PULSED INTEGRATING FEEDBACK AMPLIFIER POSITION CONTROL OF INTERMEDIATE ENERGY PROTON BEAMS

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In a parity violation study at TRIUMF steering magnets are used to keep a proton beam axis stable at the micrometer and microradian levels. A pulsed integrating feedback amplifier was developed to provide a high gain, oscillation-free feedback signal. An alternating mode of operation decouples two loops controlling the same quantity. To discount deliberate beam interruptions the amplifier operation is 'frozen'. In the absence of beam the feedback is disabled and output set to zero.

1 Introduction

Positional and angular beam stability to a few micrometers and microradians, respectively, are required in a parity violation measurement at TRIUMF using a 222.4 MeV polarized proton beam. Similar requirements have been addressed differently in other parity violation work. [1]

In the present transmission experiment, beam profile measurements and beam control are complicated by interruptions due to polarimeter target blades passing through the beam upstream. During the blade passage the signals from the split-plates are not proportional to the deviation of the beam from the central, or desired, trajectory - and so should be ignored.

Beam control begins with beam position data from an intensity profile monitor, comprising a vertical and horizontal set of harps, and vertical and horizontal split-plates. Steering is only based on split-plate data. Each movable thin foil split-plate provides two signals from which a difference signal is derived and then used as a beam centroid position indicator. The feedback system attempts to minimise all the difference signals by moving the beam to the centres of the split-plates. The beam position on target is controlled by manually adjusting the split-plates (to 1 μm).

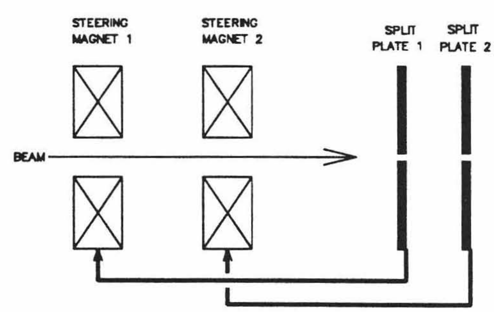

Figure 1: Diagram of coupled loops in one plane. The diagrams are identical for horizontal and vertical planes.

The difference signals from the split-plates are passed, via a four-channel amplifier, to controllers of

