds)	Charge amps (A)
NiCd	12.3	7.5	455	177	20	No Start
FLA	11.9	6.6	427	133	25	No Start
VRLA-1	11.1	6.5	347	142	11	No Start
VRLA-2	13.9	7.0	497	142	24	No Start

A second series of tests was then conducted with 1 VRLA battery and the NiCd battery. This test was of starting capability with no recharge between starts at 0°F and again at 110°F.

Table IV. Successive engine starts with no recharge, various temperatures.

Battery Type	Successful starts w/o recharge			
NiCd	0°F	2	110°F	8
VRLA-2	0°F	6	110°F	9

Field Trials

Field trials of the VRLA battery were conducted on C208 aircraft operated by Federal Express using Concorde Battery Corp. RG-380/44 and RG-380/40 batteries. The Federal Express aircraft were initially fitted with nickel-cadmium batteries. These batteries were selected to provide a low maintenance high reliability battery system for these aircraft. However, there were significant Ni-Cd battery problems in the field due to the manner in which the battey and aircraft are used.

Maintenance for the NiCd's was centrallized in Mt. Juliet, TN. Initially the NiCd battery was to be removed from the airplane after 200 flight hours of operation and sent to Tennessee for deep cycling, capacity checks, and other maintenance activities on a scheduled basis. This included batteries from the Federal Express operations in Puerto Rico and the Philippine Islands.

However, the aircraft are used for feeder operations at the end of the Federal Express delivery system. Their operation involves many short duration flights into small airports with a high number of unassisted engine starts. Typically these aircraft average 1 hour and 20 minute flight legs. However, some flights are as short as 20 minutes and there may be up to 13 engine starts per flight hour. Because of the short flights, the NiCd batteries exhibited considerable fading in capacity in a very short period of time. The 200 hour service interval was never achieved and battery removal was made based on slow starting performance and high turbine starting temperatures. A considerable number of spare batteries were required to be stocked throughout the system.

The VRLA test batteries were installed in 5 aircraft based in two locations. The locations selected were Iron Mountain, MI in order to test the battery performance in a cold climate; and Austin, TX in order to test the battery in a hot climate. Initially it was determined to make a capacity check after 200 flight hours.

When the first battery reached 200 hours of operation, it was pulled and capacity tested. As removed from the aircraft, the battery delivered 80% of its rated capacity. It was then recharged and retested. After recharge, the battery delivered 100% of its rated capacity.

Based on this test, it was decided to omit any further capacity checks and leave the batteries in the aircraft with no maintenance until failure. The results of this test are summarized in the Table V.

Table V.

Federal Express VRLA field trial					
Sample	Rated Battery Capacity (AH)	Location	Total time in service (flight hours)	Total number of flights	Months in service
1	44	Michigan	309.7	321	8
2	44	Michigan	502.5	509	13
3 [1]	44	Michigan			
4	44	Michigan	403.4	372	9
5	44	Texas	792.7	728	13
6	40	Texas	751.9	715	16
Average			552.0	529	11.9

[1] Battery failed after 172 hours due to manufacturing defect, not included in averages.

A second field trial was conducted on six Cessna Citation S-II aircraft operated by Executive Jet Aviation Inc. In the Citations, there were no significant problems reported with the nickel-cadmium batteries. Concorde RG-380/40 batteries were installed beginning in May of 1994. Capacity checks were not made and essentially no maintenance was performed on the batteries while in service.

Cost of ownership for the VRLA battery in this application is $1.65 / flight hour.

Cost of ownership for the nickel-cadmium battery is estimated based on a list price of $3679 and an estimated replacement interval of 3500 flight hours. During this time, the NiCd requires service every 100 hours at a cost of $356. This yields a total cost of $4.61 / flight hour.

Conclusions

Valve regulated lead-acid batteries provide electrical performance that is comparable with nickel cadmium batteries. VRLA can deliver excellent high rate performance at low temperatures.

VRLA batteries offer the user a maintenance free aircraft battery.

Table VI.

Executive Jet VRLA field trial		
Sample	Rated Battery Capacity (AH)	Total time in service (flight hours)
1	40	1382
2	40	1024
3	40	1021
4	40	950
5	40	1344
6	40	1080
Average		1133.5

VRLA batteries are a cost effective substitute for nickel-cadmium systems both in terms of initial purchase price and life cycle cost.

REFERENCES

1. Moseley, P.T., *Proc. 5th European Lead Battery Conference, International Lead Zinc Research Organization Inc.*, Research Triangle Park, NC, 1996,