MAGNET CIRCUITS FOR DELTA

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Abstract

The DELTA booster synchrotron magnets will be operated in a ramp mode. Fast excitation will be done only up to 300 MeV in the first stage and up to the nominel rated energy of 1.5 GeV in a later phase. For this the type of the dipole power supply is mainly determined by the influence of the mains, and different solutions are discussed.

The control loop design of the magnet circuits of the booster and the storage ring and the results of their simulation are presented.

Introduction

Both the Synchrotron and the storage ring of the 1.5 GeV DELTA project will be equipped by the same types of dipole and quadrupole magnets. The dipole magnet circuits will be excited by phase-controlled thyristor converters whereas those for the quadrupoles will be supplied by 14 kHz – PWM Transistor converters. All power supplies are closed by passive low-pass filters. Energizing of the synchrotron magnet circuits will be made in a ramp mode thus obtaining scope for the excitation curve shape. During the first development stage of the project, when fast excitation for them is only necessary between 100 MeV and 300 MeV power supplies are provided their output voltage has a DC level on a 1.5 GeV base thus allowing full excitation from 300 MeV to 1.5 GeV only in a slow manner. As dynamic error in case of a 2% step of the line voltage the magnet currents shouldn't exceed a 10^{-4} tolerance. Figure 1 shows the equivalent circuit diagram of both types of power supply.

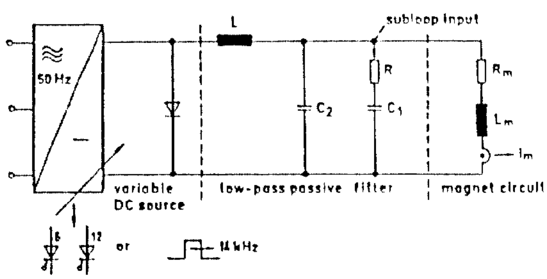

Fig. 1. First stage power supply - Basic circuit diagram

Structure of the automatic control system

Automatic control will be done by a magnet current loop and a (filter) voltage subloop. The block diagram containing all the elements of the structure is given in Fig. 2.

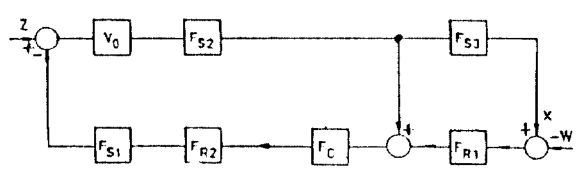

Fig. 2. Multi-loop control system - Block diagram

The transfer function of the single structure elements are listed below ($p = j\omega s^{-1}$).

F_{S1}: Approximation for the delay time T_s of the DC source

$$F_{S1} = \frac{1}{1 + T_s + T_s^2/2}$$

F_{S2}: low-pass third order passive filter (series reactor without losses)

$$F_{S2} = \frac{1 + 2d \cdot p/\omega_0}{1 + 2d \cdot p/\omega_0 + (1+m)p^2/\omega_0^2 + 2md \cdot p^3/\omega_0^3}$$

$$m = \frac{C_2}{C_1}\ ,\ d = \frac{R}{2\omega_0 L}\ ,\ \omega_0^2 = \frac{1}{LC_1} \qquad (see\ Fig.1)$$

F_{S3}: magnet circuit

$$F_{S3} = \frac{1}{1 + pT_m}\ ,\ T_m = \frac{L_m}{R_m} \qquad (see\ Fig.1)$$

$$V_0 = \frac{U_G}{I_{mn} R_m};\quad U_G : voltage\ of\ the\ DC\ source,\quad I_{mn} : nominal\ rated\ magnet\ current$$

F_{R1}: magnet current regulator

$$F_{R1} = \frac{V_I \cdot (1 + pT_m)}{pT_m} \qquad PI-characteristic$$

$$F_{R3} = \frac{V_I \cdot (1 + pT_m)(1 + pT_2)}{p^2 T_m T_2} \qquad PI^2-characteristic$$

F_{R2}: Voltage regulator

$$F_{R2} = \frac{V_{II} \cdot (1 + pT_2)}{pT_2} \qquad PI-characteristic$$

F_C: compensating element ("phase shifter")

$$F_C = \frac{1 + pT_3}{1 + pT_4} \cdot \frac{1 + pT_3}{(1 + pT_5)(1 + pT_6)}$$

The simulations were carried out by the aid of the Hewlett Packard "Linsys" method.

