Technical Manual
Important Safety Instructions

1. Read all of these instructions.
2. Save these instructions for later use.
3. This device should be operated under normal conditions.
4. Follow all warnings and instructions marked on the product.
5. This device should be placed so that the power supply switch can be operated easily.
6. Unplug this product from the wall outlet before cleaning or removing any covers. Do not use liquid cleaners or aerosol cleaners. Use damp cloth for cleaning.
7. Do not use this product near water.
8. Do not place this product on an unstable cart, stand or table. The product may fall, causing a serious damage to the product.
9. This product should be operated from a type of power source indicated on the marking label. Make sure that the voltage selector at the back panel of the power supply is set accordingly. If you are not sure of the type of power available, consult your dealer or local power company.
10. This product is equipped with a three-wire grounding type plug, a plug having a third (grounding) pin. This plug will only fit into a grounding type power outlet. This is a safety feature. If you are unable to insert the plug into the outlet, contact your electrician to replace your obsolete outlet. Do not defeat the purpose of the grounding type plug.
11. All replacement parts should be supplied and installed by manufacturer or his authorized agent.
12. This equipment should be used in a manner specified in this manual only, otherwise the protection provided by the equipment may be impaired.
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1. Quick Overview

**Features**
- One dimensional strongly nonlinear unstable system designed for studying system dynamics and experimenting with number of different control algorithms based on classical and modern control theory.
- Compact benchtop configuration, designed for on-line digital control by IBM PC computer, or 100% compatible with data acquisition A/D and D/A convertor plug-in cards.
- Ball position linear sensor connected to A/D convertor.
- Interface libraries written in Borland C language and demonstration software package with PID controllers available.
- System accessible directly from MATLAB environment in real time.
- Coil overheat protection.
- dSPACE DS1102, DS1103 or DS1104 controller optional.

**Description**
The scale model demonstrates control problems associated with nonlinear unstable systems. The system consists of a coil levitating a steel ball in magnetic field. Position of the steel ball is sensed by inductive linear position sensor connected to A/D convertor. The coil is driven by power amplifier connected to D/A convertor. The basic control task is to control the position of the ball freely levitating in the magnetic field of the coil. The Ball&Plate system is a nonlinear dynamic system with one input and one output. The system is designed to be controlled by digital controllers, but as of its nature allows using also analog controllers (analog controllers are not included).

**Specification**
The apparatus includes:
- Magnetic Levitation system
- Power Supply
- MF624 data acquisition card (standard PCI card)

**Magnetic Levitation System:**
- Ball actuation:
  - Copper coil driven by power voltage/current convertor
- Ball position sensor:
  - Inductive linear position sensor

**Power Supply:**
DC Power Supply, +10 V, ±15 V

**MF624 data acquisition card:**
PCI card with eight 14 bit A/D inputs, eight 14 bit D/A converters, 8 digital TTL inputs, 8 digital TTL outputs, 4 encoder inputs and 4 counters/timers.
Two input channels used for ball position and coil current measurement.
One analog output used for coil power amplifier driving.

**Power amplifier:**
Built-in current/voltage power convertor with coil overheat protection
Input: 0-5V
Output: 0-1.5 A, 0.3 A/V.

**Range of Experiments**
An extensive range of experiments can be carried out with this apparatus.
1. Real-time digital signal processing
2. Digital PID controller design for ball position stabilization
3. Nonlinear controller design
**Instruction Manual**

A comprehensive technical manual is provided giving details of the apparatus, information about programming the data acquisition card and full description of the apparatus control signals.

**Software**

Interface drivers written in C with source code, demonstrational package using PID controllers and drivers for MATLAB Real Time Toolbox provided.

**Ancillaries**

The apparatus is designed for control by standard IBM PC or 100% compatible computer, one PCI slot required.

**Services required**

Single phase A.C. 240 or 110 V / 50 or 60 Hz, 50VA supply, with earth. Use T 500 mA fuse only.

**Space required**

For satisfactory use of the apparatus a bench area of 800 x 500mm is required.

**Dimensions and Weights**

Magnetic Levitation:
- Main body: 200x250x175 mm
- Weight: 2 kg

Power Supply: 160x145x65 mm, 2 kg

**Figure 1: Sketch description of the Magnetic Levitation Model**
2. Hardware Installation

2.1. Delivery Checklist

The CE151 Ball & Plate Apparatus consists of the items in the following table. Please check all the items before starting the installation. There is also a list of all the items included as a separate sheet in the package. In the case of inconsistency of these two lists, the separate sheet takes precedence over this manual.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QTY</th>
<th>PART No</th>
<th>DESCRIPTION</th>
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</thead>
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<tr>
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<td>1</td>
<td>15201</td>
<td>CE152 Magnetic Levitation Base Unit</td>
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<tr>
<td>2</td>
<td>1</td>
<td>15214</td>
<td>MF624 Data Acquisition Card with Manual</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>15203</td>
<td>CE152 Power Cable</td>
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<tr>
<td>4</td>
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<td>15215</td>
<td>CE152 Control Cable</td>
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<tr>
<td>5</td>
<td>1</td>
<td>15205</td>
<td>PS904 Power Supply</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>15206</td>
<td>Power Cord</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>15207</td>
<td>½&quot; Steel Balls</td>
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<tr>
<td>8</td>
<td>1</td>
<td>15208</td>
<td>CE152 User's and Educational Manuals</td>
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<td>15209</td>
<td>Real Time Toolbox for MATLAB – Manual</td>
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<tr>
<td>12</td>
<td>1</td>
<td>BLB152</td>
<td>Test Certificate</td>
</tr>
</tbody>
</table>
2.2. Installation Procedure