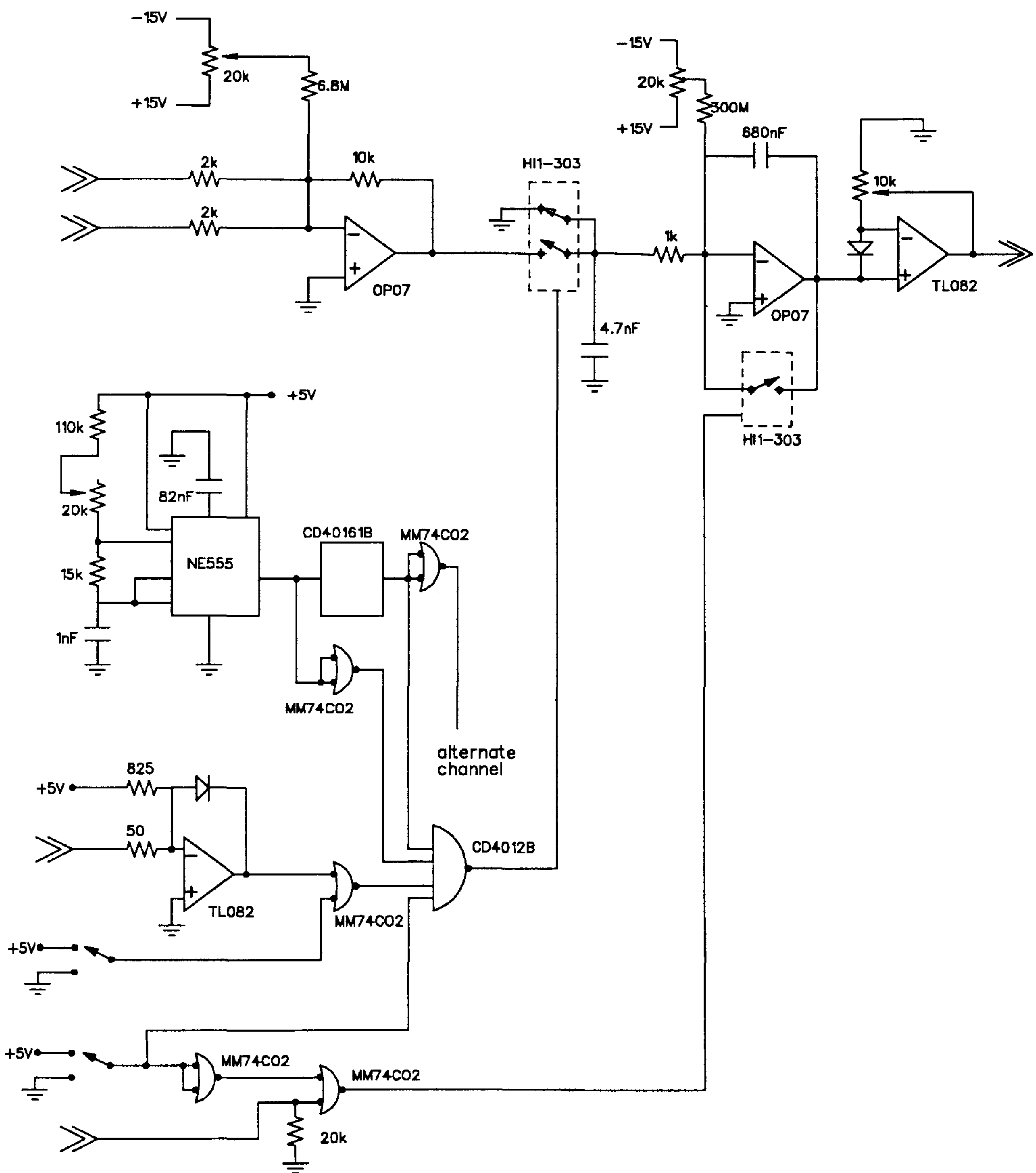

Figure 2: Circuit diagram for a pulsed integrating feedback amplifier (PIFA).

power supplies of ferrite-core steering magnets. Both magnets have independent vertical and horizontal steering coils, hence the four channels. All the steering is upstream of all the split-plates. Horizontal (vertical) steering in both magnets can be used singly to provide the same beam position control, but both are needed for horizontal (vertical) angle control. See Fig. 1 for a diagram for one plane.

The feedback amplifier is a pulsed integrating feedback amplifier (PIFA). We describe its design and operation in Section 2; performance in Section 3.

2 Design and Operation

The basic design is relatively simple. An input amplifier stage, followed by a relay, feeds into an analogue integrator. The integrator output is passed to a voltage gain output stage. An internal clock and two input circuits are fed into a CD4012B NAND gate which controls the relay. Special features of the design will be discussed later. One of the four channels of the PIFA is shown in Fig. 2.

The difference signal from the split-plate is amplified in the input stage. To compensate for charge injection by the following relay switch, a potentiometer is included. It is set manually before routine operation.

The amplified signal is then fed to the integrator through a relay switch which is controlled by the NAND gate. The inputs to this gate are from an internal 10 kHz clock, an input circuit which 'freezes' the output of the PIFA, and an input circuit which resets the PIFA output to zero.

In the present application the freezing of the output is activated when a polarimeter blade passes through the beam, invalidating the split-plate difference signal as an indicator of beam position. This allows for steady beam positions despite an interrupted input signal from the split-plate. Fig. 3 shows the output signal from the amplifier as a function of time. The quiet periods during blade passage every 25 ms can clearly be seen. A blade interruption lasts approximately 8ms. The PIFA output may be frozen manually for adjustment purposes.

In the present work the reseting of the output to zero is activated in the absence of the beam. This is to prevent magnet power supply overheating. A voltage level indicating the presence of beam is fed to the PIFA. To ensure the PIFA output drops to zero, this signal is also fed directly to a relay switch in the amplifier. There is a manual reset switch.

Charge is only integrated when the beam is on, there are no blades in the beam and the clock signal is present. The clock signal in a channel comes every 200 μs and lasts about 75 μm. The clock frequency was chosen to match the response time of the steering magnet fields. It is adjusted using a potentiometer. [Noise in the beam is mainly below 1kHz and biased to the lower frequencies.]

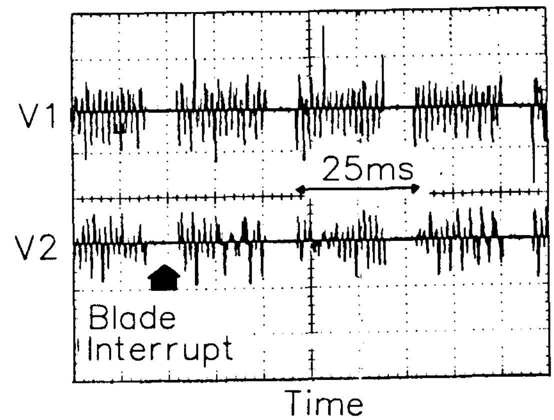

Figure 3: The output voltage of PIFA showing its inactivity during polarimeter blade passages every 25 ms.