Dipole circuit of the storage ring

The DELTA dipole circuits consist of

- Number of dipole magnets (16+4·½) $N = 18$
- Nominal rated current $I_n = 995\ A$
- Total circuit inductance $L_m = 476\ mH$
- Total circuit resistance $R_m = 329\ m\Omega$
- Circuit time constant $T_m = 1.45\ s$
- DC load voltage $I_n \cdot R_m = 327\ V$
- Power supply output voltage $1.05 \cdot 327\ V$; $V_0 = 1.05$

The operation of the storage ring magnet circuits is only DC-wise. Therefor a 6-pulse converter is sheduled for exciting the dipole magnets. With this we get

$$T_s = \frac{20\ ms}{6 \cdot 2} = 1.67\ ms$$

The low-pass filter has to meet the following requirements:

a) attenuation of the 300 Hz and 600 Hz harmonic voltage components
b) (weak) attenuation of the 50 Hz subharmonic voltage component; at least: no amplification of subharmonics.
c) favourable open-loop response of the complete automatic control system.

We analysed two different types of passive filters

- 2nd order ($m = 0$) ; $d = 0.07$; $f_0 = \omega_0/2\pi = 23\ Hz$
- 3rd order ($m = 0.1$) ; $d = 0.4$; $f_0 = \omega_0/2\pi = 15\ Hz$

To achieve the same performance of the output error, the 2nd order filter needs an additional compensating element of the structure mentioned above (F_C). With this we obtain similar open-loop responses - see Fig. 3 and similar output errors in case of a voltage step - see Fig. 4. But F_C increases the level of the higher frequency components as it is shown in Fig. 3. Thus the main harmonic component 300 Hz has the double value compared with the circuit containing the 3rd order passive filter without compensation. Both servoloop amplifiers are of the PI-type having the parameters: $V_I = 150$; $V_{II} = 3$ or 4; $T_2 = 0.1\ s$.

Magnet circuits of the booster synchrotron BoDo

For the first development stage with fast excitation from 100 to 300 MeV a DC thyristor converter is scheduled having 12-pulse rectifying ($T_s = 0.885\ ms$) and the same output parameters as for the storage ring dipoles: 995 A,(1.5 GeV) ; 1.05 · 327 V. The 3rd order passive filter mentioned above (f_0 = 15 Hz; m = 0.1; d = 0.4) is favourable for this application too. However to obtain a sufficient dynamic behavior for the automatic control system not only faster converting but also a compensating network have to be used. Both measures aim at the same enlargement of the open-loop bandwidth. Figure 5 shows the frequency response of the compensating element. Its layout is done with regard to the 600 Hz voltage component, which should not be increased.

