The University of Leicester
Department of Engineering

EG2003: Experimentation 2

Laboratory Session: Control Systems Experiments

Semester 2

EXPERIMENT: THE BALL AND BEAM CONTROL EXPERIMENT

CAUTION

For safety purpose, please do not start using any apparatus until the demonstrator has explained the equipment and the experiment.

EXPERIMENT: THE BALL AND BEAM CONTROL EXPERIMENT

1.1 Risk Assessment

- Do not start using the apparatus until the demonstrator has explained the equipment and the experiment.
- Keep clear of the moving beam which extends beyond the base of the apparatus, at all times.
- Ensure the lead to the motor drive (for details see wiring layout diagrams) is disconnected while setting the equipment.
- If during the course of the experiment the beam starts to exhibit excessive oscillations, remove the lead to the motor drive.

1.2 Apparatus

- 1 x Ball and Beam Apparatus (CE106). The picture of this is shown in Figure 1.1
- 1 x Controller Board (CE120). The picture of this is shown in Figure 1.2
- 1 x Storage Oscilloscope
- Assorted leads

1.3 Introduction

The ball and beam system is a very popular and important laboratory model for teaching control systems engineering. This system has been widely accepted across many institutions in the world because, not only is the system simple to understand, it can be used to study many classical and modern control systems theory. Importantly, it is an open loop unstable system and in this laboratory session, we shall investigate how to use feedback control techniques to stabilise the system and to improve the performance of the system.

1.3.1 Ball and Beam System: Application Areas

It is very important to study the control of unstable systems in the laboratory because many such systems exist in the real-world. These real-world systems are usually dangerous and therefore cannot be brought into the laboratory. Thus, the ball-and-beam experiment is a test-bed for the control of unstable systems such as temperature in exo-thermic chemical reactions or thrust angle of a rocket during vertical take-off, among others.

1.3.2 Control Objective

Figure 1.3 shows a simple ball and beam system. The output shaft of an electric motor mounts a beam which is tilted about its centre axis by applying an electric control signal (in the form of voltage) to the motor amplifier. The angle of tilt of the beam as well as the position of a ball on the beam can be measured using special angle and position sensors, respectively.

The objective is now to design a controller such that the ball is accurately placed at any desired location on the beam. There are many techniques that can be employed for the design of this controller such as the Proportional-Integral-Derivative (PID), Linear Quadratic Regulator, Control, Fuzzy control methods, among others. In this laboratory session, we shall move step by step towards designing a PID controller for the ball and beam system. More details on PID controllers can be found on the extra sheets provided to you in this lab session. In particular, we shall design a PD controller (a PID controller with the integral gain set to zero) for the ball and beam system.

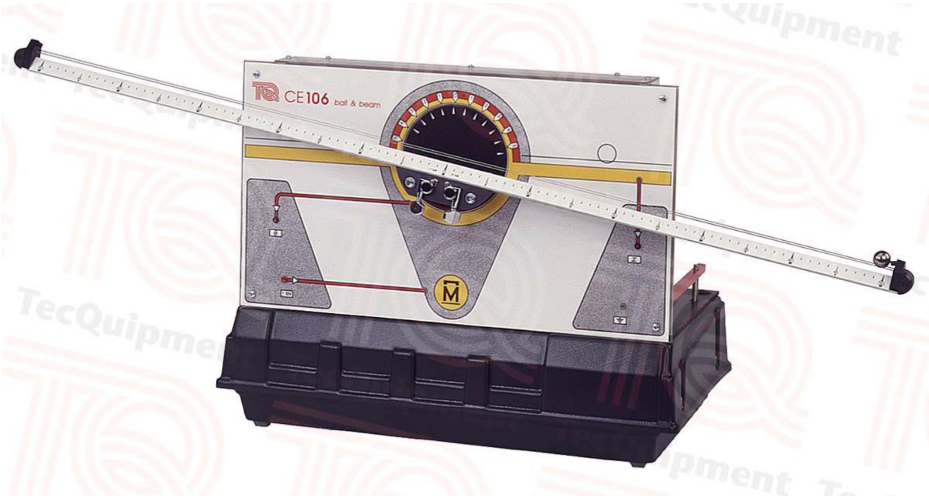

Figure 1.1: Picture of a Ball and Beam Apparatus (CE106)

Figure 1.2: Picture of a Controller Board (CE120)

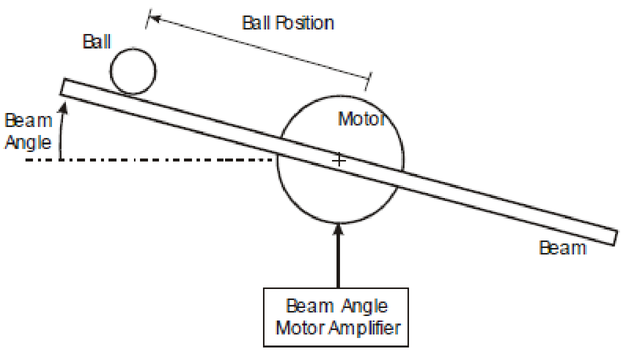

Figure 1.3: The Ball and Beam System

1.4 Set-up and Calibration

An elaborate diagram showing the front panel of the controller board is shown in Figure 1.4. Figure 1.5 shows a connection of the ball and beam apparatus to the controller board.

