POWER SUPPLY SYSTEM FOR A COMPACT 1.2 GEV BOOSTER SYNCHROTRON*

V. Popov†, M. Busch, S. Hartman, S. Mikhailov, O. Oakeley, P. Wallace, Y. K. Wu, FEL Lab, Duke University, NC 27708-0319, USA

Abstract

Low cost power supply system for compact full energy booster synchrotron was designed, developed and successfully commissioned at Duke University. 500kW second hand thyristor controlled power supply has been completely rebuilt to provide high accuracy ramping of current in the range between 150A and 700A in a 1.3 sec repetition cycle. Reproducibility of current at injection and extraction energy of better than 0.2% was achieved. Conflict of requirements of a fast ramp operation and a magnet protection in the case of emergency shutdown was resolved by means of additional thyristor switches. All trim power supplies involved in ramp have been matched with main power supply for the time response and voltage range. Vertical injection to and extraction from the booster requires a strong Y-bump. Combination of low voltage DC power supply and pulse boosting circuit has eliminated the need of expensive power supply for peak power about 4 kW. Challenges of design, main parameters of the booster power supply system and discussion of operation experience are presented in this paper.

INTRODUCTION

A 1.2 Gev booster synchrotron was recently commissioned at Duke University as part of the High Intensity Gamma Source (HIGS) upgrade of Duke FEL (DFEL) storage ring. This compact (about 32 m circumference) machine was designed with the capability of delivering up to 4nC/sec of electron beam into the storage ring in the top-off mode operation [1]. The extraction energy of the booster can vary from 270 Mev to 1.2 Gev. The duration of operation cycle is 1.3 sec in the single bunch mode and 2.5 sec in the multi-bunch mode [2].

Magnetic system of the booster synchrotron consists of 12 dipole magnets and 16 quads. In order to avoid synchronization problems the same main Power Supply Unit (PSU) feeds all the dipoles and quads in the booster in series. Total resistance and inductance of the chain of magnets respectively are 0.7 Ohm and 0.35 H. The nominal DC current required from the main PSU is 700 A for a circulating beam with energy E=1.2 GeV. Considering demanded duration of ramping cycle, power supply should be capable to provide 900 V in both polarities.

Relatively slow ramping cycle and easy requirements for matching dipole and quad current have allowed us to try do not acquire an expensive customized power supply but convert existing out-of-service 500 kW device into reliable source of ramping current.

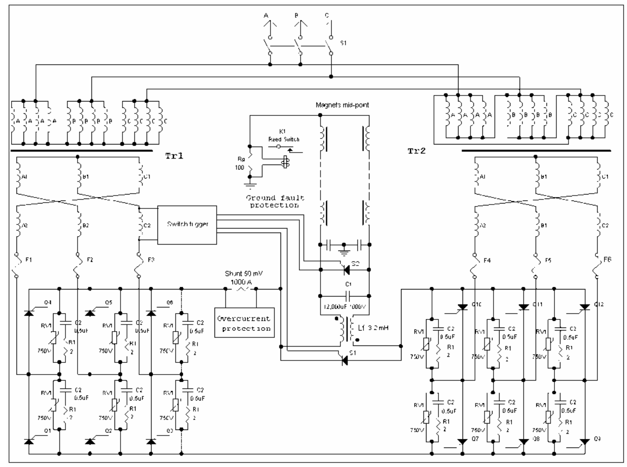

Figure 1: Main power supply configuration.

MAIN PSU

The Trans-Rex power supply was originally purchased by Fermilab in the early 1970s and was acquired by Duke FEL Laboratory (DFELL) in 2002 through the Energy-Related Laboratory Equipment (ERLE) Grant Program. This power supply is designed to produce 500 kW, and up to 5000 A DC at 100 V output, and also can be tapped to produce up to 400 V and 1250 A DC. This power supply is a Model ISR 2126-2A. Among all listed specifications only maximum power met our requirements.

In order to produce the output required for the ramped current needed for operation of the booster main magnets (900 V and 700 A), the power supply was reconfigured, starting at the secondary windings of the main transformer.

The original configuration of the power supply was a 12 phase SCR controlled output, with the input AC fed through one Y-Y and one Δ-Y transformer, which provides a 30° phase shift to the two halves of the power supply. The input transformer primaries can be wired either in parallel or in series and each secondary winding supplies one of the 12 SCR output switches, which are controlled by channels of the SCR firing modules.