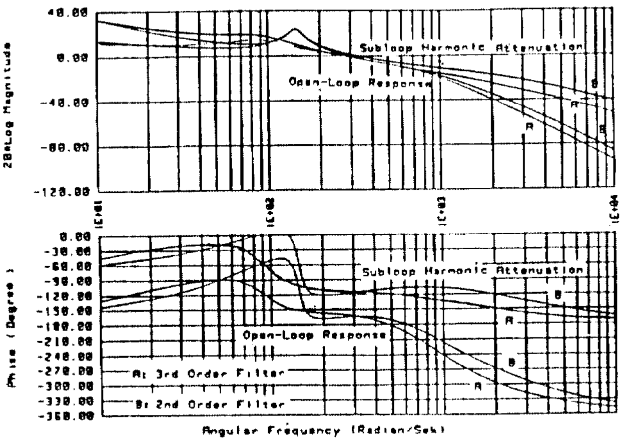

Fig. 3. Frequency responses - DELTA dipole

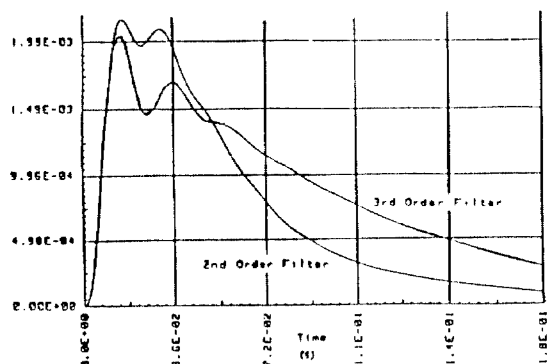

Fig. 4. Time response to a 100% line voltage step - DELTA dipoles

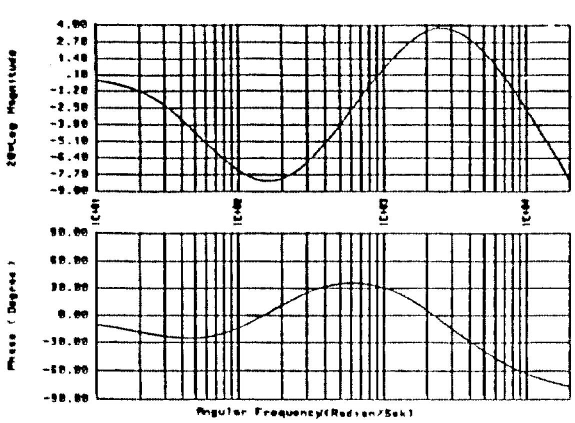

Fig. 5. Frequency responses - Compensating network BoDo dipoles

That is also obvious from Fig. 6, containing the subloop frequency characteristic B together with that of the passive filter and the open-loop response of the whole system.

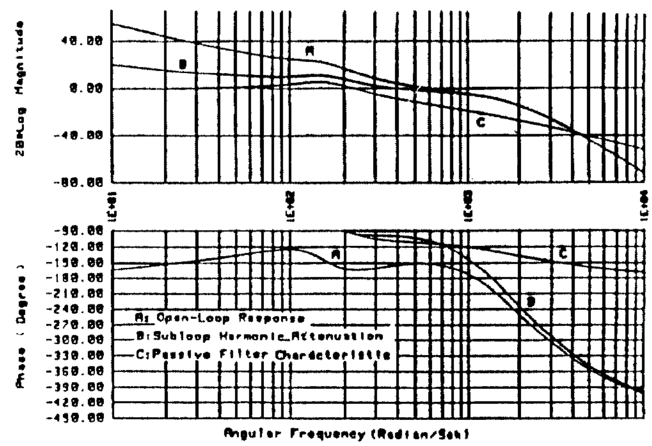

Fig. 6. Frequency responses - BoDo dipoles

The parameters for the two regulation amplifiers of the PI-type are: V_I = 850 ; V_{II} = 0.9 ; T_2 = 0.05 s. It is obvious that the subloop gain V_{II} is decreased in favour of a higher amplification in the current loop. The aim of this is to obtain a better behavior in the following the dynamic reference input. Fig. 7 shows the following error for two different rise times of the linear ramp but during the first transition period between zero and the linear ramp of 50 ms duration.

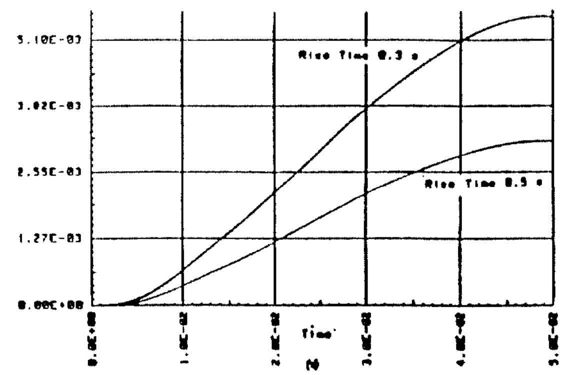

Fig. 7. Following error - BoDo dipoles

During this time the control input obeyes to the equation

$$W = at^3 + bt^4$$

The diagram figures the error related to the nominal rated value i.e. 300 MeV. The current loop PI-characteristic yields a following error proportional to the first derivative of the reference value. Therefore it is evident that this can be used as correction signal. The result of such a measure is demonstrated by Fig. 8. It is based on the introduction of $V \cdot \dot{W}$ directly into the regulating unit.

