HIGH-POWER PRECISION CURRENT SUPPLY IST2-1000M FOR ELEMENTS OF MAGNETIC SYSTEMS OF ACCELERATORS AND CHARGED PARTICLE STORAGE RINGS

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Abstract

Thyristor current supplies of the IST2-1000M type resulted from modernization of IST2-1000/115 supplies, manufactured at the Tallinn electrotechnical plant in the eighties.

These supplies are intended to power magnetic systems of accelerators, requiring high stability and low ripples of the output direct current.

The modernization was caused by the necessity to replace the outdated hardware electronics components as well as to raise reliability and quality of output parameters of the Supplies. The electronics have been developed anew and manufactured; the capacitor bank and noncontacting current transformer (DCCT) have been replaced.

Parameters of the Supplies are given in the following table 1.

Table 1. Parameters of the Supplies

Parameter	Unit	Value
Nominal output current	A	1000
Nominal output voltage	V	110
Output current control range	%	5 - 100
Control increment		2^{-20}
Nominal current instability over 12 hours	%	0,005
Temperature dependence per 1^0C	%	0,0002
Amplitude of pulsation of mains harmonics for nominal current at non-inductive load	%	0,02
Rate of current raise without disturbing operation of the system for active suppression of pulsation	A/s	100

The Supply consists of two boxes (power box PB and box of filters BF), a detached supply transformer and power switch.

Power box PB comprises the following:

- a three-phase thyristor rectifier,
- a passive filter consisting of a choker and capacitor bank,
- a crate for the electronics.

Box of filters BF comprises the following:

- a transformer for ripples suppression,
- a head of noncontacting current transformer.

The electronics place in a crate of the "Vishnia" standard. The crate contains the following radio units:

- Infeed unit IU, containing an auxiliary power supply, interlock and protection circuits, and circuit to switch the power supply regimes.
- Control unit for thyristor rectifier TR.
- Correction unit CU with elements of current and voltage feedback circuits.
- Ripples suppression amplifier RSA.
- Unit DAC-ADC to control and monitor parameters of the Supply with the help of the computer. The CAN-DAC standard is used as the communication interface.

Construction of precision current supplies is linked with the problem of achieving low ripples level for the output current of the supply.

That seems impossible to realize only using a passive LC-filter at the thyristor rectifier output (see Fig.1). So, we have to limit ourselves to reasonable sizes of the choke and capacitor bank. In practice, one can reach the level of 1% to 3% of the output current value. To suppress ripples down to the level of 0,02%, the Supply has a so called active filter, consisting of ripples suppression transformer RST, connected in serial with the load, and ripples suppression amplifier RSA, inducing EMF opposite in phase to ripples of the output voltage of rectifier TR.

On the other hand, it is also impossible to achieve the required ripples level, even with an active filter, using only one loop for current stabilization. The reason is that the loop for current stabilization contains a large number of phase-shift networks (the LC-filter of the rectifier, load inductance etc.), which results in the impossibility of providing stability and the required gain for the current stabilization loop. In that case, it is necessary to apply a combined method of stabilization – in current and in voltage.

The resulting control loop is a complicated system of stabilization loops of feedback in current and in voltage, each next loop lying in the previous one. The function diagram in fig.1 depicts the control loop of the Supply, where three feedback loops can be separated:

- Loop "C" includes error signal amplifier A5, power rectifier TR, the LC-filter and differential amplifier A8.

Loop "C" has low gain in the range of 5 to 10. It carries out the following functions:

- linearization of the non-linear voltage-current characteristic of TR,

- damping of LC-filter oscillations because of the resonance in its frequency characteristic, with the help of correction elements R2, R3, and C2;

- attenuation of the 50 Hz pulsation in the output voltage of the Supply by a factor of two or three.