Remove the ball from the beam and connect the equipment as shown in Figure 1.5. Set the potentiometer to zero volts. Use the potentiometer to adjust and drive the motor to tilt the beam at different angles. When the beam is horizontal, read the *beam angle transducer output*, it should read approximately zero, adjust the beam angle sensor to zero if necessary.

Next, connect the equipment as shown in Figure 1.6. Place the ball on the beam at 10 cm intervals, read the *ball position transducer output* from the voltmeter and tabulate the results.

1.5 Proportional Control

1.5.1 Beam Angle Control

With the ball still removed from the beam, connect the equipment as shown in Figure 1.7 with initial settings as follows:

- Function Generator to square wave output, frequency 0.1 Hz
- Level zero and offset zero
- Proportional gain = 1

Slowly increase the function generator level to 2V. Now, connect the equipment as shown in Figure 1.8. Monitor the beam response relative to the reference signal using the oscilloscope.

Quizzes

1. What effect does increasing the value of K_p (up to a maximum of 8) have on the system with respect to steady state error and speed of response?

2. What is the function of the summing amplifier?

3. With reference to the beam angle control system, what is meant by the term feedback control?

4. Why is the beam angle signal connected to the negative input of the summing amplifier as opposed to the positive input?

1.5.2 Manual Ball Position Control

Connect the equipment as shown in Figure 1.9. Set the potentiometer to zero. Place the ball on the beam at the centre. Attempt to move the ball to the positive 40 cm mark and stabilise the ball within approximately 12 seconds and then move the ball to the negative 40 cm mark and stabilise again within 12 seconds. Repeat the process.

Quiz

5. Briefly explain what the equipment is set up to do and what part the person adjusting the potentiometer plays in the control loop.