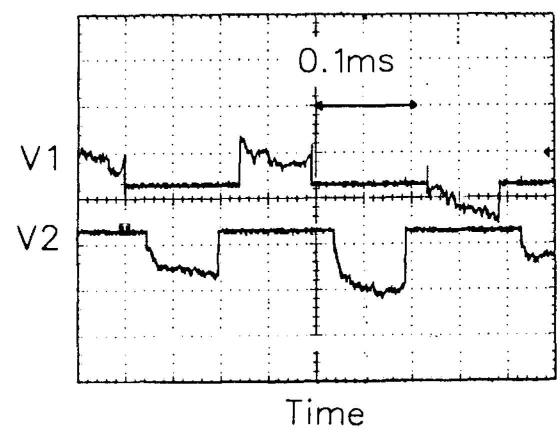

Figure 4: Output voltage of the two PIFA channels controlling steering in the same plane, showing the alternating of beam position correction between the two steering magnets. The clock frequency is 10 kiloHertz.

To allow settling of the fields before applying another correction the PIFA was designed to have clock pulses alternate between two channels which drove steering in the same plane by different magnets. When the relay is open for the other half of the period, the relay in the other channel is closed. This stabilization feature prevents runaway corrections to beam digressions which can cause inadvertent beam spills. Operating magnet power supplies with rapid changes in polarity could result in tripping or damage. Fig. 4 shows the output voltages for two channels controlling the same plane.

A potentiometer in the integrator compensates for small input leakage currents. This stabilizes the output when in the frozen mode and is set before routine operation.

While the relay stays closed charge is integrated. A proportional signal is continuously sent to the voltage gain output stage. This allows smooth ramping of the output to the required value needed to eliminate the deviation.

Finally, in the output stage the signal is amplified. The gain of this stage is set manually during normal operation so that the signal size falls comfortably in the range expected by the power supply controller.

3 Performance

The PIFA was tested with a 100 - 200nA proton beam. A marked improvement in beam stability was observed both horizontally and vertically. Fig 5. shows the beam position as a function of time. Deviations of a few millimetres are quite common but for demonstration purposes this offset was removed artificially to allow one to more clearly see the noise levels with the PIFA on and off. The horizontal and vertical behaviours are similar. Without feedback typical deviation variations are up to 100 μm. With PIFA the deviations are reduced to about a micrometer with a variation slightly larger. A deviation of 1μm at both split plates translates into a width of 4μm at the target. This is an angular stability of 1μrad. It should be noted that steering with a few millimeters offset is at the limit of the PIFA, and it is advisable to steer the beam as well one can beforehand.

The frequency power spectra with and without the PIFA is shown in Fig. 6. A 35dB reduction is achieved at 10 Hz; 20dB at 50Hz. Both slow and rapid deviations of the beam are well controlled, as can be seen in Fig. 4.

The successful operation of the PIFA in a beam control application has led to its development for use elsewhere. The system was made from fairly standard components. Stable beam control to the few micrometer and microradian levels were achieved.

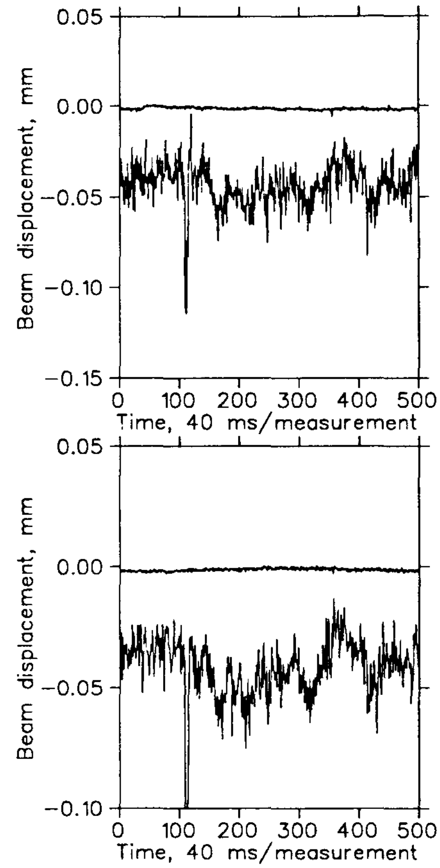

Figure 5: Horizontal(top) and vertical(bottom) beam position deviation from the central trajectory plotted as a function of time. In both cases the smoother, upper trace has PIFA feedback control; the lower trace not.

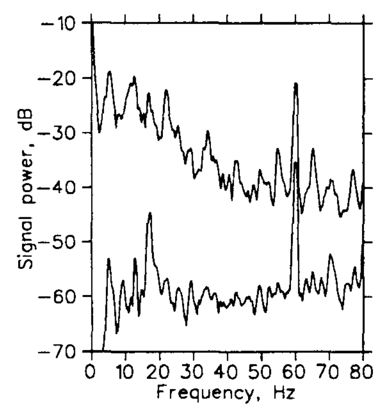

Figure 6: Power spectra for the system as a function of frequency. The lower curve is with PIFA control; the upper not.

Acknowledgements

We wish to thank the Natural Science and Engineering Research Council of Canada for its support. This work was supported in part by a grant, RFFI#94-02-03091-a, from the Russia Basic Research Foundation.

Reference

1. P.D. Eversheim, R. Gebel, H.W. Schmitt and F. Hinterberger, private communication.