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BOOSTER MAIN MAGNET CURRENT LONG TERM CORRECTION

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I. Why Long Term Correction

1. Voltage Regulation

The Booster main ring power supply voltage regulation is aimed at solving the short term magnet current repeatability problem, which is caused by the power line disturbance, and, to a less significant extent, by the rectifier parameter variation. Once the voltage regulation is accomplished, two problems remain to be solved. One is that due to the limitation on the voltage regulation loop gain the steady-state voltage error may result in a nontrivial effect in the magnet current as time lapses. The effect can be regarded as the medium term as well as the long term disturbances, where the medium term disturbance is referred to that within the cycle, and the long term disturbance is referred to that lasts cycles. Another problem to be solved is that since the voltage loop does not encircle the passive filter and the magnet, therefore the disturbances caused from there are totally immune from the correction. These disturbances are believed to be the long term ones.

2. Current Regulation and Power Line Feedforward Correction

To solve the problem, a magnet current regulation is often expected to help. Analysis shows however that because of severe restraints on the rectifier system, for a system like the Booster main ring a current regulation could only play a minor role. In general, a magnet current regulation loop designed for Booster may have a loop gain around 10, and a bandwidth around 10 Hz. Noting that in the Booster proton operation, the whole cycle takes only 133ms, and there is at most a few milli-second flat top, this is clearly not enough for any serious regulation. Although a current regulation can be applied, it cannot fulfill satisfactorily the medium and long term correction requirements.

Since a considerable portion of medium term disturbances come from the power line, a power line feedforward correction has been proposed[1]. The design can correct some transient disturbances, and some medium and long term disturbances as well. The constraint is that it corrects only for the disturbances from the power line.

3. Long Term Correction

We therefore need a long term correction system to correct the overall system long term drift. The system is a computer-controlled magnet current regulation system. It differs from the voltage and current regulation loops in two aspects. One is that it is not a continuous feedback system. Another is that it is designated to correct the overall long term drift. With this scheme, the whole correction system will be operated as the follows. The voltage regulation corrects mainly the short term disturbances, say in a range of less than ten milli-seconds. The power line feedforward correction corrects mainly the medium term disturbances, say in a range of tens of milli-seconds, and a part of long term drifts, both from the power line. Then the long term correction system corrects the overall slow drift.

The magnet voltage and current readback system, which is under construction, can provide a 12 bit "on the fly" reading all the time. The signal may be locally processed or sent to the host processor. We have a DCCT magnet current measurement system, which is with a measurement precision as good as 0.001%. We are also building an overall reference function generating system. The system can start from a magnet current reference function, it then figures out the required voltage function and splits the overall voltage function into six individual rectifier substation voltage references. The references will be transferred to analog signals to drive the substations. The rest of the required are these such as a couple of synchronized D/A converters, a signal processing package, and a control package.

II. Proposed Long Term Correction System

1. The Long Term Correction Scheme

A long term correction scheme block diagram is shown in Fig.1, where the plant represents the rectifier system together with the voltage regulation loop, the passive filter, and the main ring magnet. The input of the plant is the six substation voltage references, the output of the plant is the magnet current. The magnet current is detected by the DCCT. The function generating system produces a magnet current reference, an overall voltage reference, and six individual substation voltage references. The six substation voltage references are converted into the analog voltage signal by synchronized D/A converters. The magnet current reference is converted by another D/A converter, it is then compared with the DCCT magnet current signal. The difference is read by the data acquisition system which is a part of the readback system. The processed information on the difference of the real magnet current and the function is then transferred into the voltage function by a plant inversion. The converted error correction signal simply join the substation voltage references in order to correct the error.

2. The Use of the Correction System

The correction system has two uses. First use is to help the operation set up. In the set up, the real magnet current must be different, more or less, from the expected current function. It is anticipated that because a great deal of dynamics and nonlinearities are involved in the whole process, to revise the reference function generation into details is not an easy task. If the difference is within, for instance, 1 percent, the function generating algorithm might be considered satisfactory. Once the current error is shown to be within such a limit, the long term correction system can take over the trim. Second use of the correction system is to keep the long term magnet current tracking the reference repeatably from cycle to cycle. This is the major use and it is self-explanatory.

