Operating of the Magnet Power Converters for the Cooler Synchrotron COSY - Jülich

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Abstract

All magnet power converters for the cooler synchrotron COSY-Jülich are installed. Most of them are commissioned at the original magnetic load meeting the required tight tolerances within a broad operating area. The paper presents the different installations of dynamic converters for the synchrotron mode. The results of the commissioning of the main converters concerning stability, ripple and repeatability of the output current are shown and discussed.

1. INTRODUCTION

The power converter for the dipole- and for the quadrupole magnets of COSY-Jülich have to meet special diverging requirements as

- operating area: 1% ... 100% of rated value
- stability plus ripple of load current during flat top/bottom $1 \cdot 10^{-4}$ with respect to the set value
- dynamic behavior at nominal load: 100% current variation within 1.6s with a ripple of max. $8 \cdot 10^{-4}$.

Due to the requirements for the dipole magnet system which consists out of 25 single dipole magnets connected in series a power converter is necessary able to deliver 1200 V at 5000 A. The most promising design concept to meet these requirements splits the power converter into two very different parts: a big slow converter is combined with a small fast power controller. To fulfill the necessary power requirements a 12-pulse thyristor controlled bridge acting as a current source is connected in parallel with a fast voltage source providing a voltage necessary at the load for exact current (Fig. 1) [1].

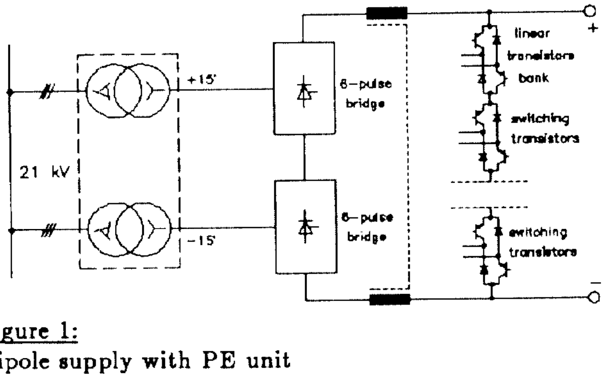

Figure 1:
Dipole supply with PE unit

For the 56 ring quadrupoles a solution is used where always a set of 4 quadrupoles connected in series are powered by one power converter. For each of the 14 quadrupole power converters a 6-pulse thyristor controlled step down stage acting as a voltage source is connected in series with a fast current controller in transistorised switch mode technology.

Commissioning of these two different types of power converters on magnetic loads is discussed in the following including the description of the test setup at KFA in order to have an independent check of the performance achieved.

Commissioning of dipole magnet power converter

The power converter feeds 25 dipole magnets connected in series via a busbar system. The rated load data are L = 300 mH/R = 80 mΩ. The inductance decreases drastically at max. current of 5000 A due to iron saturation to a value of 80 ... 100 mH. The behavior of the load is changing its character from a power consuming device to a source at a current value of about 2.6 kA. This is an additional tough requirement for the power converter at ramping up/down the current is severe especially in our case: the power converter needs two set values for proper operation 1) the (usual) current set value (19 bit resolution) and 2) the set value for the output voltage.

The voltage set value has to be decreased at saturation in order to maintain a constant current slope. Figure 2 shows the measurement on 2 dipoles connected in series. It can be imagined that the required voltage shape has to be gained by an iterative trial and error process. Fortunately it has shown that a current/voltage shape once fixed can be used to reproduce a specific current slope extremely well.

The goal at the final commissioning campaign was to create a voltage shape functioning as a disturbance variable. Thus an adaption of the feedback loop to eliminate continuously corrections could be achieved. Hence it is possible to make use of the very high gain of the fast control loop thus decreasing the remaining deviation to very small values.

In Fig. 3 one can see the dipole current measured via the analog output signal on the power supply front panel (trace 1) . For better resolution of ripple and

