

APPENDIX B

SAFETY

Torsion Experiment

The following are safety features of the ECP Torsion Experiment system and cautions regarding its operation. This section must be read and understood by all users prior to operating the system. If any material in this section is not clear to the reader, contact the TA for clarification before operating the system.

Important Notice: In the event of an emergency, control effort should be immediately discontinued by pressing the red "OFF" button in front of the control box.

Hardware

A relay circuit is installed within the Control Box which automatically turns off power to the Box whenever the real-time Controller (within the PC) is turned on or off. Thus for the PC bus version of the real-time Controller the user should turn on the computer prior to pressing on the black ON switch. This feature is implemented to prevent uncontrolled motor response during the transient power on/off periods. The power to the Control Box may be turned off at any time by pressing the red OFF switch.

Although not recommended, it will not damage the hardware to apply power to the Control-Box even when the PC is turned off. However, doing so does not result in motor activation as the motor current amplifier will be disabled. The *amplifier enable* signal input to the Control Box is connected to the real-time Controller via the 60-pin flat ribbon cable. This input operates in a normally closed mode. When power to the real-time Controller is off, this input becomes open which in turn disables the motor amplifier.

The recommended procedure for **start up** is as follows:

First : Turn on the PC with the real-time Controller installed in it.

Second: Turn on the power to Control Box (press on the black switch).

The recommended **shut down** procedure is:

First: Turn off the power to the Control Box.

Second: Turn off the PC.

FUSES: There are two 3.0A 120V slow blow fuses within the Control Box. One of them is housed at the back of the Control Box next to the power cord plug. The second one is inside the box next to the large blue colored capacitor.

Software

The Limit Exceeded indicator of the Controller Status display indicates either one or more of the following conditions have occurred:

- Over speed of the motor
- Excessive deflection (twisting) of the torsion shaft
- Excessive drive motor power

The real-time Controller continuously monitors the above limiting conditions in its background routine (intervals of time in-between higher priority tasks). When one of these conditions occurs, the real-time Controller opens up the control loop with a zero torque command sent to the actuator. The Limit Exceeded indicator stays on until a new set of (stabilizing) control gains are downloaded to the real-time Controller via the Implement Algorithm button of the Setup Control Algorithm dialog box, or a new trajectory is executed via the Command menu. Obviously the new trajectory must have parameters that do not cause the Limit Exceeded condition.

The Limit Exceeded indicator of the Disturbance Motor Status display indicates either one or both of the following conditions have occurred:

- Over speed of the disturbance motor
- Excessive disturbance motor power

Also included is a *watch-dog timer*. This subsystem provides a fail-safe shutdown to guard against software malfunction and under-voltage conditions. The use of the watch-dog timer is transparent to the user. This shutdown condition turns on the red LED on the real-time Controller card, and will cause the control box to power down automatically. You may need to cycle the power to the PC in order to reinitialize the real-time Controller should a watch-dog timer shutdown occur.

Safety Checking The Controller

While it should generally be avoided, in some cases it is instructive or necessary to manually contact the mechanism when a controller is active. This should always be done with caution and never in such a way that clothing or hair may be caught in the apparatus. By staying clear of the mechanism when it is moving or when a trajectory has been commanded, the risk of injury is greatly reduced. Being motionless, however, is not sufficient to assure the system is safe to contact. In some cases an unstable controller may have been implemented but the system may remain motionless until perturbed – then it could react violently.

In order to eliminate the risk of injury in such an event, you should always safety check the controller prior to physically contacting the system. This is done by lightly grasping a

slender, light object with no sharp edges (e.g. a ruler without sharp edges or an unsharpened pencil) and using it to slowly move either the load or drive disk from side to side. Keep hands clear of the mechanism while doing this and apply only light force to the disk. If the disk does not spin up or oscillate then it may be manually contacted – but with caution. This procedure must be repeated whenever any user interaction with the system occurs (either via the Executive Program or the Controller Box) if the mechanism is to be physically contacted again.

Warnings

WARNING #1: Stay clear of and do not touch any part of the mechanism while it is moving, while a trajectory has been commanded (via Execute, Command menu), or before the active controller has been safety checked.

WARNING #2: The following apply at all times except when motor drive power is disconnected (consult TA if uncertain as to how to disconnect drive power):

- a) Stay clear of the mechanism while wearing loose clothing (e.g. ties, scarves and loose sleeves) and when hair is not kept close to the head.
- b) Keep head and face well clear of the mechanism.

