APPLICATION EXAMPLES OF THE

KRi Inverted Pendulum PP-300

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KRi Inverted Pendulum PP-300

IMPORTANT NOTICES

Acknowledgements

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TABLE OF CONTENTS

TABLE OF FIGURES

APPLICATION EXAMPLES FOR THE *KRi* INVERTED PENDULUM PP-300

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OVERVIEW

This note has been prepared to guide the user on applications of the *KRi* Inverted Pendulum PP-300. It describes four example applications of the apparatus for teaching or research in control systems.

The four examples of applications are (in order of increasing difficulty):

1. **Simulating a crane at a construction site,**
2. **Balancing the inverted pendulum,**
3. **Swing up and balancing the inverted pendulum, and**
4. **Swing up and balancing the inverted pendulum at a specific orientation.**

DESCRIPTION OF APPARATUS

The *KRi* Inverted Pendulum PP-300 consists of: (1) a short arm which rotates in a horizontal plane, driven by a DC motor mounted vertically; and, (2) a pendulum rod at one end of the arm which can rotate 360º in a vertical plane orthogonal to that of the arm. The angular position and speed of the DC motor are measured by an optical encoder (with 1000 lines resolution) and tachometer. The pendulum itself is attached to the rotating arm via a servo potentiometer which measures the angular position of the pendulum in the vertical plane. A proprietary mechanism is used to provide the electrical connections between the servo potentiometer and terminal blocks on the stationary base.

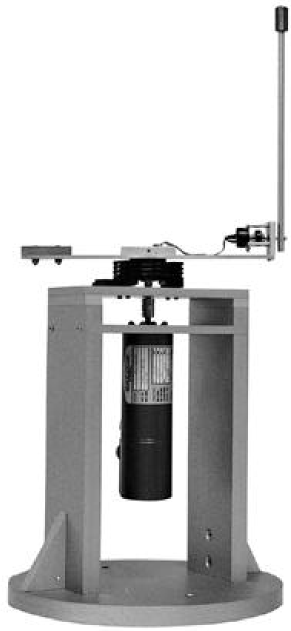

Figure 1 Inverted Pendulum Model PP-300

The *KRi* Inverted Pendulum Apparatus PP-300 is a *low cost pilot plant designed for teaching advanced control systems theory in the laboratory*. Compared to conventional linear pendulums, it occupies very little bench space. The motor and pendulum also rotates freely (360° clockwise or counter-clockwise) with no mechanical restrictions. The PP-300 incorporates mechanical safety guards.

This apparatus is _useful to illustrate how to design control algorithms - ranging from classical controllers to modern fuzzy-logic or neural controllers - for balancing a pendulum_. For example, in the swing up mode, open-loop schemes can be compared with feedback-based optimal controllers. In the balancing mode, it allows demonstration of phase-lead compensators, fuzzy-logic controllers, neural controllers, or variable-structure controllers. It also demonstrates the use of linear models for a non-linear system and requires the realization of mode switching in controllers from swing up to balance. Thus one simple and compact apparatus successfully provides a point of comparison amongst the rich variety of classical and modern algorithms.

EXAMPLE 1 SIMULATING A CRANE AT A CONSTRUCTION SITE

With the pendulum at rest in its natural stable position, the apparatus can be used to emulate the behaviour of a crane at a construction site. Using the voltage to the motor amplifier as the manipulated variable, the arm can be swung from one position to another. This would resemble the crane operator moving a load (in this case, the pendulum and the mass at its tip).

The control objective here is to move the load in the shortest possible time while keeping the load as stable as possible (minimum perturbations on angle α of the load), see Figure 2 on the left.

With this setup, it is possible to study control techniques ranging from simple single loop PID control (with the angular position θ of the arm as the measured variable) and inner loop feedback (with the angular position α of the pendulum as an additional measured variable) to state feedback/state observer or fuzzy/neutral techniques.

An important pedagogical feature of this application is that whilst a linearised model can be developed when operated cautiously with "small perturbations" , the plant quickly becomes nonlinear for larger angular displacements. This provides a simple but realistic and repeatable environment for the evaluation of controllers.