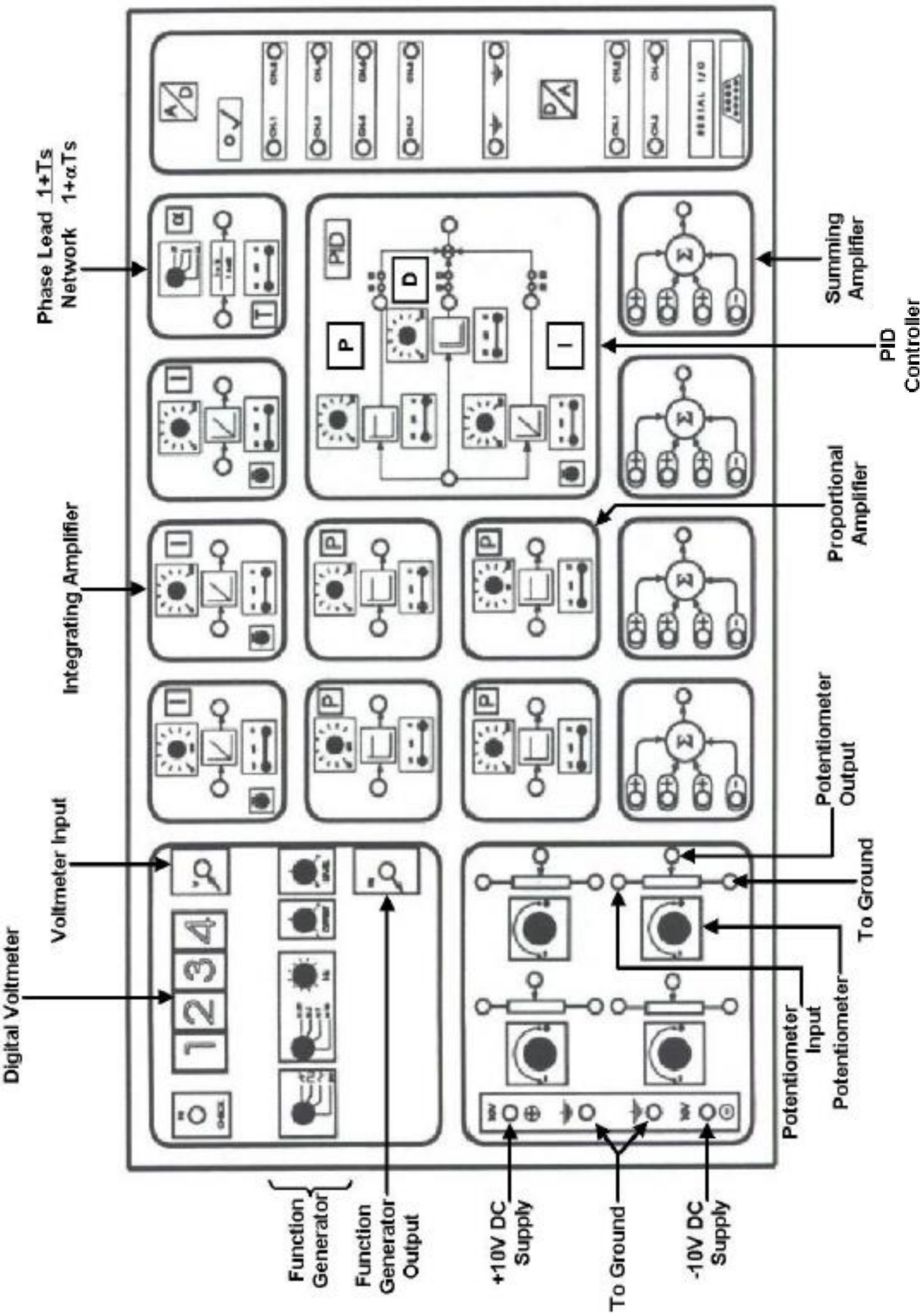

Figure 1.4: Diagram of the front panel of the controller board

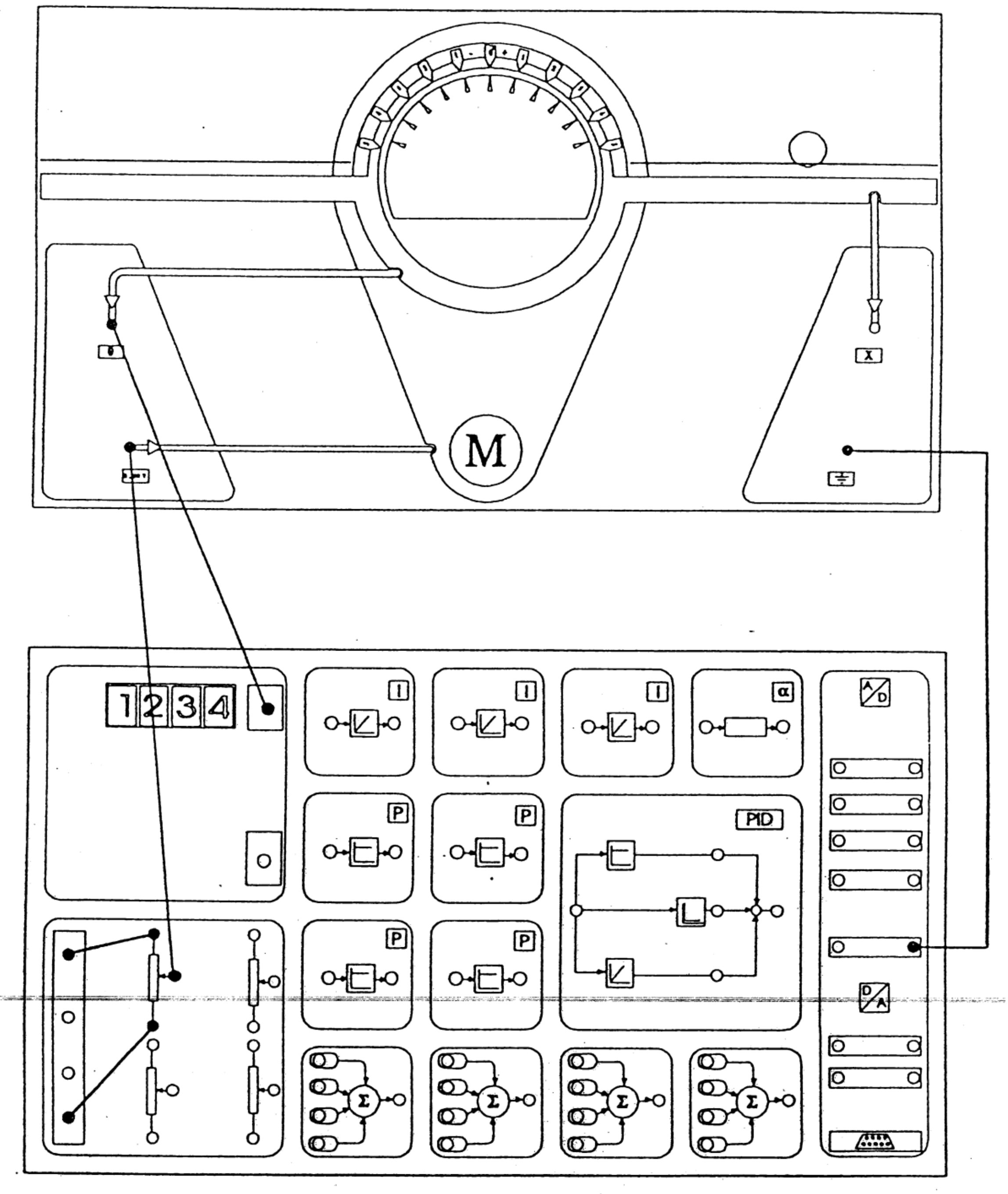

Figure 1.5: A connection of the ball and beam apparatus to the controller board: Calibration of the beam angle transducer

