CURTIS

Manual

Model **1220**

Electric Steering Controller
for Brushed PM Motor

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Read Instructions Carefully!

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The Curtis Difference

You feel it when you drive it

CONTENTS

FIGURES

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1 OVERVIEW

The Curtis Model 1220 controller is designed to drive a brushed permanent magnet motor for electric power steering (EPS). The 1220 performs as the steering system controller, interpreting the steering command input and wheel position feedback, then driving the steering motor to move the steered wheel(s) to the desired position.

The steering motor must be speed reduced to get the high torque required to rotate the drive wheel. Typically this is done with a gearbox around 50:1 and a chain or gear with an additional reduction of around 4:1. The steering command comes either from a linear potentiometer or an analog voltage sensor. The wheel position feedback comes either from a linear potentiometer, an analog voltage sensor, or an encoder with a home switch.

Fig. 1 *Curtis 1220 electric steering controller.*

The 1220 works only with Curtis AC traction controllers with embedded VCL. A "handshake" with the traction controller is required at startup to enable operation.

Intended applications are material handling vehicles such as reach trucks, order pickers, stackers, "man up" warehouse trucks, and other similar industrial vehicles.

Advanced Motor Control

- ✓ Absolute position control mode.
- ✓ 16 kHz PWM switching frequency ensures silent operation.
- ✓ Advanced PWM techniques produce low motor harmonics, low torque ripple, and minimized heating losses, resulting in high efficiency.
- ✓ Configurable homing methods, center offset, and end-stop protection.
- ✓ 24 V, 40 A 2-minute current rating.
- ✓ 24 V nominal supply voltage.

Maximum Safety

- ✓ Dual steering command inputs and dual analog position inputs for redundant check.
- ✓ Fault output can be used to turn off traction controller's main contactor or interlock connection.
- ✓ Steered wheel position (angle) output can be used to limit the traction motor speed.
- ✓ Following error check ensures the wheel position tracks the steering command.
- ✓ Power On Self-Test: FLASH, ALU, EEPROM, software watchdog, RAM, etc.
- ✓ Power On Hardware Check: Motor Open, Motor Short, and MOSFET short.
- ✓ Periodic Self-Tests: EEPROM parameters, Motor Open, and command and feedback devices.

Unmatched Flexibility

- ✓ Integrated hourmeter and diagnostic log functions.
- ✓ Curtis 840 Spyglass can be connected to show traction and steering information such as BDI, hour meter, fault, traction speed, and steered wheel angle.
- ✓ +5V low-power supply for input sensors, etc.
- ✓ Curtis 1313 handheld programmer and 1314 PC Programming Station provide easy programming and powerful system diagnostic and monitoring capabilities.
- ✓ External Status LED driver gives instant diagnostic indication.

Robust Reliability

✓ Intelligent thermal cutback and overvoltage/undervoltage protection functions maintain steering while reducing traction speed until severe over/under limits are reached.

✓ Standard Mini-Fit Molex Jr. and Faston terminals provide proven, robust wiring connections.

✓ Electronics sealed to IP65.

✓ Reverse polarity protection on battery connections.

✓ Inputs protected against shorts to B+ and B-.

Familiarity with your Curtis controller will help you install and operate it properly. We encourage you to read this manual carefully. If you have questions, please contact your local Curtis representative.

CAUTION ☞

Working on electrical systems is potentially dangerous. Protect yourself against uncontrolled operation, high current arcs, and outgassing from lead acid batteries:

UNCONTROLLED OPERATION — Some conditions could cause the motor to run out of control. Disconnect the motor or jack up the vehicle and get the drive wheels off the ground before attempting any work on the motor control circuitry.

HIGH CURRENT ARCS — Batteries can supply very high power, and arcing can occur if they are short circuited. Always open the battery circuit before working on the motor control circuit. Wear safety glasses, and use properly insulated tools to prevent shorts.

LEAD ACID BATTERIES — Charging or discharging generates hydrogen gas, which can build up in and around the batteries. Follow the battery manufacturer's safety recommendations. Wear safety glasses.

CAUTION ☞

The Curtis Model 1220 does not satisfy EN1175-1:1998+A1:2010 Article 5.9.6 as it is not a Category 3 device under EN ISO13849-1:2008. It should not be used on any vehicle within the scope of Machinery Directive 2006/42/EC that will be operated within the European Economic Area (EEA).