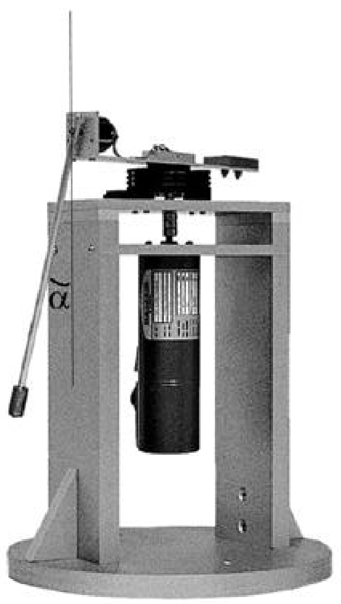

Figure 2 Using the PP-300 apparatus to simulate a crane

EXAMPLE 2 BALANCING THE INVERTED PENDULUM

In this application, the pendulum is first positioned upright manually, that is, in a position of unstable equilibrium. The controller is then switched in to balance the pendulum and to maintain this balance in the presence of disturbances, see Figure 3. A simple disturbance may be a light tap on the balanced pendulum. A complex disturbance may be gusts of wind (use a fan!).

This setup can be used to study the control of open loop unstable system. It is a demonstration of the stabilizing benefits of feedback control. A range of control techniques ranging from the simple phase advance compensator to neural net controllers can be applied. Some of these are described in the references listed at the end of this note.

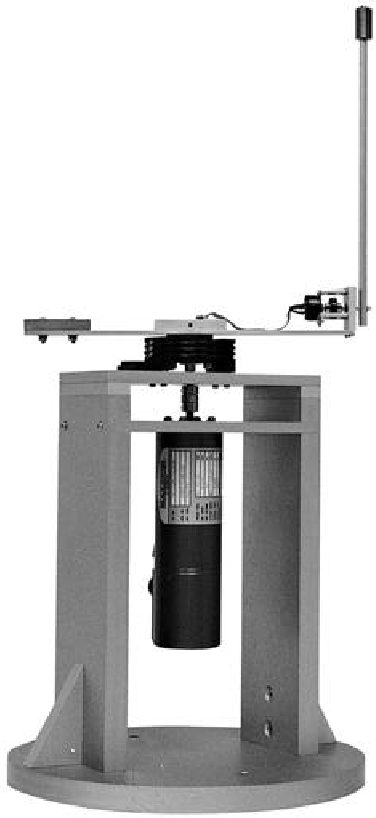

Figure 3 Balancing the pendulum

EXAMPLE 3 SWING UP THE INVERTED PENDULUM

In this application, the pendulum is initially at rest in a stable, hanging down position. The control objective is to swing the pendulum upright and to subsequently maintain it at this balanced position.

Figure 4 Swing up and balancing the pendulum

The control realization requires mode switching in the controller from swing up to balance. A variety of performance criteria can be applied to the swing up problem. These may be to achieve swing up in minimum time using minimum energy. Only the rotary arm position angle may be used or both angle and velocity measurements may be utilized This setup allows the demonstration of both open loop optimal control or nonlinear feedback control such as variable structure control.

Figure 5 Balancing pendulum at specific orientation

EXAMPLE 4 SWINGING UP AND BALANCE THE INVERTED PENDULUM AT A SPECIFIC ORIENTATION

In this application, Example 3 is extended so that the pendulum is required to swing up and balance at a specific orientation, measured by the angular position θ_b of the horizontal rotary arm.

The problem posed makes for an interesting comparison of strategies. A minimum time performance criteria for example may compare a strategy which first swings the pendulum upright and then moves the rotary arm to the desired position θ_b (if necessary) while keeping the pendulum balanced with one which moves the arm to the desired position before swing up and balance. Other strategies may allow both performance objectives to be attempted simultaneously. This setup will be an interesting test-bed for the comparison of controllers with multi-objective performance criteria but only one manipulated variable.

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OTHER *KRi* PRODUCTS

KentRidge Instruments Pte Ltd offers a family of control apparatus or equipment for teaching and research in control engineering:

- Coupled-Tank Control Apparatus PP-100
- Fan & Plate Control Apparatus PP-200
- FlexiDrive PP-400
- Dual Process Simulator KI-101
- Mixed Signal Test Unit TU-100
- Controller Boards UC96

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