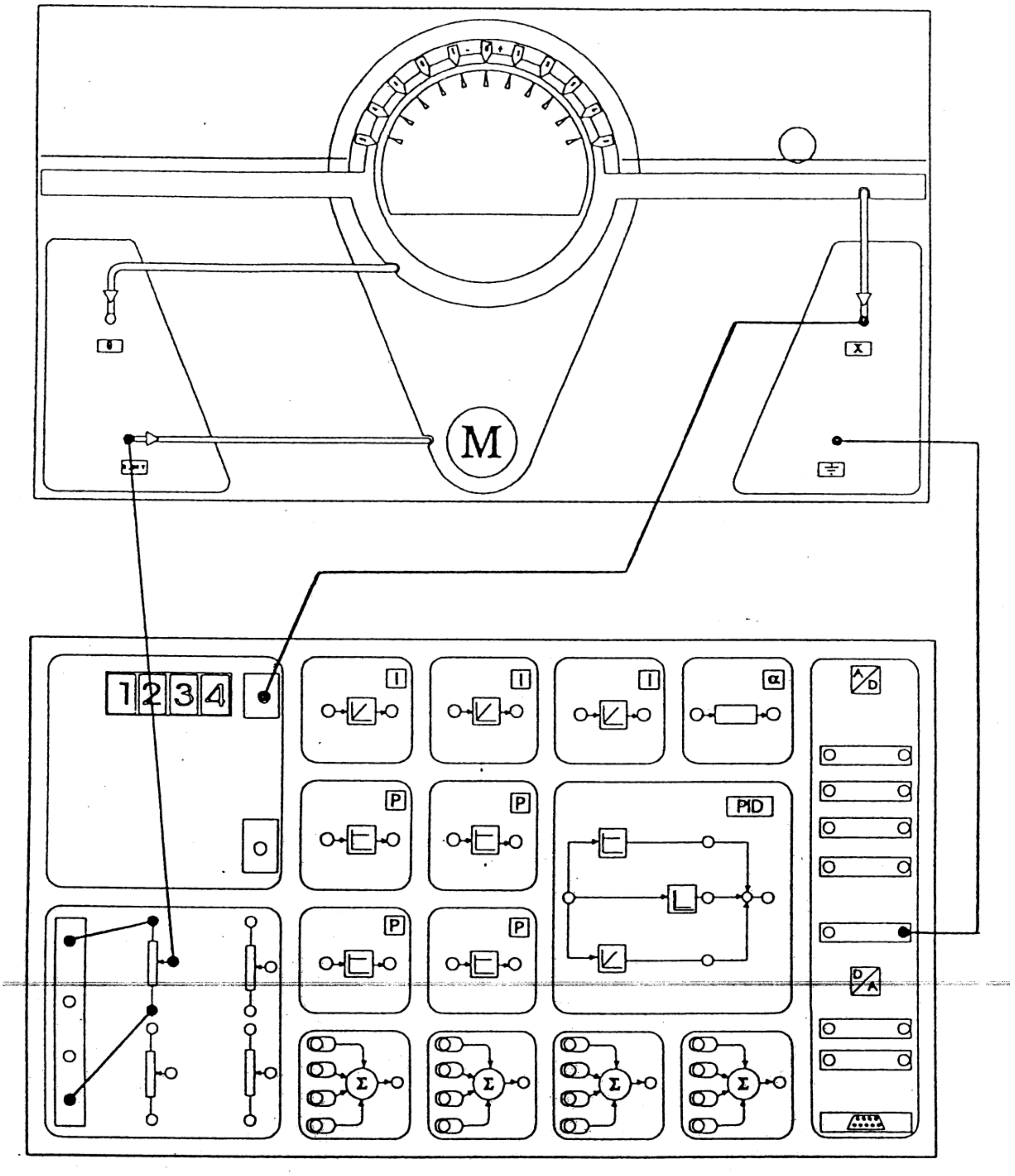

Figure 1.6: A connection of the ball and beam apparatus to the controller board: Calibration of the ball position transducer