2

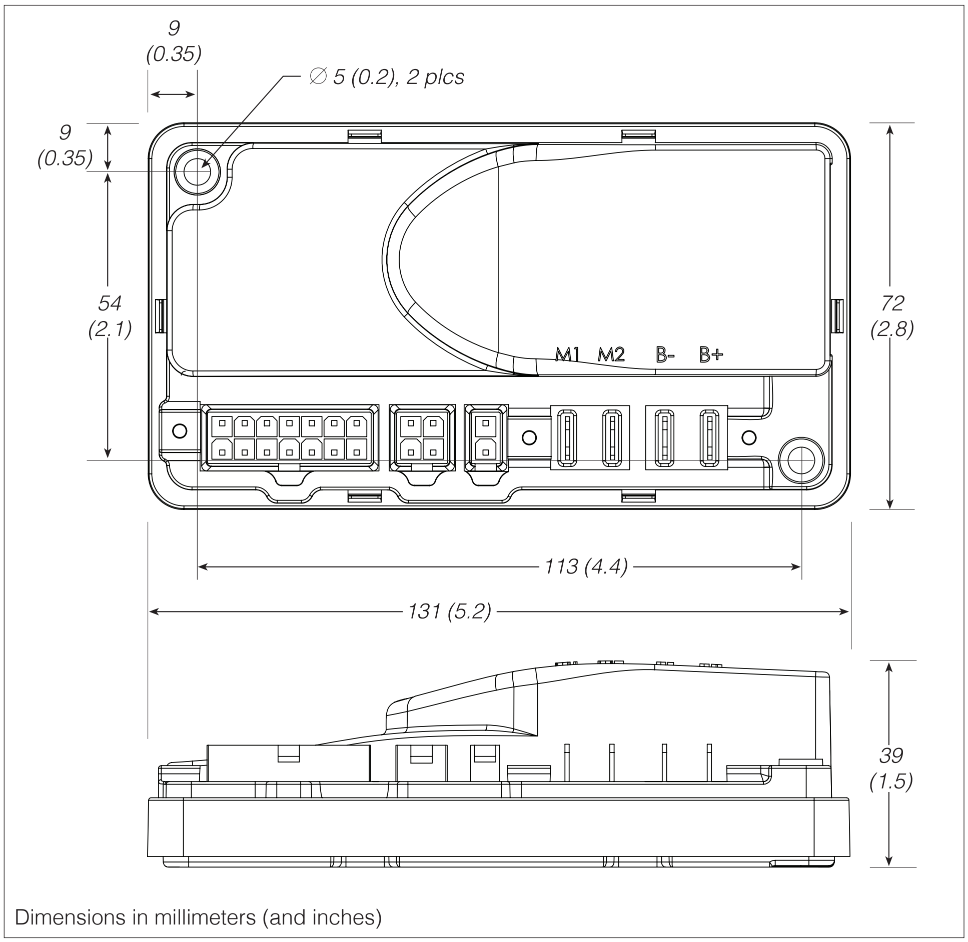
INSTALLATION AND WIRING

MOUNTING THE CONTROLLER

The 1220 controller can be oriented in any position, but **the mounting location should be carefully chosen to keep the controller clean and dry. If a clean, dry mounting location cannot be found, a cover must be used to shield the controller from water and contaminants**.

The outline and mounting hole dimensions are shown in Fig. 2. The controller should be mounted by means of the two mounting holes at the opposing corners of the heatsink, using M4 (#8) screws.

Fig. 2 *Mounting dimensions, Curtis 1220 motor controller.*

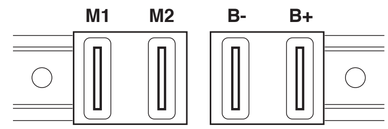


You will need to take steps during the design and development of your end product to ensure that its EMC performance complies with applicable regulations; suggestions are presented in Appendix A.

The 1220 controller contains **ESD-sensitive components**. Use appropriate precautions in connecting, disconnecting, and handling the controller. See installation suggestions in Appendix A for protecting the controller from ESD damage.

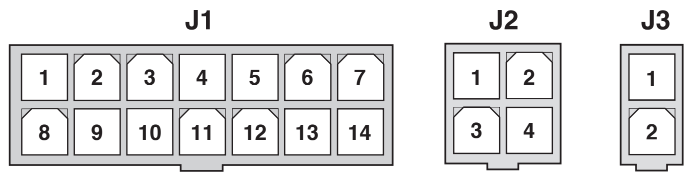
CONNECTIONS: High Current

Four 1/4” Faston terminals are provided for the high current connections. The motor connections (**M1**, **M2**) and battery connections (**B+**, **B-**) have one terminal each.



CONNECTIONS Low Current

The low current connections are made through three connectors: J1, J2, and J3.



Mating connectors:
Molex Mini-Fit-Jr
receptacle p/n
J1 39-01-2140
J2 39-01-2040
J3 39-01-2020
with appropriate
45750-series
crimp terminals.