3. Some Interesting Points of the Scheme

The proposed correction system has some interesting points.

i) System Reliability

In the correction system, the main ring magnet is mainly controlled by the magnet voltage reference. The correction signal is supposed to provide a trim. It should, and could, be kept low. Therefore, even if the correction system tripped, the main magnet power supply would still be operational, of course, it will be operated without long term corrections then.

ii) Plant Inversion

In a continuous feedback system this scheme cannot be adopted. The difficulty lies in the plant inversion. The plant inversion is an improper transfer function operation, or, a differential operation, which is not implementable in the reality because of the noise considerations. In our scheme, the noise problem can be solved by smoothing, filtering, or simply averaging. Also, in the computation of the plant inversion, the algorithm can be manipulated to avoid the problem. For instance, the AI and the knowledge-based techniques can be applied.

iii) Performance Trade Off

In a continuous feedback system, the performance indexes have to be traded off with the system stability and the reliability. In the proposed system, such a link becomes much weaker. The dynamics has been reduced to the minimum and there are several means to gain the control on it.

III. Design Considerations

1. Separated Function

To accomplish the design, the long term correction must not react to the short term variations from both the disturbances and the corrections. The system should treat the short term variations as noises. Thus, we propose a filtering algorithm applied to several cycle samplings, say 5 cycles. In an overall view, the voltage regulation, the current regulation, the feedforward correction, and the long term correction now are serving their separated functions, and will not disturb with each other.

2. Stability Problem

The stability problem may be studied from two aspects.

i) Overcorrection

This is determined by the gain of the correction system from the error signal to the correction signal. It is easy to understand that if this gain is too high, then the system correction may generate an oscillation. To prevent such a problem, we may develop a correction evaluation algorithm. The system error will be compared with the original error, if the present error shows in a different polarity from the original error then the correction should be stopped. The next is to apply a lower gain to the correction algorithm, until the problem is resolved. A further consideration may suggest to split the whole cycle into several segments, some of them are dedicated to the troublesome transient precess, and apply different gains to each segment, provided that a unique error correction gain cannot fulfill the requirement.

ii) Phase problem

This problem is related to the correction speed. In principle if there exists an initiative disturbance that possesses a fundamental frequency component synchronized to the correction speed, then theoretically there is an opportunity to give rise to an oscillation. To resolve the problem, a multi-speed correction system should be prepared in case such a problem happened.