WARNING #3: Verify that the masses and inertia disks are secured to powering up the Control Box or transporting the mechanism.

WARNING #4: Do not take the cover off or physically touch the interior of the Control Box unless its power cord is unplugged (first press the "Off" button on the front panel) and the PC is unpowered or disconnected.

WARNING #5: The power cord must be removed from the Control box prior to the replacement of any fuses.

Control Moment Gyro Experiment

This section describes important safety features of the ECP Control Moment Gyro system and cautions regarding its operation. This section must be read and understood by all users and anyone in the physical vicinity of this equipment prior to operating it. If any material in this section is not clear to the reader, contact the TA for clarification before operating the system. This system can possess high kinetic energy and therefore it is vital that the safety notices, instructions and warnings of this section be followed explicitly.

Important Notice #1: The system's safety functions must be verified before each operational session.

Important Notice #2: The system must be checked visually before each operational session to verify that the rotor support structure, protective clear rotor cover, brakes, and

inertia switches all appear to be undamaged and securely fastened.

Important Notice #3: In the event of an emergency, control effort should be immediately discontinued by pressing the red "OFF" button on front of the Control Box.

Important Notice #5: Warnings regarding the use of this equipment are provided at the end of this section. All persons in the vicinity of this equipment when the control box is powered must be aware of these warnings.

Verifying The System Safety Functions

1. Make sure that there are no connections to the Control Box (e.g. DAC inputs or encoder readouts) or that they are providing no signal voltages to the box if they are connected.
2. Connect the mechanism to the Control Box and plug the control box into an appropriate power source.
3. Verify that there is nothing interfering with the free motion of the gimbals.
4. Turn on power to the Control Box via the red “on” button. With the brakes switched off, verify that axes 2, 3 and 4 rotate freely.
5. Manually rotate axis 2 (inner gimbal ring) slowly to one limit of travel. You should hear a clicking sound, the Control Box should power down, and the axis 3 and 4 brakes should engage. Move assembly off the mechanical stop and turn the power to the Control Box back on. Move the inner ring in the opposite direction until contacting the stop and verify that the Control box powers down and that the brakes engage. If the system fails to automatically shut down after reaching the limit in either direction of travel, do not further operate the system and contact ECP before continuing.
6. Manually rotate axis 3 (outer gimbal ring) slowly to get a feel for how to move it briskly without injuring fingers. Move the gimbal briskly to achieve approximately 100 rpm (1.7 rev/sec). The system should automatically power down and the axis 3 and axis 4 brakes should engage. If the system fails to automatically shut down, do not further operate the system and contact ECP before continuing.
7. Repeat step 5 for the axis 4 gimbal (vertical yoke at the base of the mechanism). Here it will require approximately 120 rpm to cause the automatic shut-down.

Other Safety Features.

Relay circuits are installed within the Control Box that cause the brakes to engage and the motors to become shorted across their windings whenever power is turned off. The effect of shorting the motor windings is to cause the motors to operate in the generating mode and hence to provide viscous damping. This in turn decelerates the motion of the connected assemblies.

The g-switches (inertial switches) that sense the excessive gimbal rates are set to 2.1 g's. They are normally closed so that any inadvertent open in the associated circuit will cause the system to power down and the brakes to engage. The brakes are of the "fail-safe" power off type meaning that power must be applied in order for them to be released. Therefore the Control box must be powered and the respective switch "off" before the associated gimbal is free. Any inadvertent open in the brake circuit will cause it to engage.

There are two limit switches and mechanical stops that provide over-travel detection and protection for Axis 2. When an over-travel condition is detected, the normally closed switches open and the controller box is powered off.

Safety Checking Your Controller

While it should generally be avoided, in some cases it is instructive or necessary to manually contact the mechanism when motion control is active. This should always be done with caution and never in such a way that clothing or hair may be caught in the apparatus. By staying clear of the mechanism when it is moving or when a trajectory has been commanded, the risk of injury is greatly reduced. Being motionless, however, is not sufficient to assure the system is safe to contact. In some cases an unstable controller may have been implemented but the system may remain motionless until perturbed – then it could react violently.