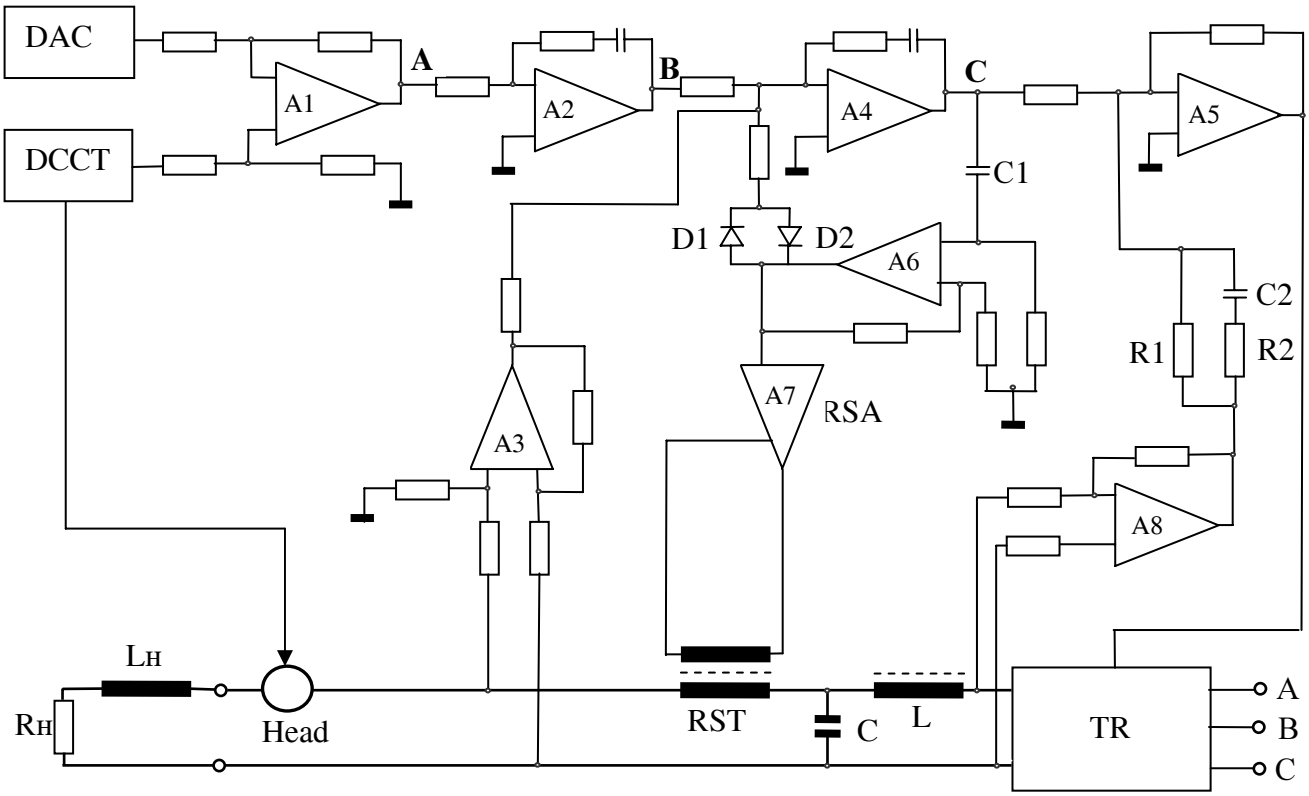

Figure 1: passive LC-filter at the thyristor rectifier output.

- Loop “B” includes error signal amplifier A4, limiting amplifier A6, ripples suppression amplifier A7, differential amplifier A3 and feedback loop “C”.

Voltage at point “B” is applied to the input of amplifier A4 as control voltage. Through differential amplifier A3, the output voltage Uout is applied in the opposite polarity to the same input. Amplifier A4 amplifies the difference voltage (the error signal). The output voltage of this amplifier (point C) controls loop “C”. In parallel, the alternating component of this voltage is applied to ripples suppression amplifier A7, through coupling capacitor C1 and limiting amplifier A6. Amplifier A7 induces alternating voltage of the mains frequency ripples spectrum in the output winding of ripples suppression transformer RST. This voltage is opposite in phase to ripples of the output voltage of the LC-filter.