All 6 quadrupole families have the same circuit parameters: N = 4 magnets per circuit; I_n = 55 A (1.5 GeV); L_m = 1.374 H; R_m = 2.09 Ω; T_m = 0.657 s; T_s = 0.036 ms

Excitation will be done by individual 14 kHz-PWM-transistor choppers having DC input, connected to a common DC diode converter. The passive filters of these device, used so far for DC operation, shall be kept and are of second order having the parameters m = 0; d = 0.11; f_0 = 691 Hz. The characteristics of the regulating amplifiers are: current loop PI^2-type with the parameters: V_I = 2000 V_{II} = 0.2 ; T_2 = 0.002 s

A compensating network similar to this of the dipole supply is provided. Figure 9 shows the following error obtained by the application of these servoloop parameters with the result that the error is nearly zero at the begin of the linear ramp due to double integration. Specially for 0.6 s rise time the following error during the transition phase is nearly within the tolerance. Therefor a correction seems to be unnecessary.

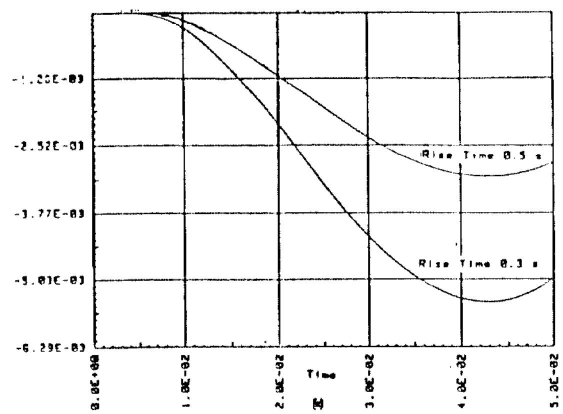

Fig. 8. Compensation of the following error of Fig. 7

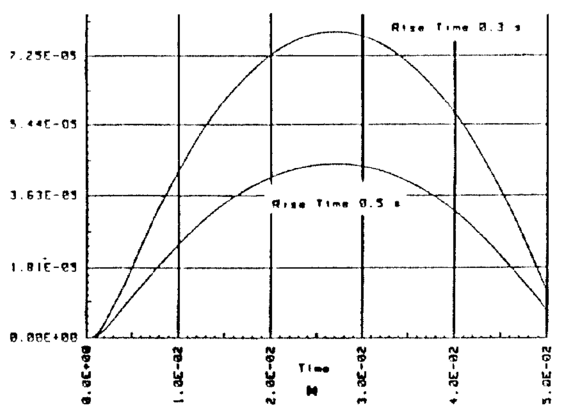

Fig. 9. Following error - BoDo quadrupoles

Full range fast excitation of the BoDo dipole magnets

In the second development stage the total cycle period is planned to be 1.5 s. For this all interesting quantities for the dipole circuit are given in the simplified diagram of Fig. 10. All nominal rated quantities are related to 1.5 GeV.

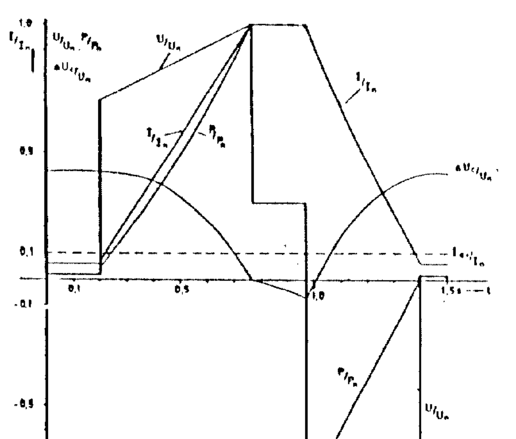

Fig. 10. Wave shapes for full range fast excitation - BoDo dipoles

$$I_n = 995\ A \quad ; \quad U_n = 1085\ V \quad ; \quad P_n = 1.08\ MW.$$

Energizing is made by linear ramping whereas for de-energizing the mode with maximum possible inverse voltage is assumed.