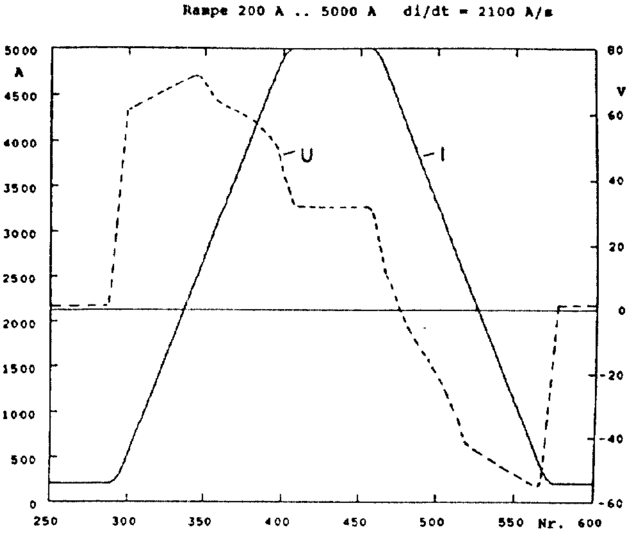

Figure 2:
Decreasing dipole voltage

stability trace 2 indicates the deviation. It is seen that the deviation does not exceed the range of ± 120 mA with respect to the programmed function. The requirements during ramping the dipole current are indicated in Fig. 3 also where the dipole current stays within the limits of $8 \cdot 10^{-4}$. Trace 3 is the output signal of the fast power - unit providing the required tolerances. While switching back and forth in combination with the analog stage the exact output value will accord to the analog input signal. This gives a good valuation of the self controlled switching of this part.

The reference potential ground connection is placed exactly mid load, which means that the 25th dipole magnet is divided into two parts. The measuring head of the DCCT delivering the actual current value for the control of the power converter is placed in the connection of these two part windings as close as possible to ground in order to prevent an influencing by capacitive currents to ground. Due to these connections a very clean current signal is obtained resulting in an extremely stable output current.

Test Setup for an external deviation measurement

The results presented so far were obtained using the internal measuring equipment of the power converter. They deliver some aspects of the operating behavior but a complete picture can be obtained via an independent measurement/comparison only. So an external DCCT was installed at the output of the power converter, the signal of which was used as the "true current" signal. A comparison between the interal DCCT and the external DCCT showed deviations in offset and slope well within some ppm of rated value which is within the allowed tolerances.

The data are recorded by a high resolution DVM which is triggered at each data valid signal obtained during the set value update cycle with a frequency of 10 kHz for the power converter. Thus the digital set value array stored in the computer memory can be compared directly with the actual data array stored in the memory of the DVM. The difference of two corresponding values is the so called tracking deviation. It includes the time delay produced in the control electronics of the power converter and in the power part as well as errors in the signal conversion (DAC) and processing (comparator). This test setup was used during acceptance tests. As an example the tracking deviation of the dipole power converter is shown in Fig. 4. It is inclueneed mainly by a misalignment of the DAC used for the set value when changing a bit at a level of 16 bit or more. The maximum complete deviation is about

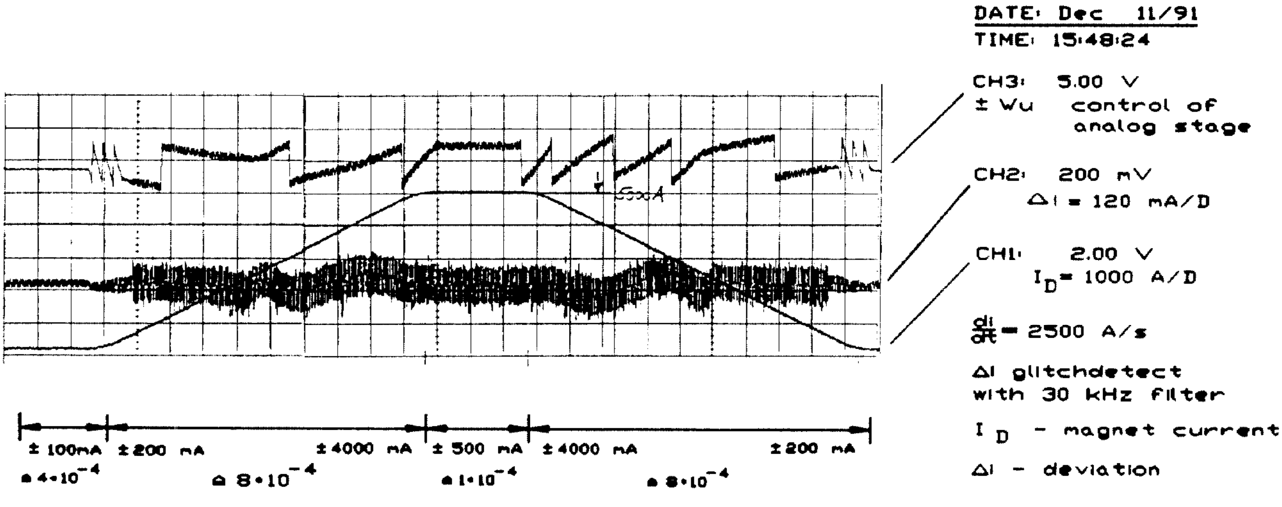

Figure 3:
Dipole measurements

± 50 mA for the dipole power converter. It gives a good valuation of the remaining deviation and accuracy.