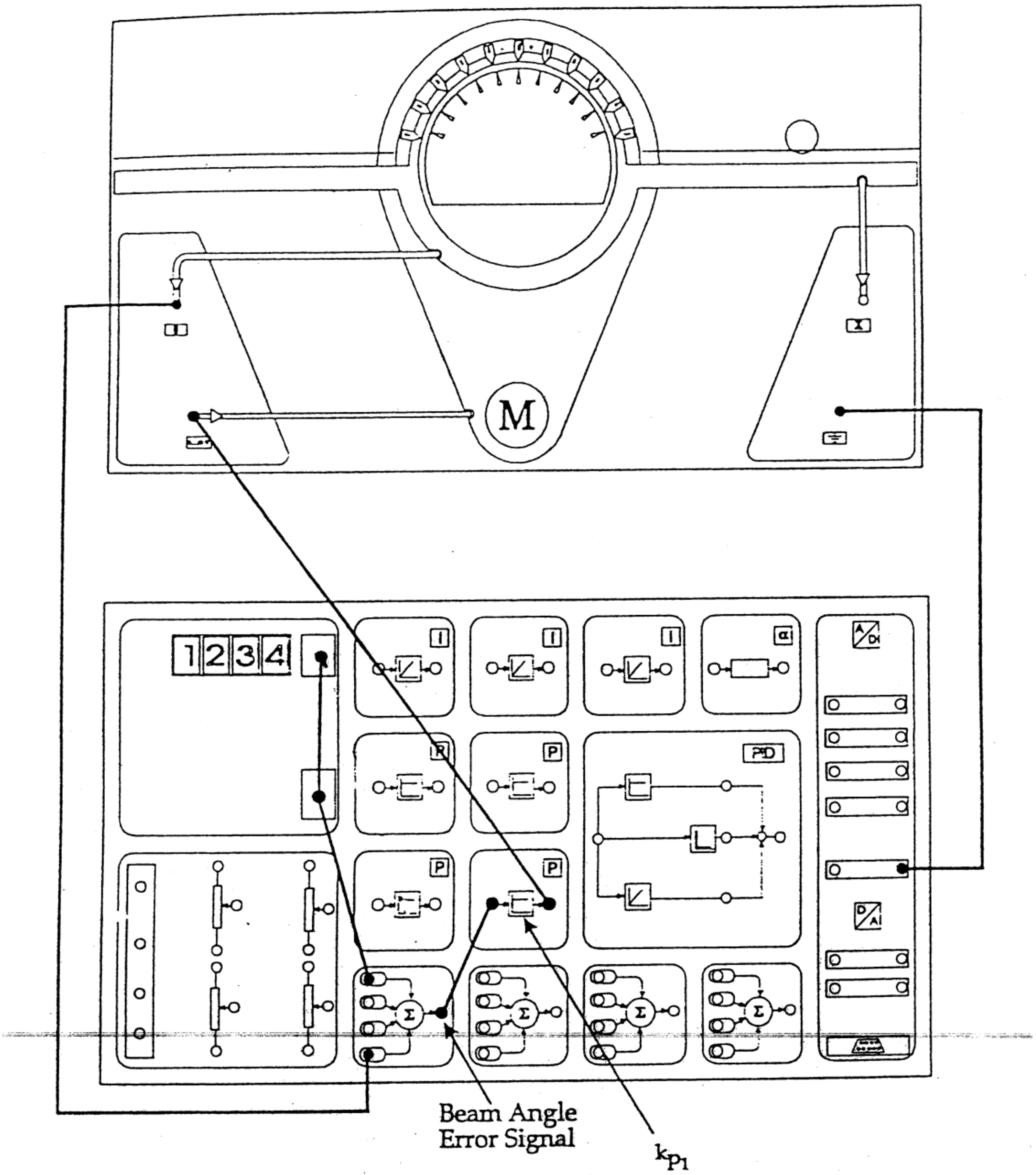

Figure 1.7: A connection of the ball and beam apparatus to the controller board: Beam Angle Control – Experiment 1

