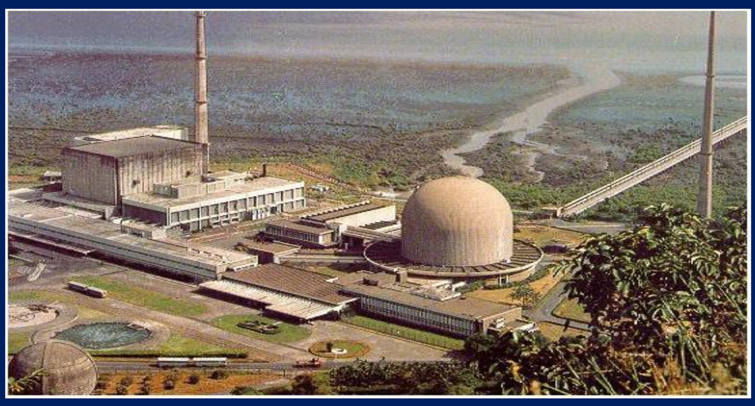
DESIGN AND ANALYSIS OF SECOND HARMONIC MODULATOR FOR DC CURRENT TRANSFORMER



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Introduction

❖ Ion current in a particle accelerator is a key performance measurement parameter.

❖DC Current Transformer (DCCT) is a non-destructive current measuring instrument used in particle accelerators.

❖We have been involved in a project of technology development for Accelerator Driver Subcritical Systems and as a part of development of high resolution DCCT, a second harmonic magnetic modulator for DCCT was designed and implemented.

❖ DCCT is a device which produces even harmonics, predominantly second harmonics corresponding to DC beam current flowing through two toroids.

❖The second harmonics is detected by digital synchronous detector implemented in programmable logic.

❖Current proportional to the detected second harmonic is passed through the toroids in a feedback loop such that the flux due to the DC beam current is cancelled by it. This feedback current is the measure of average beam current.

❖ The high permeability toroid's, excitation and output windings are collectively called magnetic modulator, which is a key component of DCCT.

Design & Development

❖ The toroid cores used for magnetic modulator are made up of amorphous magnetic alloy tapes. Core dimensions were decided according to the beam pipe diameter. Based on BH curve and permeability curve, the operating frequency and number of turns for excitation coil winding were selected. The mismatch in excitation windings were adjusted by adjusting the turns.

❖ A sinusoidal excitation signal of 10 kHz frequency with the help of programmable logic and 16 bit DAC module was generated. DAC output was filtered and amplified with power amplifier.

❖ The second harmonics of the modulator output was extracted by a digital Lock-in Amplifier implemented in programmable logic. Hardware also detects the phase of second harmonics and it was adequate for the control action and feedback loop implementation.

❖ A digital PID controller was implemented using programmable logic. Final PID output was fed to the amplifier which provides a current in order to nullify the effect of beam current.

Second Harmonic Modulator

❖Two identical cores arranged in series opposition manner so that the odd harmonics would cancel each other.

❖ In practical conditions, imperfections in core matching and the presence of even harmonics in excitation signal causes zero error in magnetic modulators. The earth's magnetic field and any other stray fileds, thermal e.m.f.s in circuit connections are the other causes of zero error and drift. The zero error caused by memory effects is removed by proper demagnetization.

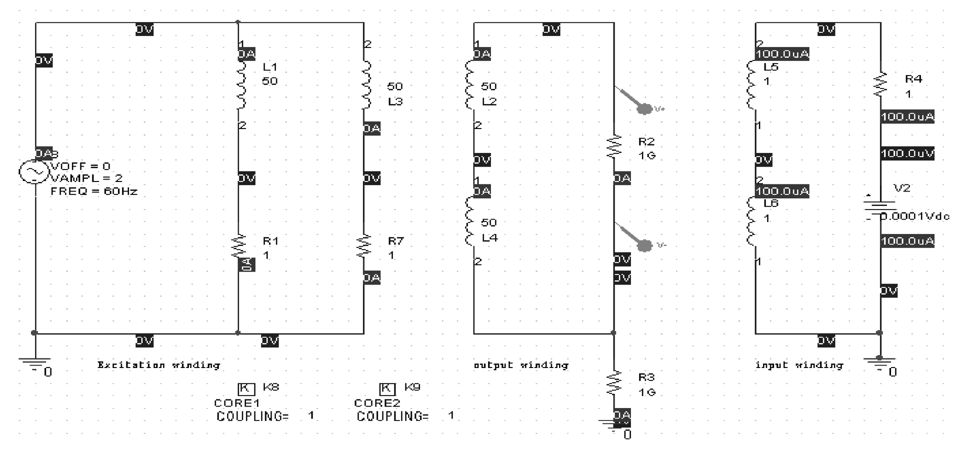
❖Magnetic properties of the cores are the main factors which determine the resolution and the zero stability of the instrument.