The input transformer was modified, first by changing the connections in the secondary to be in a "zig-zag" configuration, which put two alternating secondary windings of each main transformer in series (A1+B2, B1+C2, C1+A2) (see Fig.1) to provide the higher voltage

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†vpopov@fel.duke.edu

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needed while maintaining the 60° phase shift between each secondary output. Each secondary supplies a pair of SCRs, which are now configured in a 3-phase bridge. Reconfiguring the secondary connections (which are hollow water-cooled copper conductor) also had required reconfiguration of the water-cooled connections.

The SCR firing modules and current control circuit have been replaced with the modules designed at DFEL for the power supplies employed to excite Duke FEL wigglers [3]. The SCRs, power diodes, SCR snubber capacitors and transient voltage suppressors have been replaced with higher voltage rated components. A conventional LC filter with a resonant frequency of about 26 Hz (C=10mF and L=3.2 mH) has been used to reduce ripples of the thyristor rectifier. Commercial 1000 A DCCT from Danfysik (type 860R-2000) [4] has been installed to provide required current stability and reproducibility.

A typical challenge for such kind of the power supply systems is a great reactive power circulating in magnetic elements. Two most important issues follow from this.

Peak power being consumed from AC main is significantly higher than average power. The shape of main current has no longer sine form that can produce broadband interferences. In order to estimate possible impact of this problem a detailed computer model of the 12-phase rectifier has been developed. It helped our electrician stuff to choose correct equipment. Additional power compensator has been acquired as a result of this computer simulation.

Electrical energy stored in the magnets and filter choke may cause significant damage both the main PSU and the corrector power supplies which are magnetically coupled with dipoles and quads. The necessity for main PSU to operate in both polarities does not allow us to employ free-wheel diodes across the rectifier output. Two thyristor switches have been implemented in order to damp energy stored inside the booster magnets and filter choke. Triggering pulses come to the switches if the voltage across the secondary windings of the main PSU disappears. The Trans Rex interlock system prohibits to turn on power until all corrector power supplies are on. This simple procedure helps to protect secondary power supplies against over-voltage, because all of them have been designed to stand maximum possible voltages induced in the coils for normal operation.

REGULATOR AND CURRENT TRACKING ACCURACY

A traditional analogue PI-regulator has been realized. Current feedback loop bandwidth limited by great inductance of the booster magnets and a low-pass resonance LC filter. The frequency response of controlled rectifier with a firing circuit also is not great. Combination of current feedback and feed-forwards makes it possible to stabilize current on the injection and extraction levels with required accuracy. Fig. 2 shows the current regulator configuration. Additional local voltage feedback provides the suppression of a resonant peak of the filter frequency response. Fig. 3 represents real 1.4 sec cycle of the booster operation with extraction energy 600 Mev. Normal operation also includes ramp up to 1200 Mev for magnetic normalization. Relative error of the current tracking does not exceed 0.2% for both injection and extraction levels.

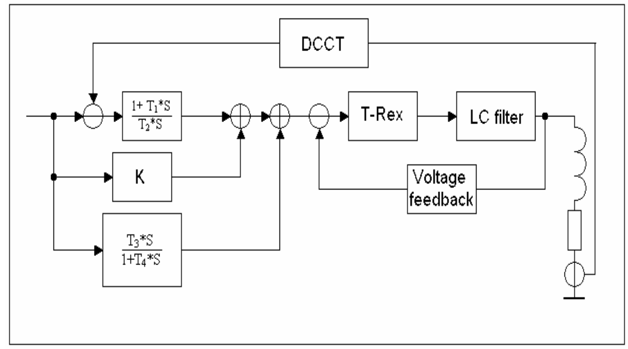

Figure 2: Simplified block diagram of the current regulator.

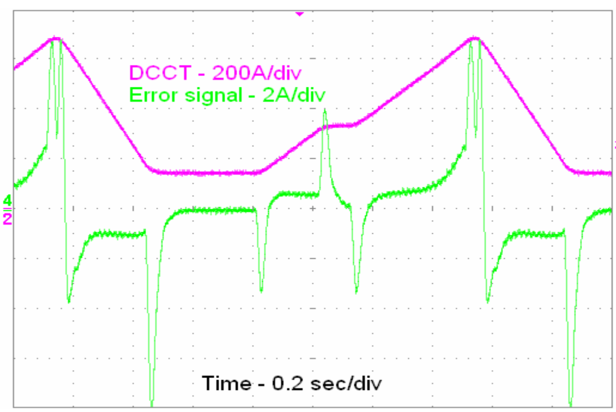

Figure 3: Booster power supply cycle of operation.