In order to eliminate the risk of injury in such an event, you should always safety check the controller prior to physically contacting the system. This is done by lightly grasping a slender, light object with no sharp edges (e.g. a ruler without sharp edges or an unsharpened pencil) and using it to slowly move each gimbal from side to side. Keep hands clear of the mechanism while doing this and apply only light force to each gimbal. If the mechanism does not spin up or oscillate then it may be manually contacted – but with caution. This procedure must be repeated whenever any user interaction with the system occurs (either via the ECP Executive program, the user's data processing hardware or software or the Controller Box) if the mechanism is to be physically contacted again.

Start Up and Shut Down Procedures

The recommended procedure for **start up** is as follows:

First : Turn on the PC with the real-time Controller installed in it.

Second: Turn on the power to Control Box (press on the black switch).

The recommended **shut down** procedure is:

First: Turn off the power to the Control Box.

Second: Turn off the PC.

FUSES: There are two 3.0A 120V slow blow fuses within the Control Box. One of them is housed at the back of the Control Box next to the power cord plug. The second one is inside the box next to the large blue colored capacitor.

Warnings

WARNING #1: Stay clear of and do not touch any part of the mechanism while it is moving, while a trajectory is being executed, or before the active controller has been safety checked.

WARNING #2: The following apply at all times except when motor drive power is disconnected (consult TA if uncertain as to how to disconnect drive power):

- a) Stay clear of the mechanism while wearing loose clothing (e.g. ties, scarves and loose sleeves) and when hair is not kept close to the head.
- b) Keep head and face well clear of the mechanism.

WARNING #3: The rotor should never be operated at speeds above 825 RPM. The user must take precautions to assure that this limitation is not exceeded.

WARNING #4: Never leave the system unattended while the Control Box is powered on.

WARNING #5: Any modification of the Model 750 mechanism or its electronics box could render the system unsafe. ECP is not responsible for any such modification.

WARNING #6: The power cord must be removed from the Control box prior to the replacement of any fuses.

WARNING #7: In order for the brakes to remain effective after continued use, the associated gimbals must not be moved repeatedly when the brakes are engaged. The user must minimize forced movement of the gimbals when the brakes are engaged to minimize their wear.

WARNING #8: In order for the brakes to remain effective, the brake pads and disks must not become contaminated. The user must assure that no oily or greasy materials are allowed to contaminate the brakes.

Industrial Emulator Experiment

The following are safety features of the ECP Industrial Emulator system and cautions regarding its operation. This section must be read and understood by all users prior to operating the system. If any material in this section is not clear to the reader, contact the TA for clarification before operating the system.

Important Notice: In the event of an emergency, control effort should be immediately discontinued by pressing the red "OFF" button on front of the control box.

Hardware

A relay circuit is installed within the Control Box which automatically turns off power to the Box whenever the real-time Controller (within the PC) is turned on or off. Thus for the PC bus version¹ of the real-time Controller the user should turn on the computer prior to pressing on the black ON switch. This feature is implemented to prevent uncontrolled motor response during the transient power on/off periods. The power to the Control Box may be turned off at any time by pressing the red OFF switch.

Although not recommended, it will not damage the hardware to apply power to the Control-Box even when the PC is turned off. However, doing so does not result in motor activation as the motor current amplifier will be disabled. The *amplifier enable* signal input to the Control Box is connected to the real-time Controller via the 60-pin flat ribbon cable. This input operates in a normally closed mode. When power to the real-time Controller is off, this input becomes open which in turn disables the motor amplifier.

The recommended procedure for **start up** is as follows:

First : Turn on the PC with the real-time Controller installed in it.

Second: Turn on the power to Control Box (press on the black switch).

The recommended **shut down** procedure is:

First: Turn off the power to the Control Box.

Second: Turn off the PC..

¹The majority of this section (2.3.1) pertains to the PC bus installation of the real-time controller. For the controller box/RS-232 version, the control box should generally be powered on before entering the executive software.

FUSES: There are two 3.0A 120V slow blow fuses within the Control Box. One of them is housed at the back of the Control Box next to the power cord plug. The second one is inside the box next to the large blue colored capacitor.

Software

The Limit Exceeded indicator of the Controller Status display indicates either one or more of the following conditions have occurred:

Over speed of the motor.

Excessive drive motor power

The real-time Controller continuously monitors the above limiting conditions in its background routine (intervals of time in-between higher priority tasks). When one of these conditions occurs, the real-time Controller opens up the control loop with a zero torque command sent to the actuator. The Limit Exceeded indicator stays on until a new set of (stabilizing) control gains are downloaded to the real-time Controller via the Implement Algorithm button of the Setup Control Algorithm dialog box, or a new trajectory is executed via the Command menu. Obviously the new trajectory must have parameters that do not cause the Limit Exceeded condition.