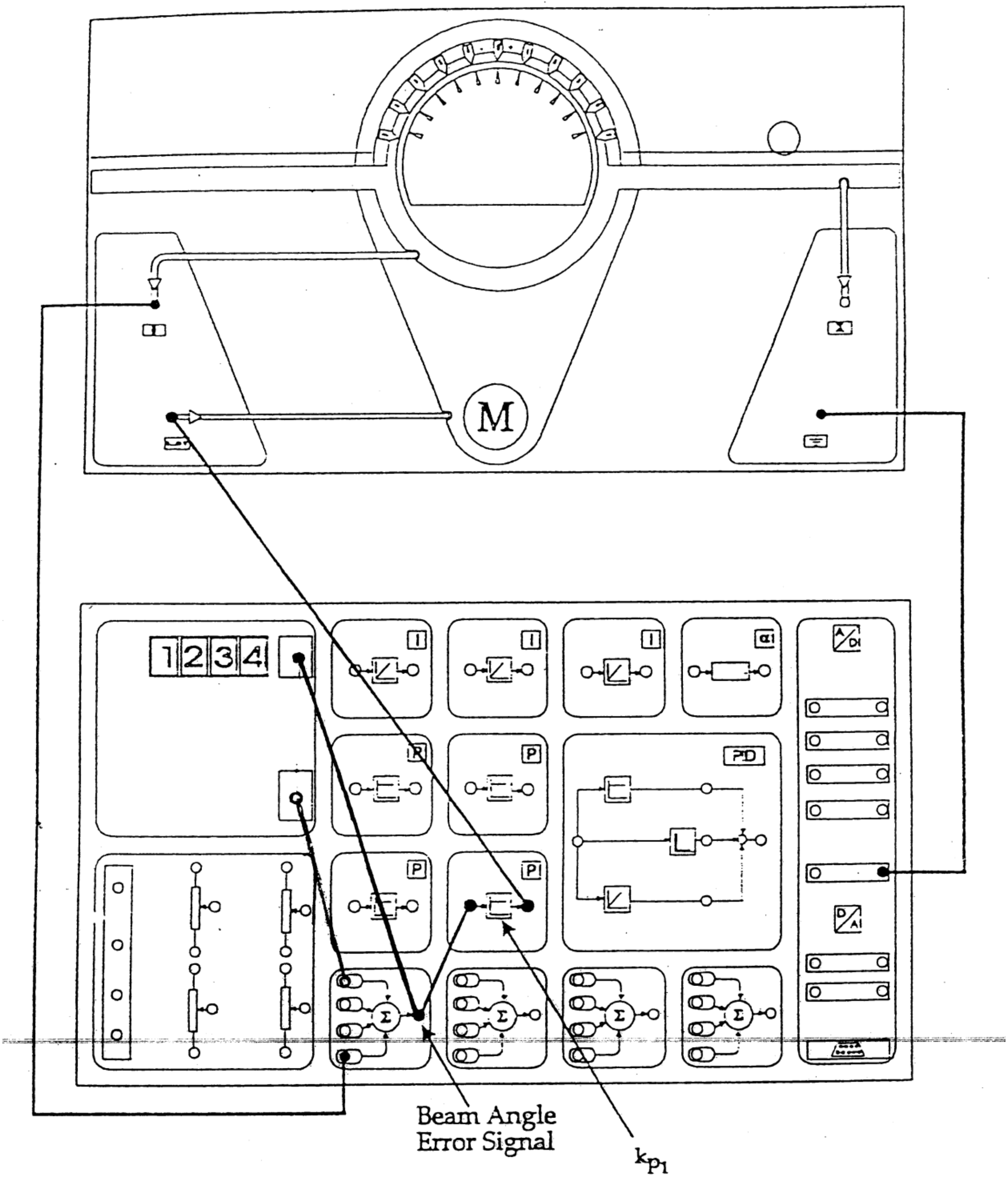

Figure 1.8: A connection of the ball and beam apparatus to the controller board: Beam Angle Control – Experiment 2