OTHER POWER SUPPLIES

In addition to the main PSU, the booster power supply system includes PSU for septum, sextupole, trim and Y-bump magnets. We tried to use commercially available power supplies. So we have acquired MCOR-30 from BiRa Systems to feed X-correctors. For trim coils with the current range below 2 A DFEL has in-house fabricated bipolar power supplies based on OPA541 power amplifier (JimTrim, 4-channels per module, 6 modules per crate) Number of trims require increased up to 40 V output voltage. In order to meet new demands JimTrim power supply has been modified. Two OPA541 amplifiers arranged in a bridge configuration makes possible to double the output voltage. Both JimTrim versions are totally compatible in the sense of control and monitoring connections.

We also have very good performance experience with another trim power supply designed and fabricated at DFEL. It is bipolar 15 A and 15 V power supply based on a linear MOSFET regulator (8-channels). There are 28 channels of this power supplies now in operation in the booster. Detailed information about this device is available at [5]. It is important to mention that all power supplies based on a linear regulator have low noise and very good dynamic capabilities for being used for the booster performance.

Y-BUMP POWER SUPPLY

The injection/extraction scheme in the booster is vertical. Four horizontal dipoles form vertical bump while the energy of the electron beam is ramping up. This chain of magnets needs 27 A unipolar current at 1.2 Gev of e-beam and about 110 V supply to provide ramp up. We decided do not buy an additional power supply, but to employ MCOR-30 from BiRa Systems (30 A and 65 V, bipolar) and to boost ramping current by discharging preliminary charged capacitor. Fig. 4 shows the structure

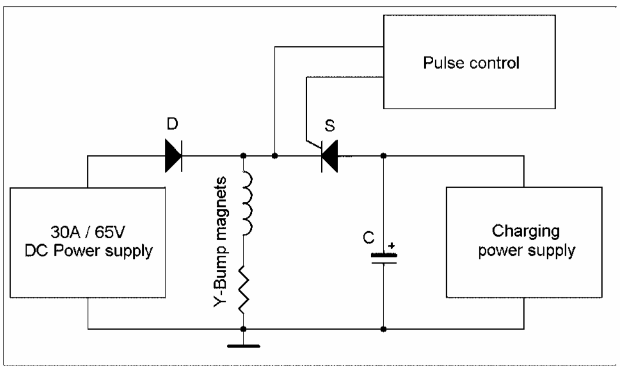

Figure 4: Structure of the Y-bump power supply.

of this hybrid device. Fig. 5 depicts curves of the current through DC power supply and the total current in the magnets. The DCS150-7E from Sorensen has been used as a charging power supply.

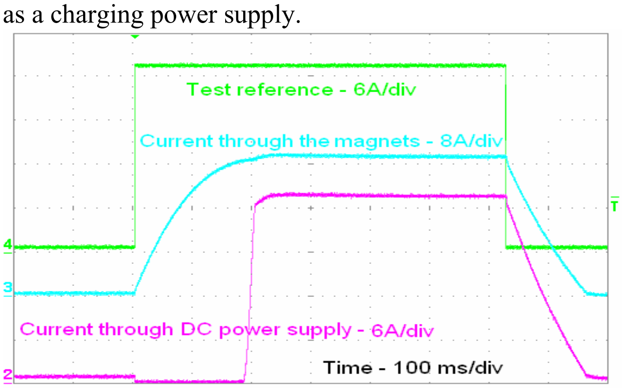

Figure 5: Current switching diagram.

CONCLUSION

In the beginning of the booster commissioning we had experienced very serious troubles with a protection of trim and corrector power supplies against over-voltage induced by the main PSU. A few MCOR-30 modules were significantly damaged. We have developed start-up procedure for power supply system. To prevent possible human mistakes some hardware alterations have been taken. Now it is disabled to turn-on main PSU until raw power supplies feeding JimTrim, VIC15 and MCOR-30 have nominal voltage. Also, additional capacitors across the outputs of the raw power supplies have been added, which are big enough to "swallow" over-voltage spikes. Two thyristor switches installed across the main PSU output protect Trans Rex transformers and the secondary power supplies as well against over-voltage, which would be caused by unexpected disconnection of the main circuit breaker.

Since June 2006, when power supply system has been commissioned, we have no failure of the main PSU, VIC15 and JimTrim. Some additional optimizations of trims and correctors time response have been made to match current in the main dipoles and in the secondary coils. Recently the booster power supply system demonstrates very good reliability and adequate accuracy in its performance.

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