The Limit Exceeded indicator of the Disturbance Motor Status display indicates either one or both of the following conditions have occurred:

Over speed of the disturbance motor.

Excessive disturbance motor power

Also included is a *watch-dog timer*. This subsystem provides a fail-safe shutdown to guard against software malfunction and under-voltage conditions. The use of the watch-dog timer is transparent to the user. This shutdown condition turns on the red LED on the real-time Controller card, and will cause the control box to power down automatically. You may need to cycle the power to the PC in order to reinitialize the real-time Controller should a watch-dog timer shutdown occur.

Safety Checking The Controller

While it should generally be avoided, in some cases it is instructive or useful to manually contact the mechanism when a controller is active. This should always be done with caution and never in such a way that clothing or hair may be caught in the apparatus. By staying clear of the mechanism when it is moving or when a trajectory has been commanded, the risk of injury is greatly reduced. Being motionless, however, is not sufficient to assure the system is safe to contact. In some cases an unstable controller may have been implemented but the system may remain motionless until perturbed – then it could react violently.

In order to eliminate the risk of injury in such an event, you should always safety check the controller prior to physically contacting the system. This is done by lightly grasping a

slender, light object with no sharp edges (e.g. a ruler without sharp edges or an unsharpened pencil) and using it to slowly move either the load or drive disk from side to side. Keep hands clear of the mechanism while doing this and apply only light force to the disk. If the disk does not spin up or oscillate then it may be manually contacted – but with caution. This procedure must be repeated whenever any user interaction with the system occurs (either via the Executive Program or the Controller Box) if the mechanism is to be physically contacted again.

Warnings

WARNING #1: Stay clear of and do not touch any part of the mechanism while it is moving, while a trajectory has been commanded (via Execute, Command menu), or before the active controller has been safety checked.

WARNING #2: The following apply at all times except when motor drive power is disconnected (consult the TA if uncertain as to how to disconnect drive power):

- a) Stay clear of the mechanism while wearing loose clothing (e.g. ties, scarves and loose sleeves) and when hair is not kept close to the head.
- b) Keep head and face well clear of the mechanism.

WARNING #3: Verify that the masses and inertia disks are secured prior to powering up the Control Box or transporting the mechanism.

WARNING #4: Do not take the cover off or physically touch the interior of the Control Box unless its power cord is unplugged (first press the "Off" button on the front panel) and the PC is unpowered or disconnected.

WARNING #5: The power cord must be removed from the Control box prior to the replacement of any fuses.

Magnetic Levitation Experiment

The following are safety features of the ECP Magnetic Levitation system and cautions regarding its operation. This section must be read and understood by all users prior to operating the system. If any material in this section is not clear to the reader, contact the TA for clarification before operating the system.

Important Notice: In the event of an emergency, control effort should be immediately discontinued by pressing the red "OFF" button on front of the control box.

Hardware

A relay circuit is installed within the Control Box that automatically turns off power to the Box whenever the real-time Controller (within the PC) is turned on or off. Thus for the PC bus version of the real-time Controller the user should turn on the computer prior to pressing on the black ON switch. This feature is implemented to prevent uncontrolled

motor response during the transient power on/off periods. The power to the Control Box may be turned off at any time by pressing the red OFF switch.

Although not recommended, it will not damage the hardware to apply power to the Control-Box even when the PC is turned off. However, doing so does not result in current activation as the motor current amplifier will be disabled. The *amplifier enable* signal input to the Control Box is connected to the real-time Controller via the 60-pin flat ribbon cable. This input operates in a normally closed mode. When power to the real-time Controller is off, this input becomes open which in turn disables the motor amplifier.

The recommended procedure for **start up** is as follows:

First : Turn on the PC with the real-time Controller installed in it.

Second: Turn on the power to Control Box (press on the black switch).

The recommended **shut down** procedure is:

First: Turn off the power to the Control Box.

Second: Turn off the PC.

FUSES: There are two 3.0A 120V slow blow fuses within the Control Box. One of them is housed at the back of the Control Box next to the power cord plug. The second one is inside the box next to the large blue colored capacitor.