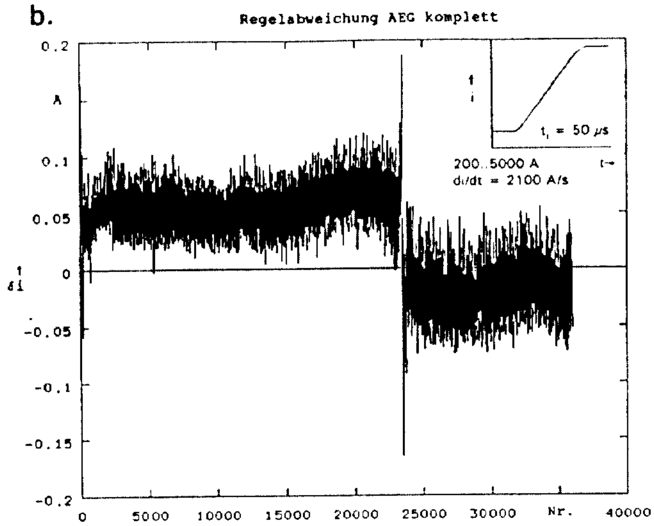

Figure 4:
Complete tracking deviation of the dipole power converter

Quadrupole power converter commissioning

In order to produce a well defined ramping down of the load current the converter has to have an invertor part for feeding back the inductively energy stored to the supply net. This is realized by a 6 pulse thyristor bridge which works at firing angles between 0...90° as a controllable rectifier and at firing angles > 90° as an invertor. The controlled rectifier ability can be used for a coarse preset of the intermediate dc voltage providing for the required small current ripple even at low currents.

The fast current controller consists of 5 2-quadrant switch mode choppers connected in parallel via selected chokes with tight tolerances. Each chopper is equipped with two power transistors being operated in push-pull mode with 30 kHz pulse width modulation each. So the resulting modulation frequency is 60 kHz. The 5 modules are shifted in operation against each other by 72° resulting in an overall modulation frequency of $5 \cdot 60$ kHz = 300 kHz. All quadrupole converters were commissioned on a load consisting of two units-cells magnets and two target cells magnets all conncected in series representing an inductance of 220 mH and a resistance of 260 mΩ.

The commissioning was done in several steps beginning with a coarse adjustment of the thyristor controlled invertors and the associated control loop producing the intermediate voltage. The smaller the difference between intermediate voltage and required output voltage the better the start level for the fine adjustment to be done at the fast current controller. The result of an acceptance test of the quadrupole power converter is shown in Fig. 5.

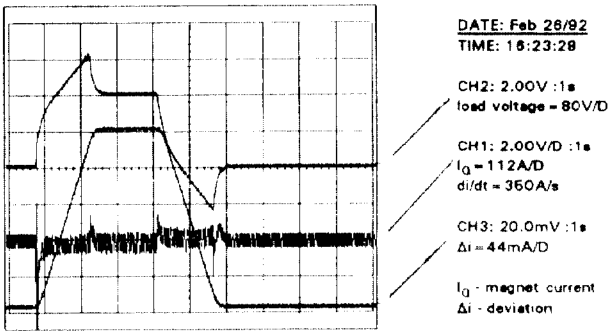

Figure 5:
Quadrupole measurements

The three traces show

- the trapesoidal shaped actual current with soft transitions from/to flat regions to/from ramps (trace 1)
- the intermediate voltage (trace 2). It can be seen that the voltage rises with a step slope due to the soft transitions of the current. The flatter slopes following corresponds to the product of the rising current with the constant ohmic resistance of the load. Besides these two different slopes there are no further changes in the voltage shape; this indicates a constant inductance of the magnetic load; no saturation of iron at all.
- the control deviation (trace 3). It gives a figure of merit about the performance achieved in operation: except of the start points of the transition regions, which are indicated by a jump of the deviation signal, the deviation remains in a band of ± 15 mA equal to $\pm 3 \cdot 10^{-5}$ with respect to the rated current.

In addition to the recording of such internal data similar checks as described above for getting the "true tracking deviation" were carried out on the quadrupole power converters. Except for the start level the recorded deviation stays within the specified limits. It consists of two parts: a well reproducible ramp rising with the current rise and a noise band of ± 10 mA around this ramp. The noise band gives the real error because of the possibility of pre-correcting the error ramp.

2. CONCLUSION

The dynamic power converters for COSY-Jülich are commissioned successfully. They show an operating behavior with error bands much smaller than specified and expected.

3. REFERENCE

[1] R. Fing, R. Wagnits, AEG Berlin, New principle for power supplies for synchrotron magnets without tracking error.