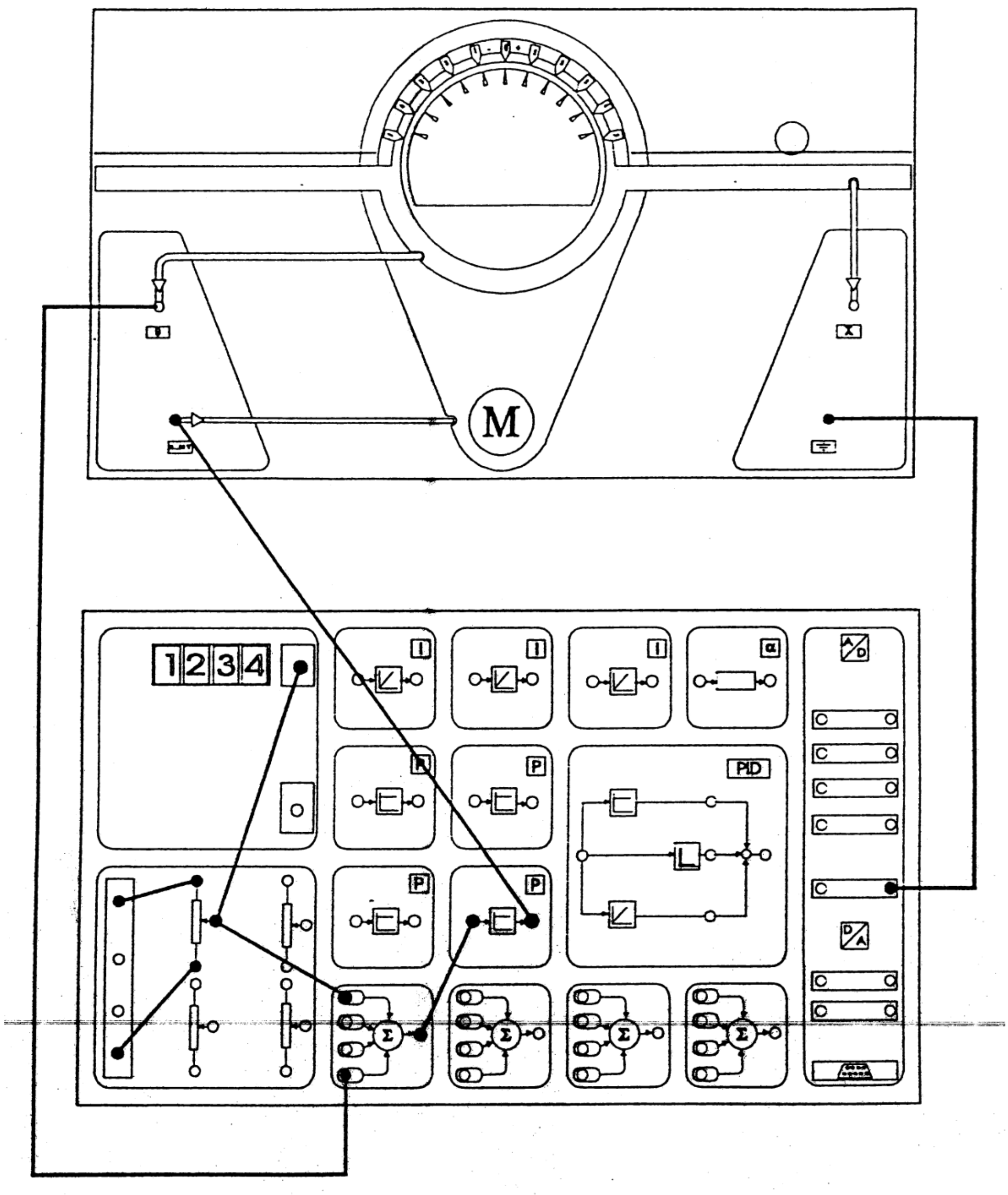

Figure 1.9: A connection of the ball and beam apparatus to the controller board: Manual Ball Position Control

1.6 Proportional – Derivative (PD) Control of Ball Position on the Ball and Beam System

The block diagram for the ball and beam control system that uses a PD controller is shown in Figure 1.10. The implementation of this control system using the ball and beam apparatus and the controller board is shown in Figure 1.11. Connect the equipment as shown in Figure 1.11 with the following initial settings:

- Potentiometer 0V
- Beam angle controller gain $K_{p\theta}$ = 8
- Proportional gain of the PID block K_{px} = 0.5
- Derivative gain of the PID block K_d = 0.5
- High frequency filter K_I = 4

1.6.1 Ball Position Control

Use the potentiometer to vary the reference ball position.

Quiz

6. Why is ball position control easier with the equipment set in this mode as opposed to the manual control method of Section 1.5.2?

1.6.2 Ball Position Control using a Dynamic Reference Signal

Disconnect the potentiometer and connect the function generator to the summing amplifier using the following initial settings:

- Square wave output, frequency 0.04 Hz
- Level 0 and offset 0

Place the ball at the centre of the beam and slowly increase the function generator level to a magnitude of 4V. Use the oscilloscope to monitor the ball position with respect to the reference signal.

Quizzes

7. With K_p set at 0.5 and K_d set at 0.5, comment on the system performance with respect to overshoot, rise time, settling time and steady-state error.

8. Increase K_d to 0.7, what effect does this have on the system?

9. Increase K_d to 1, comment on the system performance with respect to overshoot, rise time, settling time and steady-state error.

10. How does the system respond with K_p set at 0.1 and K_d set at 1?

11. How does the system respond with K_p set at 1 and K_d set at 0.1?

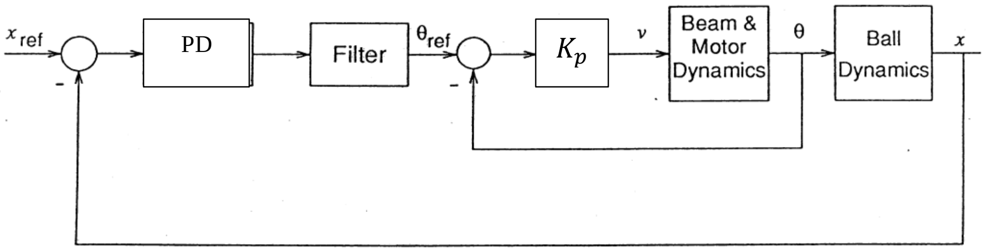

Figure 1.10: A block diagram of the ball and beam control system with a PD controller

