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AN ABSOLUTE CALIBRATOR FOR DCI BEAM CURRENT MONITORS*)

M. Bergher

Laboratoire de l'Accélérateur Linéaire
91405 Orsay (France)

Summary

Beam current monitors owing bunch per bunch measurement have no means of absolute calibration, and a d.c. current transformer (D.C.C.T.) is generally used. The practical application of this well-known method is limited by the D.C.C.T. resolution and zero stability. A simple way to improve these characteristics is presented, and first experimental results are given concerning the device worked out for DCI.

Introduction

Beam current monitors owing bunch per bunch measurement have no means of absolute calibration, and a d.c. current transformer (D.C.C.T.) is generally used to calibrate them.

The basic principle of the D.C.C.T. is well known[1] and mainly consists in a second harmonic modulator. The arrangement is schematically indicated in figure 1 :

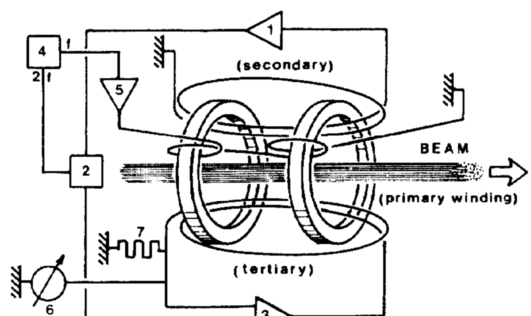

Fig. 1 : Basic principle scheme
1 - Selective Amplifier ; 2 - Synchronous Modulator
3 - V to A Converter ; 4 - Oscillator ; 5 - Modulator
6 - Voltmeter ; 7 - Standard Resistor.

two identical toroidal cores are disposed surrounding the beam line and excited in opposite senses. The voltage induced by the beam current (primary) in a winding common to the cores (secondary) presents a modulation at the second harmonic of the excitation frequency.
A feedback loop is used to cancel this voltage and consists in a high selective amplifier, a synchronous demodulator, a V to A converter, and another common winding (tertiary). The tertiary current, equal to the average beam current for an infinite loop gain, is measured in a standing way.

Circuits of this type are intrinsically slow : the weak amplitude of the modulation, necessary to optimize the response at the second harmonic, leads both to a rather long time constant (a few minutes for a 500 Hz modulation) and to troublesome hysteresis effects. A short time constant would be anyway increased in consequence of the high selective amplification.
When a good zero stability and a large dynamic range are required, a D.C.C.T. has to be associated with some a.c. fast circuit (active L/R integrator[2]). A simple way to improve these characteristics without any additional circuit is presented here.

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Brief Description of the System

In comparison with classical D.C.C.T., two modifications are worked out, concerning the working conditions of the toroidal cores and the selective amplification of the detected voltage.

Working Conditions of the Toroidal Cores

The response of a magnetic modulator strongly depends on the way the ferromagnetic cycle of the cores is described. Let us consider a square symmetrical modulation with a short rise-time. If the modulator impedance is low enough during the rise-time, a full saturation of the cores can be achieved. Then the self-inductance drops and the peak magnetizing current is only limited by the circuit resistance. A modulator was designed for that purpose, and completed by a peak current feedback loop allowing to settle the ferromagnetic cycle while limiting high order odd harmonics and power dissipation of the modulator.

Significant improvements are obtained : the time constant drops from a few minutes (Fig. 2-a) to less than half a period of the modulation (Fig. 2-b) and any memory effect disappears. Furthermore, the weakening of the second harmonic is compensated by an increase of other even harmonics.

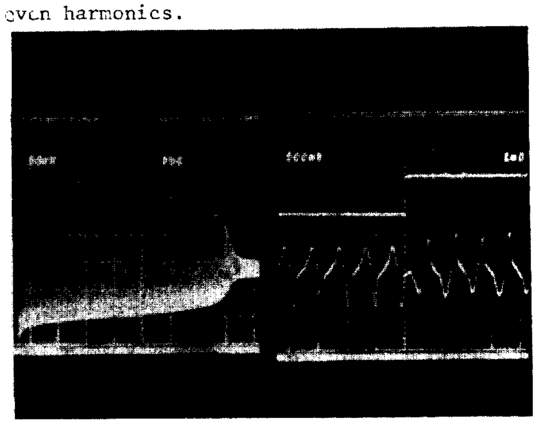

Fig. 2-a : The decay of the second harmonic signal induced by current suppression (Horizontal scale : 25 s/cm)