Neither special tools nor special skills are required to install the model. Please follow these instructions:

- Remove transport cover from the Magnetic Levitation base unit.
- According to the information in user's manual install the PC add-on card MF624 into the host PC computer. Please refer also to the chapter "Software Installation" in this manual.
- Make sure that the voltage selector at the back panel of the power supply is set accordingly.
- Connect all parts of the model together according to descriptions of cabling and block diagrams. Power cords of all system components should be unplugged.
- Plug in the power cords.
- Put the steel ball into its place.
- Switch on the power.
- Continue with software installation.
2.3. Block Diagrams and Cabling

Figure 2: Block diagram of the model
Figure 3: Base unit diagram
Figure 4: Description of the control cable

Figure 5: Description of the power cable
3. Software

3.1. Software installation

The software supplied with the CE 152 is able to run in Windows 2000 and Windows XP.

Before using the apparatus please install MF 624 board according to MF 624 user's manual. Then install the MF 624 driver for Windows. Refer to MF 624 User's manual.

Magnetic Levitation model is delivered with Windows demo control application. This application is CE152.EXE and is on the Magnetic Levitation installation floppy. Once you have installed MF 624, demo application does not require any installation. You can just copy it to any location on your disk and run it.

For MATLAB/Simulink based experiments you need MATLAB and Simulink R14SP3 or higher. You have to install Extended Real Time Toolbox version 3.12 or higher which comes with the model. Follow instructions in Real Time Toolbox User's Manual. Simulink models for model control are located in RT_TBX directory on the Helicopter installation floppy. Copy the files to MATLAB working directory or to any other directory on your MATLAB path.

Minimum requirements for the computer are: PC, Pentium4, Windows 2000 or higher.

3.2. PID Demonstration Program

The PID demonstration program is intended for the basic experiments only and for quick start with using the model. It is supposed that after these initial experiments you proceed with using MATLAB and Real Time Toolbox or Real-Time Windows Target to perform more sophisticated control tasks. The demonstration program consists of one file, CE152.EXE.

3.2.1. Running Demonstration Program

Run the CE152 program by typing ce152 in the application directory, or you can create a shortcut to CE152.EXE and double-click the icon.

After running the program you'll see the main control panel window.
At the main control panel you can see the model on the left, graphic representation of three potentiometers on the right, and buttons labeled **Start**, **Stop** and **Plot** at the down right corner of the screen. In the working area there is a filled white circle representing the actual position of the metal ball and an empty red circle showing the setpoint.

The software is controlled by the mouse. By clicking the **Start** button you start the control process. Pressing the **Stop** button stops the experiment. You can change the setpoint by pointing the mouse cursor to the working area and clicking the mouse at the position of the new setpoint. The cursor changes its shape to indicate that the setpoint setting is active. The red circle changes its position and controller immediately accepts the new value of the setpoint. You can also change the PID coefficients by dragging the button to change the mantissa. Another possibility for changing the PID coefficients is to use the **Controller** menu item. You can exit the demonstration by closing the main control panel window. **Start** and **Stop** commands can be
executed also from the main menu selecting the **Controller** item. Selecting **Set Factory Defaults** from the **Model** menu puts the software to the initial conditions.

There's no need to change the hardware settings because they are pre-set from the manufacturer. But if you want to, you can change them from the **Hardware** menu of the main control panel. It is useful if several I/O boards are installed. It is not recommended to change the sample period. Lowpass filter can be applied on measured position signal. Incorrect filter settings may cause system instability.

By clicking the **Plot** button you open a new screen to see history plots. Similarly to the main control panel, the red line represents the setpoint and the green line represents the actual position. The lines automatically update to show the new values from the controller. You can hold the updating by selecting **Hold** menu command and clear the plots by the **Clear** command. The range of the time axis can be set from the **Range** menu.

![History plots](image)

**Figure 7:** History plots
3.3. Programming, software drivers

For programming of the model refer also to the user's manual of the MF 624 data acquisition card.

The model uses two input and one output channels of the MF 624 board. Logical inputs and outputs are used for data and control signals as follows:

<table>
<thead>
<tr>
<th>Logical</th>
<th>Analog Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>ball position</td>
<td>analog input 0</td>
</tr>
<tr>
<td>coil current</td>
<td>analog input 1</td>
</tr>
<tr>
<td>coil voltage</td>
<td>analog output 0</td>
</tr>
</tbody>
</table>

All necessary control functions can be found in the commented library sources MF614.C, so you don't have to program the equipment directly. Object version of the library is compiled by Microsoft Visual C++ compiler.

Using Real Time Toolbox for MATLAB with MF 624 driver:

First install Real Time Toolbox for MATLAB according to the toolbox documentation. For further use of the Real Time Toolbox refer to the toolbox documentation. For driver specification and channel assignment refer to Real Time Toolbox documentation.
We are ready to answer your questions at the address:

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