❖Toroidal cores were characterized and selected matched pairs by matching BH curve and permeability characteristics.

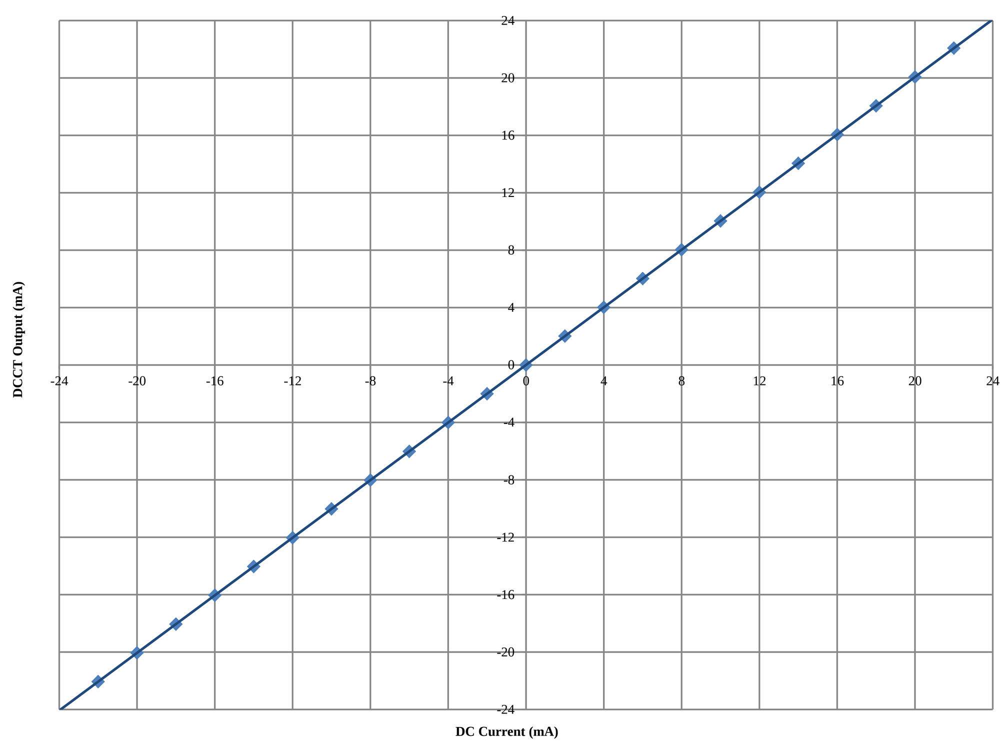
❖ The selected toroidal cores were modelled in PSPICE based on Jiles-Atherton model of a ferromagnetic core.

❖If two cores are identical the combination doubles the even harmonic output components and reduces the odd harmonic output components to zero.

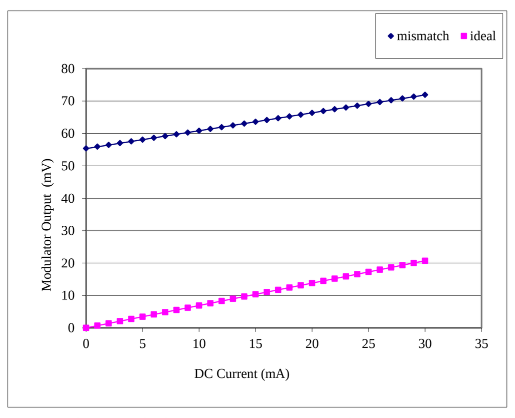
❖ If the cores are non identical, odd harmonics and hence a non-zero voltage appears in the modulator output even if it is operated with zero input signal.