Fig. 2-b : The first even harmonics signal response to current inversion

Selective Amplification of the Detected Voltage

Up to now both cores were assumed to be identical. Any difference between them induces parasitical signals which have to be rejected if a high accuracy is required. The usual rejection, ensured by selective amplification at the second harmonic, would lead to an increase of the short time constant we have obtained. The parasitical signals at even harmonics, mainly due to modulation asymmetry are strongly reduced by pulse shaping of the modulator input (- 80 dB for the first even harmonics). The rejection of odd harmonics is obtained with selective active dipoles connected to the input of a broad-band amplifier. The secondary winding is connected to the amplifier input through a suitable resistance. The gain between the secondary and the amplifier output is higher than 60 dB for the first even harmonics, and about 1 for the first odd harmonics. The dynamic range at the amplifier output is ± 10 V, with good symmetry and linearity.

In short, for the considered shape signal, the amplification system acts like an aperiodic amplifier, and the time constant only depends on the bandwith. The bandwith must be then adjusted as a function of the modulation frequency.

Synchronous Demodulation and V to A Conversion

Synchronous demodulation and V to A conversion are optimized to preserve the characteristics of the previously described circuits.

Synchronous Demodulation : Without input signal, the d.c. zero stability of the demodulator is less than ± 100 μV. For the considered a.c. gain, a 1 μA beam current gives a detected voltage higher than 1 mV (the voltage sign is given by the current direction). Rejectors corresponding to 1, 3, 5, 7 harmonics are sufficient to obtain a parasitical d.c. voltage much lower than ± 1 mV. The zero stability and sensitivity of the whole systems are then better than 1 μA. The dynamic output range at the synchronous demodulator is ± 10 V.

V to A Conversion : A special filter with 3 dB per octave attenuation is followed by the V to A converter used as an integrator amplifier. Owing to this 3/2 order filtering, the whole feedback loop presents both the advantages of first and second order systems, and none of their disadvantages[3]. The converted current passes through the tertiary. The intensity is adjusted as to cancel the effect of the beam, and then measured through a series resistance. The measurement accuracy is essentially defined by the series resistance and voltmeter quality.

Shielding of the Set-Up : The magnetic shielding is ensured for static and ramping fields up to 100 Gauss. The cores and their shielding are presented on figures 3 and 4.

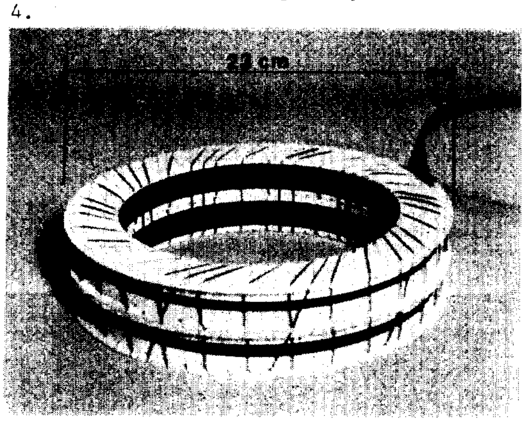

Fig. 3 : The cores with their windings

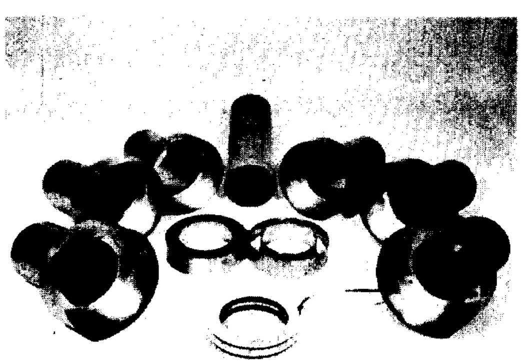

Fig. 4 : The cores and their shielding

The currents in the vacuum chamber are cut off by a ceramic insolator.

For the part of the set-up on the vacuum chamber, the materials were selected to enable 300° baking.

An automatic system ensures the demagnetization at every switching-on.

Obtained Performances

The dynamic range is limited to ± 10 A by the maximum current given by the converter.

The zero stability is better than 1 μA over a week.

Remark : the high accuracy of the system, its low noise level have enabled a straightforward realization of a lifetime monitor.

Conclusion

A beam current monitor owing high sensitivity measurement with excellent zero stability and large dynamic range was realized. The flexibility of the time response is ensured by the choice of the frequency of the modulating signal. For DCI a 500 Hz frequency is convenient.

Tests on time constant dependance versus frequency of the modulating signal were carried up to 100 kHz.

Acknowledgments

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