So, two negative feedback loops are created:

- loop “B$_{=}$”, including elements A3 and A4 and loop “C”,
- loop “B$_{\sim}$”, including elements A3, A4, A6, and A7 and RST.

Loop “B$_{=}$“ has a high gain in the frequency range from 0 to 100Hz (see fig.2), thus ensuring stabilization of the output voltage of the Supply in this frequency range. Loop “B$_{\sim}$”, called a ripples suppression loop, or an active filter, covers the frequency range approximately from 30 Hz to 10 kHz. It is intended to suppress ripples of mains harmonics after the passive LC-filter down to level of 0,02%.

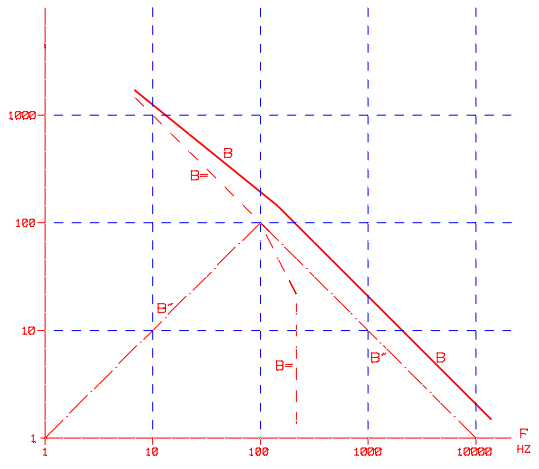

Figure 2: Loop “B$_{=}$“ frequency range.

These two loops together ensure an amplitude-frequency characteristic with a tilt of 20 db/dec. and unity gain frequency about 10 kHz, which ensures stability of loop "B".

A reservation should be made about operation of loops "$B_{=}$" and "$B_{\sim}$": a conditional stability can occur in such structure. Cases of RSA saturation (e.g. at an abrupt jump of control voltage from the DAC output) are possible. In this case, amplification of the ripples suppression channel (loop "$B_{\sim}$") drops; the abrupt roll-off of the amplitude-frequency characteristic of loop "$B_{=}$" leads to origination of large-amplitude self-oscillations in the loop. These oscillations do not decay, even if the primary cause disappears, because the dynamical voltage range of RSA A7 is immeasurably smaller than the range of the rectifier TR. In the automatic control theory such situation is called a conditional stability, or stability in small, i.e. the system is stable at small disturbances and unstable at large ones.

For preventing self-oscillations at large disturbances, we change the loop structure and, correspondingly, its amplitude-frequency characteristic, in order to retain stability. In the control loop of the Supply is has been realized as is described below.

If large-amplitude disturbances arise in the control loop, diodes D1 and D2 are turned on. On the one hand, that prevents amplifier A7 saturation; on the other hand, diodes D1 and D2 turned-on decrease the integrator A6 gain and, therefore, that of loops "$B_{=}$" and "$B_{\sim}$" down to the required value, the control loop remains stable with.

If the large-amplitude disturbance disappears, diodes D1 and D2 are turned off and the former parameters of the control loop are renewed. Thus, the control loop has two operation regimes, of small and of large disturbance. The small-disturbance regime is the normal mode of Supply operation, which secures all its parameters. In the large-disturbance regime, the loop of active suppression of ripples does not work and output voltage pulsations increase up to the level of 1% to 3%.

- Outer loop "A" is a loop of stabilization in the output current of the supply.

Loop "A" includes the following elements: digital-analog converter DAC, error signal amplifier A1, integrating amplifier A2, negative feedback loops "B" and "C" and non-contact current transmitter DCCT. This loop has a high gain in the low frequency range from zero to 10 Hz. Namely this loop secures long-term stability of output current of the Supply.

The combined frequency characteristic of the control loop has a 20 db/dec. drop in the broad frequency range from a few Hz to 10 kHz and, thus, makes it possible to achieve aperiodic transient process at a change of current.

19 IST supplies have been modernized by now: 8 at the "Sibiria" facility, 9 at BINP facilities and 2 at the TNK complex (Zelenograd).