Alcator C-Mod Power Systems

Alternator/Flywheel System
• 225MVA, 1800RPM, 14.4kV GE Alternator, 120 Ton Rotor, 500MJ stored at 1800 RPM. See Fig. 1
• 75 Ton Flywheel stores 1500MJ at 1800 RPM, runs in vacuum to reduce windage losses. See Fig. 2
• 2GJ Stored Energy (limited by alternator maximum and minimum RPM to 371MJ available to EOF)

C-Mod High Yard
• Substation: 13.8kV, 3 phase, 42MVA (100ms pulses), 32MVA (10s flattop) capability. See Fig. 3

C-Mod Power Room and Supplies
• All magnet supplies are located in the C-Mod Power Room. See Fig. 4.
• 13.8kV Switchgear, Air Switch provide protection and isolation for Supplies from Alternator. See Fig. 5.
• TF Magnet supply provides up to 260kA with open circuit voltage 1550/full load voltage 800V. See Fig. 6.
• Two 2.5MVA substations/breakers in power room provide 480VAC to some supplies.

Fig. 1 - 2000HP Motor/225MVA Alternator
Fig. 2 – 75 Ton Flywheel
Fig. 3. 13.8kV C-Mod High Yard
Fig. 4. Alcator C-Mod Power Room
Fig. 5. C-Mod Power Room Switchgear for Alternator Loads
Fig. 6. TF Magnet Supply Converters
Abstract—The Advanced Divertor Experiment (ADX) [B. LaBombard, this conference] is a compact, high field (6.5 T) tokamak being proposed to test new advanced divertor concepts at reactor-level conditions. Development and testing of advanced Lower Hybrid Current Drive (LHCD) and Ion Cyclotron Range of Frequency (ICRF) concepts including high-field-side launch capability is also an important goal for ADX [G.M. Wallace and S.J. Wukitch, this conference]. Where possible the design of the ADX experiment will make extensive use of existing power systems at MIT that presently support Alcator C-Mod, which includes a 225 MVA generator/flywheel (2 GJ stored energy) and 30 MVA (peak) substation. Analysis of existing generator/flywheel, substation, and power system supply capabilities and their application to support ADX operation up to 6.5 T will be discussed. Power system supplies, magnet voltages and currents and operating requirements based on the current point design will be presented. Potential power system upgrades that would support ADX operation at 8 T and 32 MVA plasma current will also be described.

FIG. 7 ADX

C-Mod Power Supplies Available

- See Fig. 8
- C-Mod has 14 primary magnets (coils)
- C-Mod has 11 power converters providing current to coils
- All except EF3, EF4 and EF4-L are driven by own supply
- EF3-U and EF3-L coils are driven in series by one supply
- EF4-U and EF4-L are driven in parallel by a single supply with resistive compensation.
- EF4-U and EF4-L are driven in anti-series by one supply
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- C-Mod Power Supplies and Poloidal Field Coils
- First iteration analysis underway for 6.5 T, 1 MA Plasma
- Determine if C-Mod power supplies are suitable for ADX for current point design.
- First Iteration Design/Analysis Assumptions Used
- ADX EF is assumed to equal C-Mod EF requirements
- DX-U and DX-L will each have a single power supply and will use the existing upgrade design for C-Mod EF2 four quadrant supply.
- ADX OH1 and OH2 coils will be considered to be equal to C-Mod coils and use the same supplies.
- The New ADX OH1 coil will be considered to be the same as the ADX OH2 coil.
- Commutation circuits are required for all OH supplies, as in C-Mod.
- The ADX EF4 coils are to be run in parallel as in C-Mod and use an upgraded C-Mod EF4 supply.
- ADX EF3 coils are in series, as in C-Mod, and designed to use the existing EF3 supply if possible.
- ADX power supply response is expected to be equal or better than C-Mod requirements.
- The 8 new DX2-DX5 power supplies will use modular H-Bridge converters and share a common DC supply if possible.

ADX Power Supplies Work Sheet Intervals

- t = 0 to 0.04 s: initiation, initial current formation interval.
- t = 0.04 to 0.20 s: early current rise and shaping interval.
- t = 0.20 to 0.60 s: final current ramp-up interval.
- t = 0.60 to 1.5 s: flattop interval.
- t = 1.5 to 1.93 s: ramp-down interval.

FIG. 10 ADX Power Supply Worksheet

First Iteration Design/Analysis Goals
- Determine maximum pulse length of TF current flattop with C-Mod Alternator/Flywheel source for ADX 6.5 T, 1 MA plasma current.
- Determine if C-Mod power supplies are suitable for ADX for current point design.

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FIG. 9. ADX Fields/MA-turns for Point Design

FIG. 11  ADX Worksheet Plasma Current, Coil Currents and Voltages

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Maximum ADX TF Magnet Current Flattop Length

- Simple PSIM model developed
- C-Mod data and new ADX TF Coils used.
- ADX Coil is ~0.0092 H and 0.00215 Ohms for magnet/bus.
- ADX TF coils ~0.5 m taller than C-Mod.
- Coil resistance ~7.5% greater
- RPMstart = 1731 RPM, RPMend = 1568 RPM, based on C-Mod experience
- Available Energy for Pulse = 371MJ to EOF.
- ADX Current Requirement for 6.5T = 0.72/0.67*185kA = 199kA.
- TF Flattop Time = 0.72 S.
- Inversion Time = 2.55 S.
- TF Magnet uses ~81% of available Alternator Energy TF current flattop.
- Remaining energy is available for other ADX supplies.
- Upgrade in energy storage is required for longer flattop length or higher TF fields.

Results and Comments for First Iteration Analysis

- As expected, largest voltages occur at initiation, t = 0 s.
- For forward biased coils, supplies can be assisted by commutation resistors.
- EF2 and EF3 coils require large voltages at this stage, over 1kV.
- No current required before 0.04 s in EF2, but 1.3 kV could appear across open switch.
- EF3 coils begin to swing negative at this time, and supply must provide 3150V in EF3U,L coils. Requirement can be relaxed by reducing the number of turns to 75 turns/coil for more voltage headroom.
- Individual EF2 coils could also be reduced to 80 turns as on C-Mod.
- Current requirements in EF2 coils are modest compared to C-Mod, less than 2 kA. Proposed “new EF2” four quadrant supply designed for C-Mod could be used with reduced number of turns.
- New DX1 coils and EF1 coils carry substantial current, 5kA/turn in this scenario. Voltage requirements are modest, maximum values ~100 V in 0.04-0.20 s interval.
- For this scenario, 4 quadrant not needed for DX1 or EF1, but will provided since many different ADX divertor configurations are to be studied.
- EF1 currents and voltages are within rating of the existing C-Mod EF1 supply.
- EF4 coil voltage and current requirements in this scenario challenge existing supply as configured. Voltage after switch closure in 0.04-0.2 s interval > 1.1kV per coil, present supply capability is 900 V and 6.3 KA per coil (13 kA if coils paralleled). Current limit is 10 kA, but upgradable to 50 kA.
- ADX cylinder not modeled here. Main effect is to slow response of fields at plasma to EF4 changes. Voltage demand may be under-estimated in this scenario.
- Reduction of coil number of turns must be considered for next design iteration to reduce supply voltage requirements in normal operation, and to reduce voltage at terminals during commutation and disruption events.
- More detailed studies are needed to determine upgrades to power systems needed for 6.5 T or possibly 8 T operation.