Software

The Limit Exceeded indicator of the Controller Status display indicates that one or more of the following conditions have occurred:

High transient control effort (coil current)

High coil power over a sustained period (Excessive thermal build-up)

Servo time limit exceeded

The Limit Exceeded condition may occur whenever a non-stabilizing controller is implemented, an excessively large or rapid trajectory is executed, or the levitation distance is too great. The real-time Controller continuously monitors the above limiting conditions in its background routine (intervals of time in-between higher priority tasks). When one of these conditions occurs, the real-time Controller opens up the control loop with a zero current command sent to the actuator. The Limit Exceeded indicator stays on until a new set of (stabilizing) control gains are downloaded to the real-time Controller via the Implement Algorithm button of the Setup Control Algorithm dialog box, or a new trajectory is executed via the Command menu. Obviously the new trajectory must have parameters that do not cause the Limit Exceeded condition.

If the servo time limit is exceeded, the real-time computation burden has exceeded the capability of the processor. You should either increase the sampling period, reduce the complexity of the real-time algorithm, or reduce the computational requirements of the trajectory (i.e. sine sweep and sinusoidal are most complex).

Also included is a *watchdog timer*. This subsystem provides a fail-safe shutdown to guard against software malfunction and under-voltage conditions. The use of the watchdog timer is transparent to the user. This shutdown condition turns on the red LED on the real-time Controller card, and will cause the control box to power down automatically. You may need to cycle the power to the PC in order to reinitialize the real-time Controller should a watchdog timer shutdown occur.

Safety Checking The Controller

While it should generally be avoided, in some cases it is instructive or necessary to manually contact the apparatus when a controller is active. This should always be done with caution and never in such a way that clothing or hair may be caught in the apparatus. By staying clear of the mechanism when it is moving or when a trajectory has been commanded, the risk of damage or injury is greatly reduced. Being motionless, however, is not sufficient to assure the system is safe to contact. In some cases an unstable controller may have been implemented but the system may remain motionless until perturbed – then it could react violently.

In order to eliminate the risk of injury in such an event, you should always safety check the controller prior to physically contacting the system. This is done by lightly grasping a slender, light object with no sharp edges (e.g. a ruler without sharp edges or an unsharpened pencil) and using it to lightly perturb the magnet up and down. If the magnet does not move rapidly or oscillate then it may be manually contacted – but with caution. This procedure must be repeated whenever any user interaction with the system occurs (either via the Executive Program or the Controller Box) if the mechanism is to be physically contacted again.

Warnings

WARNING #1: Stay clear of and do not touch any part of the mechanism while it is moving, while a trajectory has been commanded (via Execute, Command menu), or before the active controller has been safety checked.

WARNING #2: The following apply at all times except when motor drive power is disconnected (consult the TA if uncertain as to how to disconnect drive power):

- a) Stay clear of the mechanism while wearing loose clothing (e.g. ties, scarves and loose sleeves) and when hair is not kept close to the head.
- b) Keep head and face well clear of the mechanism.

WARNING #3: Verify that the magnets and glass rod are secured per section 2.2 of this manual prior to powering up the Control Box or transporting the mechanism.

WARNING #4: Do not take the cover off or physically touch the interior of the Control Box unless its power cord is unplugged (first press the "Off" button on the front panel) and the PC is unpowered or disconnected.

WARNING #5: The power cord must be removed from the Control box prior to the replacement of any fuses.

Important Notes

1) The high intensity magnets must be kept at least 20 cm. (8 in.) from each other and from other objects of ferromagnetic material. Failure to do so could cause the magnet and other body to be rapidly attracted and collide thereby damaging the magnet. It is highly recommended that the provided post for magnet storage be used when a magnet is not installed about the glass rod. It is particularly important

to secure the magnets during the operation of installing and removing two magnets on the glass rod.

2) The magnets should be kept a minimum of 40 cm. (16 in) from cathode ray tubes (CRT's, e.g. computer monitors and televisions) and from magnetic media such as floppy and hard disks. Failure to do so could result in permanent magnetic distortion and in the case of media, loss of data.

3) The magnets must be secured at all times either via installation on the glass rod or the magnet storage post.

4) The plastic safety clip should always be used to support the magnet prior to implementing attractive levitation via the upper coil / sensor.

Digital Pendulum Experiment

- Do not enter the workspace of the Equipment whilst it is in operation.
- In the event of an emergency the control effort should immediately be discontinued by hitting the Red Stop button on the Pendulum Control Unit.
- All users of this equipment should be familiar with and trained in good Laboratory Practice where electrical machinery is used.
- When running any control experiment ensure that the Real Time control program is running before pressing the Start button on the equipment control unit.