3. Correction Speed

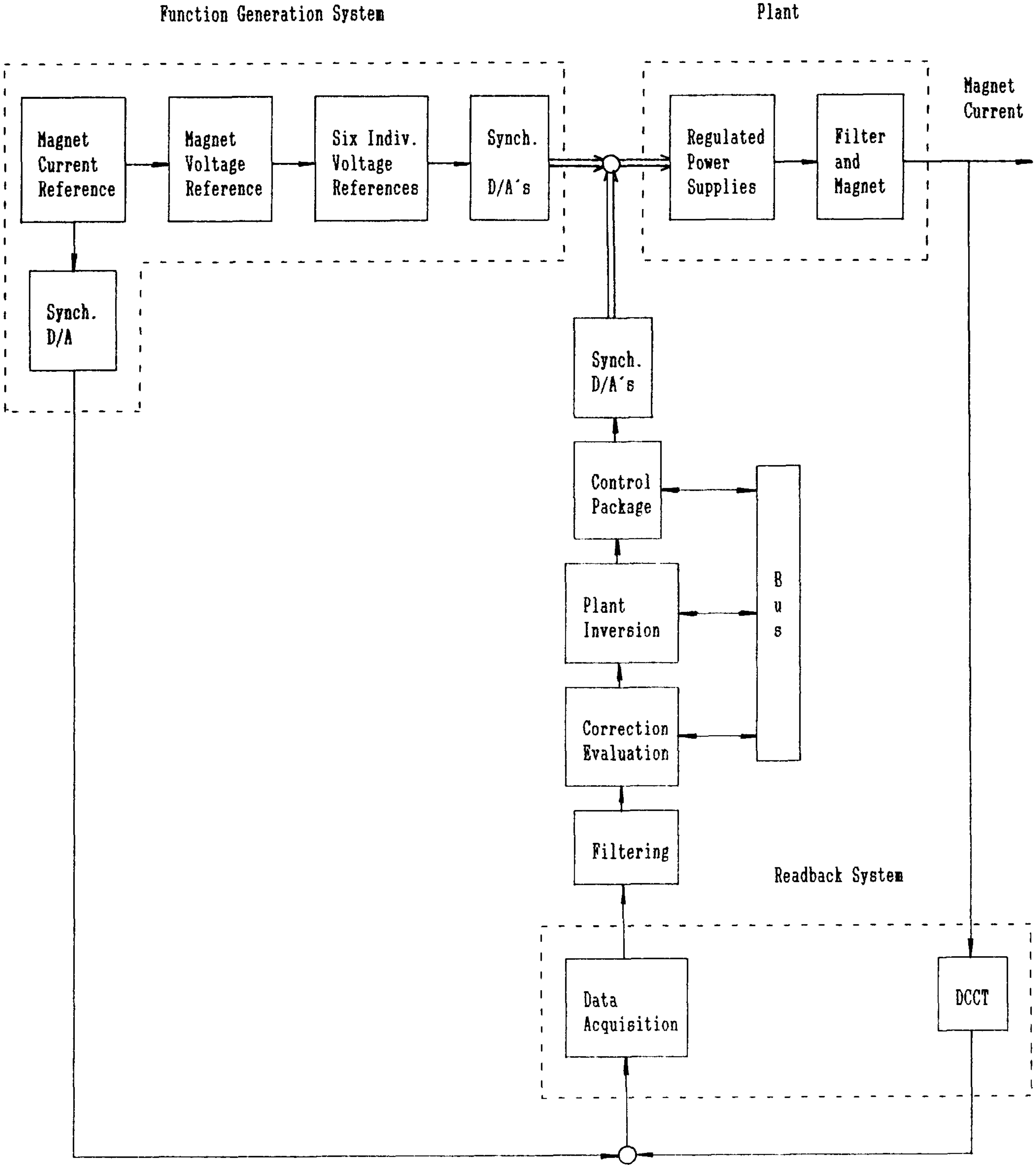
We calculate the correction speed as the follows. We assume that the sampling period is 100 micro-second, and we take the proton AGS SEB operation as the example. Every Booster magnet cycle is 133 ms, and every AGS cycle is 3.3 seconds. We may sample one of the Booster cycle for each of the AGS cycle for the correction. To transfer the whole cycle data to the main processor by using the DATACON, we need 3 seconds. This time fits the AGS cycle. We sample for instance 5 cycles. This takes 16.5 seconds. The plant inversion may need relatively long time for the computation, say, 15 seconds. The correction evaluation in a normal operation condition is not necessary for every step, and in fact it takes only a short time, say 1 second. To transfer the correction data to the executive data buffer needs another 3 seconds. Therefore totally we need about 35 seconds for a correction.

IV. Concluding Remarks

The proposed correction scheme is not a new idea. In fact, several institutes have already implemented various versions of similar schemes, and recently people are showing increasing interest to the implementation of such an idea to their specific concerns. In our opinion there are two things of particular interest at present. One is that we have not seen such or similar schemes turned to a real accomplishment at the AGS yet. Second is that for the long term drift correction, an effective magnet current regulation should be applied, whereas at Booster as mentioned even a current regulation is applied, it cannot solve the long term drift problem. Therefore such a system or a similar one is considered to be necessary.

Reference

[1] S. Y. Zhang and A. V. Soukas, "Booster Dipole and Quadrupole Voltage Regulation Loop," AD Booster Tech Note, No.148, June 1989.



Function Generation System
Plant
Magnet Current
Magnet Current Reference
Magnet Voltage Reference
Six Indiv. Voltage References
Synch. D/A´s
Regulated Power Supplies
Filter and Magnet
Synch. D/A
Synch. D/A´s
Control Package
Plant Inversion
Correction Evaluation
Filtering
B u s
Readback System
Data Acquisition
DCCT