The response of the grid to the presented current and the active power (P) waveforms and additional to this : reactive power (P_Q) as secondary effect of phase controlled thyristor application has to be estimated by the knowledge of the 10 kV, 3 phase 50 Hz-network parameters. The institute is connected to a 10 kV, 31.5 MVA-transformer by a relatively long cable. Therefore the ohmic resistances are not negligible and we obtain (P_{TR} = 31.5 MVA, nominal rated transformer size)

$$u_r = 8.4\% \qquad u_x = 22\%$$

$$\frac{\Delta U}{U_n} = \frac{P}{P_{Tr}} \cdot u_r + \frac{P_Q}{P_{Tr}} \cdot u_x$$

(as line voltage magnitude variation)

$$\Delta\phi = \arctan(\frac{P}{P_{Tr}} \cdot u_x - \frac{P_Q}{P_{Tr}} \cdot u_r)$$

(as line voltage phase angle variation)

Normally thyristor controlled power sources without energy storage between line and converter are used. In our case a second power supply for about 2/3 of the total output power has to be installed and by the use of gate fired thyristors as fly-wheel valves the demand of reactive power in the critical phase during transition to flat top may be restricted to 50 % of the maximum total active power.

With this we estimate these linear voltage variations:

magnitude: $5 \cdot 10^{-3}$

phase angle: 0.7^0.

Thereby other sensitive laboratories supplied by the same line could be disturbed.

Improvement may result from:

a) a fast source of reactive power e.g. a reactor controlled by back to back connected thyristors. With that either the magnitude or the phase angle can be corrected.

b) Correction of the line voltage magnitude as mentioned above. Phase angle compensation by addition of a fast variable 90^0 shifted voltage to the supply voltage. The most practicable method would be the use of a transductor series connected to the main transformer output.

c) Application of a self-commutating power source with DC interlink and energy storage , see Fig. 11. Using the quantities of Fig. 10 and a given voltage variation of $\Delta U/U_r = \pm 25\%$ a storage capacitance of 0.5 F is necessary. The variation of the storage capacitor voltage U_c/U_n is shown. Smoothing of the input current is done by the filter choke.

The size of the storage capacitor reduces by nearly 20% if a pulse load of 20% of the nominal rated active power is tolerated. In this case charging of the storage capacitor is carried out only during the de-energizing phase and the input current has to be interrupted. This method stabilizes not only the local line voltage but liberates the grid from pulsating load. Of course it is the most expensive one and realization is only possible by the use of electrolytic capacitors. With regard to their overvoltage safety 4200 units of 6 mF ; 350 V are necessary to get a storage capacitance of 0.5 F $U_{max} \approx 1500$ V.

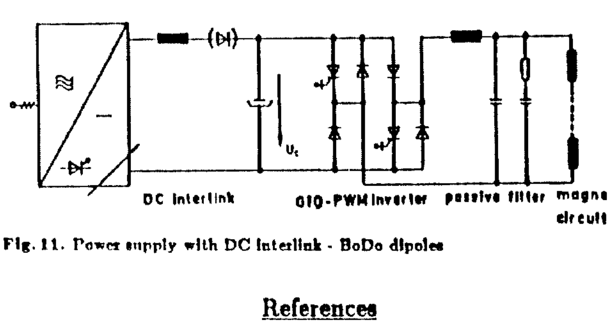

Fig. 11. Power supply with DC interlink - BoDo dipoles

References

[1] *J.Friedl* , DELTA, The Electron Storage Ring Accelerator, (presented at this conference)