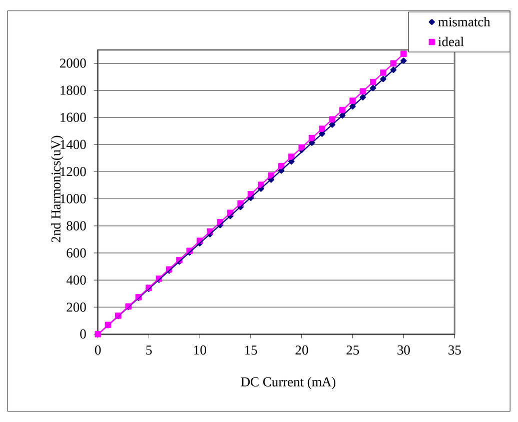
Magnetic modulator circuit



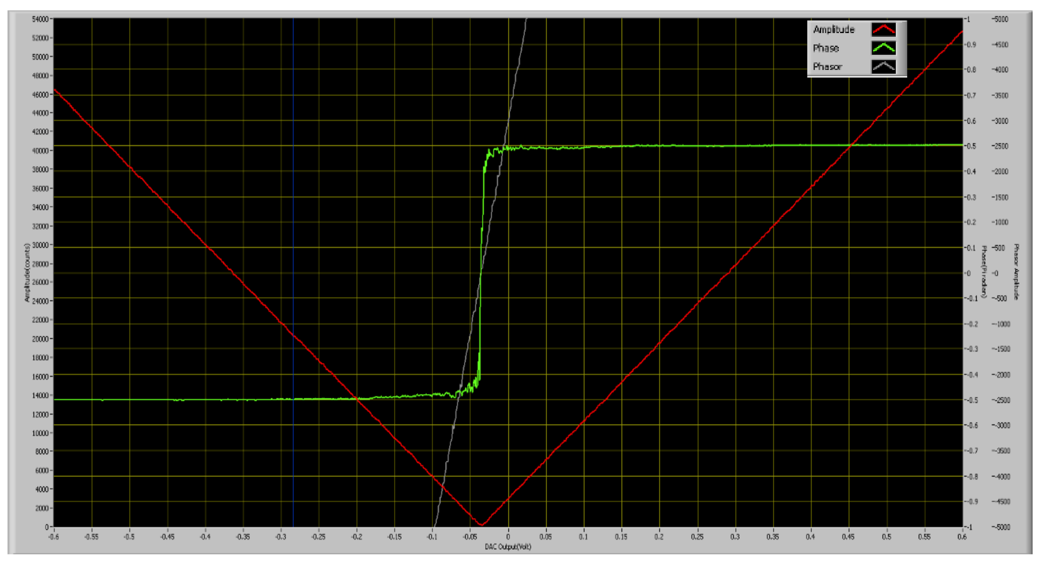
DCCT output vs. input DC current



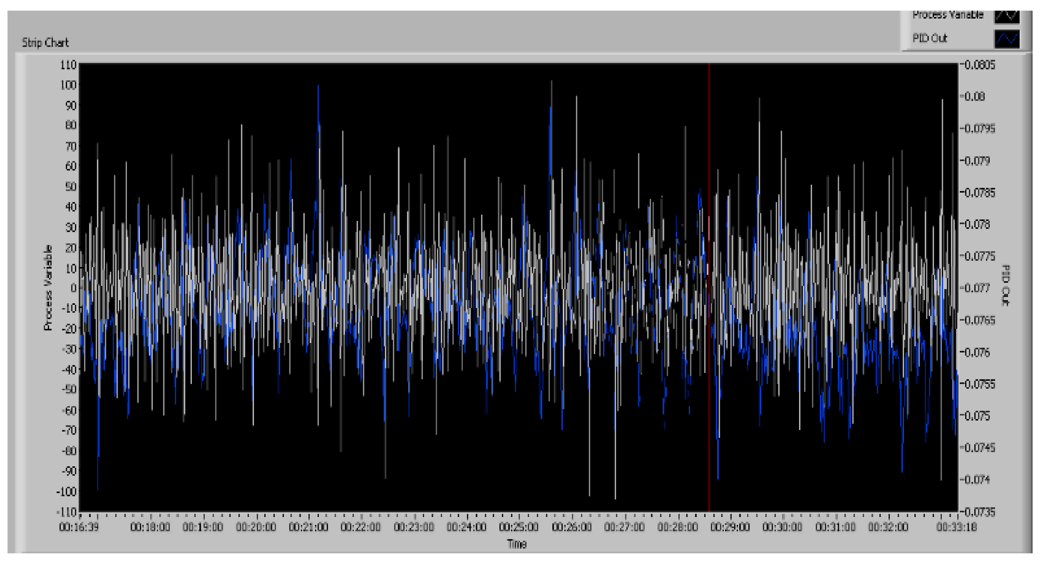
Peak modulator output vs. input signal



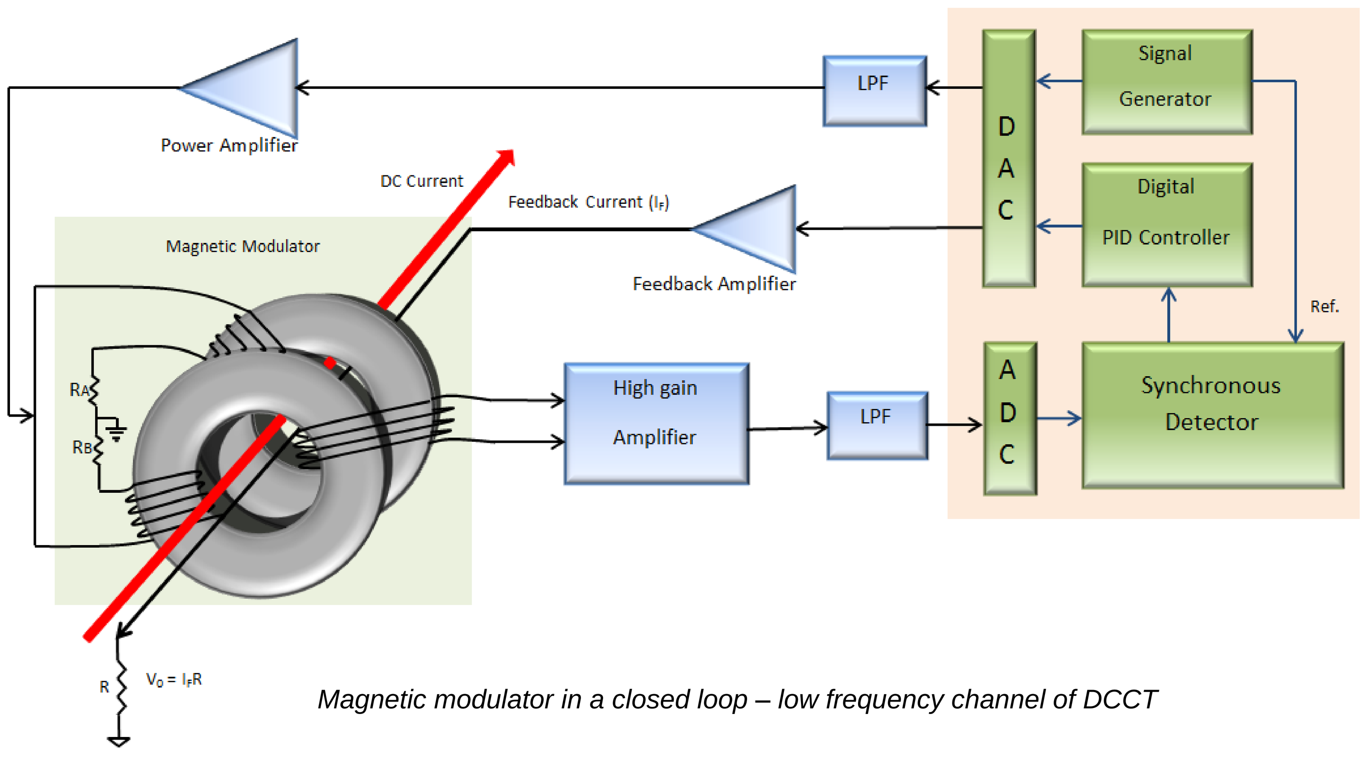
Second harmonics output vs. input signal



Open loop transfer curve of second harmonic modulator



PID output for zero input signal



Magnetic modulator in a closed loop – low frequency channel of DCCT

Results & Conclusions

The magnetic modulator was tested with both primary and secondary side pick-ups. Primary side output was taken across the series resistors R_A and R_B and summed up by an instrumentation amplifier.

In secondary side pick-up, the output was directly taken from the output winding.

The modulator having secondary side pickup showed better common mode rejection and fundamental harmonic suppression than that of primary side.

The memory effect observed in the transfer curve was reduced by proper adjustment of excitation voltage.

There is noise below 30 µA is visible. DCCT implemented with the second harmonic modulator was tested in laboratory with the help of a calibrator kit which is capable of supplying DC current with a resolution of 1 µA.

We achieved a 30 µA resolution of measurement in the range of ±30 mA. Bandwidth of the measurement was DC to 0.1Hz.

Acknowledgment

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