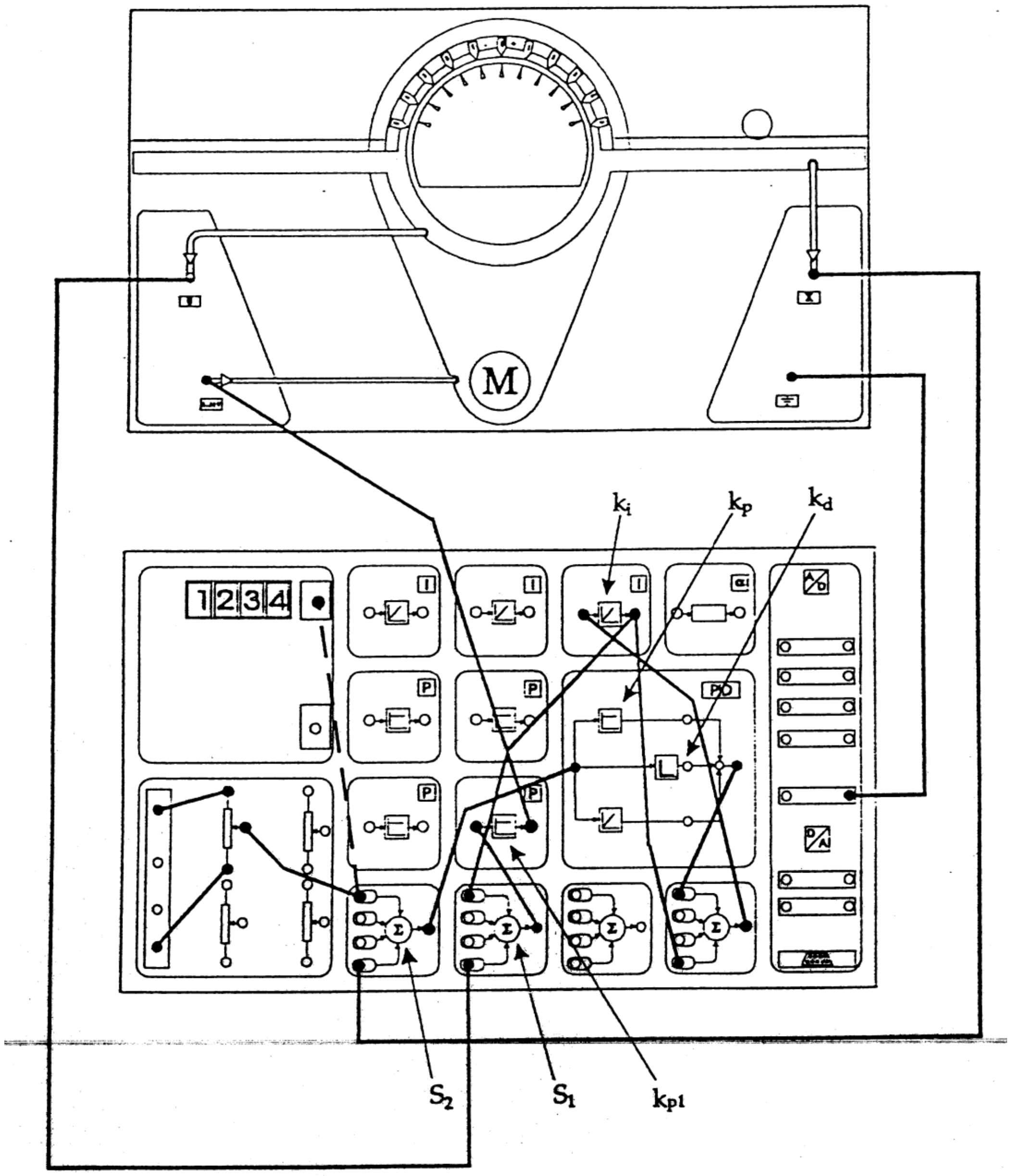

Figure 1.11: A connection of the ball and beam apparatus to the controller board: Position Control with a PD controller

References

[1] P. E. Wellstead, Introduction to Physical System Modelling. London: Academic Press Ltd, 1976.

[2] P. E. Wellstead, V. Crimes, P. R. Fletcher, R. Moody, and A. J. Robins, "The ball and beam control experiment," Int. J. Electr. Eng. Educ., 1977.

[3] R. C. Dorf and R. H. Bishop, Modern Control Systems, 8th ed. Addison-Wesley Longman, Inc., 1998.

[4] P. E. Wellstead, "Ball and Beam 1: Basics." [Online]. Available: http://www.control-systems-principles.co.uk/whitepapers/ball-and-beam1.pdf. [Accessed: 06-Jan-2014].

Information Source: Figures 1.1, 1.2 and 1.3 are taken from manuals and website of the manufacturer (TQ TecQuipment Ltd, Nottingham UK: www.tecquipment.com) of the ball and beam laboratory apparatus.