J1 14-pin Molex 39-28-8140		
	1	Status LED
	2	Steer Motor Encoder Phase A
	3	Position Analog 2
	4	Interlock Input
	5	KSI
	6	Command Analog 1
	7	+5V
	8	Rx2 (from traction controller)
	9	Steer Motor Encoder Phase B
	10	Feedback Pot Low
	11	Position Analog 1
	12	Steering Angle Output
	13	Command Analog 2
	14	Command Pot Low

J2 4-pin Molex 39-28-8040		
	1	Rx1 (from programmer)
	2	GND
	3	Tx1 (to programmer / 840)
	4	B+

J3 2-pin Molex 39-28-8020		
	1	Fault Output
	2	Home Switch

CONTROLLER WIRING

As shown in the wiring diagrams (Figs. 3a, 3b), the 1220's keyswitch power must go through the traction controller so that when the keyswitch is turned off both controllers turn off. The fault output (Pin J3-1) must be able to shut down the traction system in the case of a serious fault, in order to meet international safety requirements.

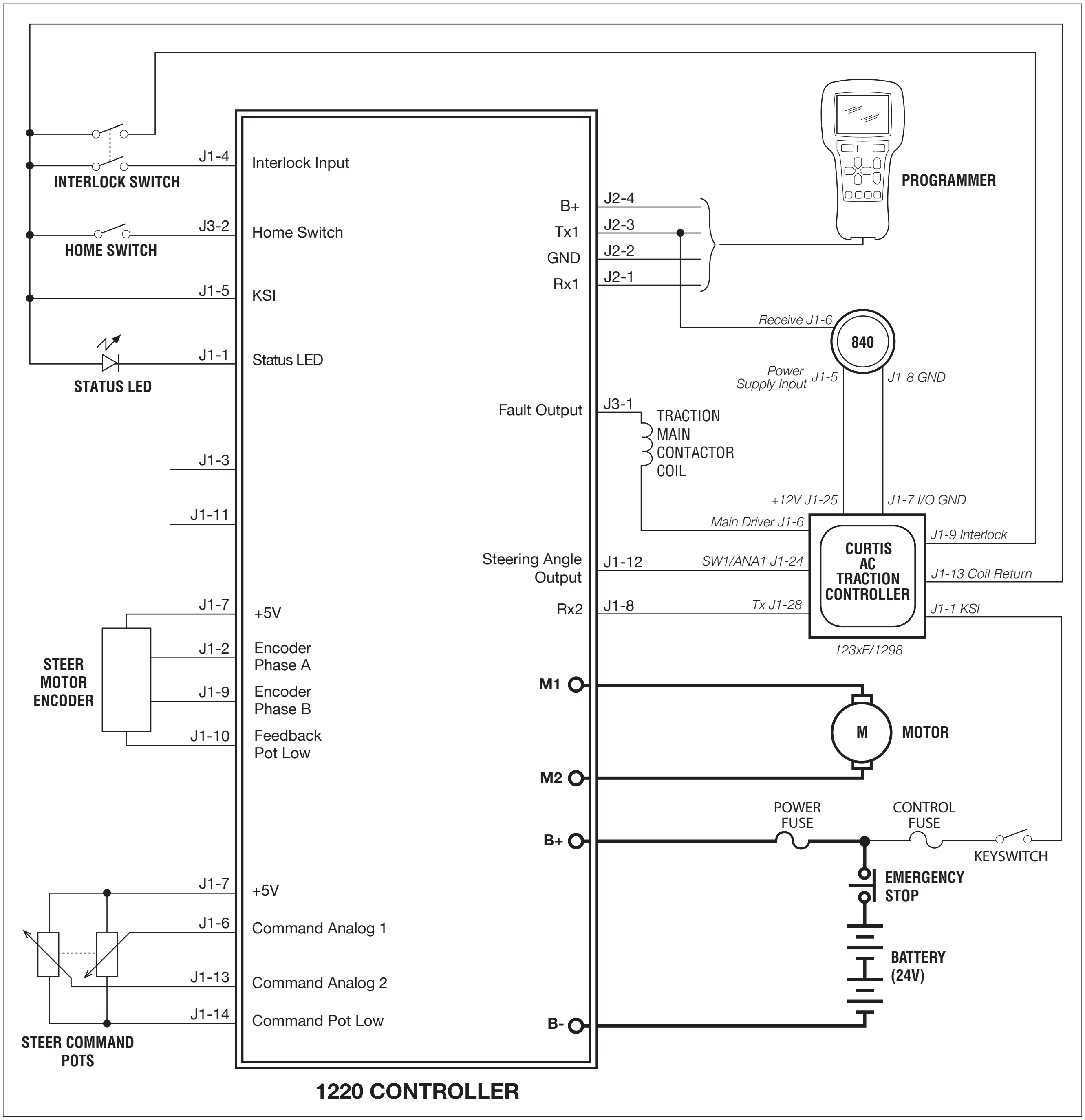


Fig. 3a *Basic wiring diagram, using motor encoder for feedback device.*

These wiring diagrams (Figs. 3a, 3b) show generic applications and may not fully meet the requirements of your system. You may wish to contact your local Curtis representative to discuss your particular application.

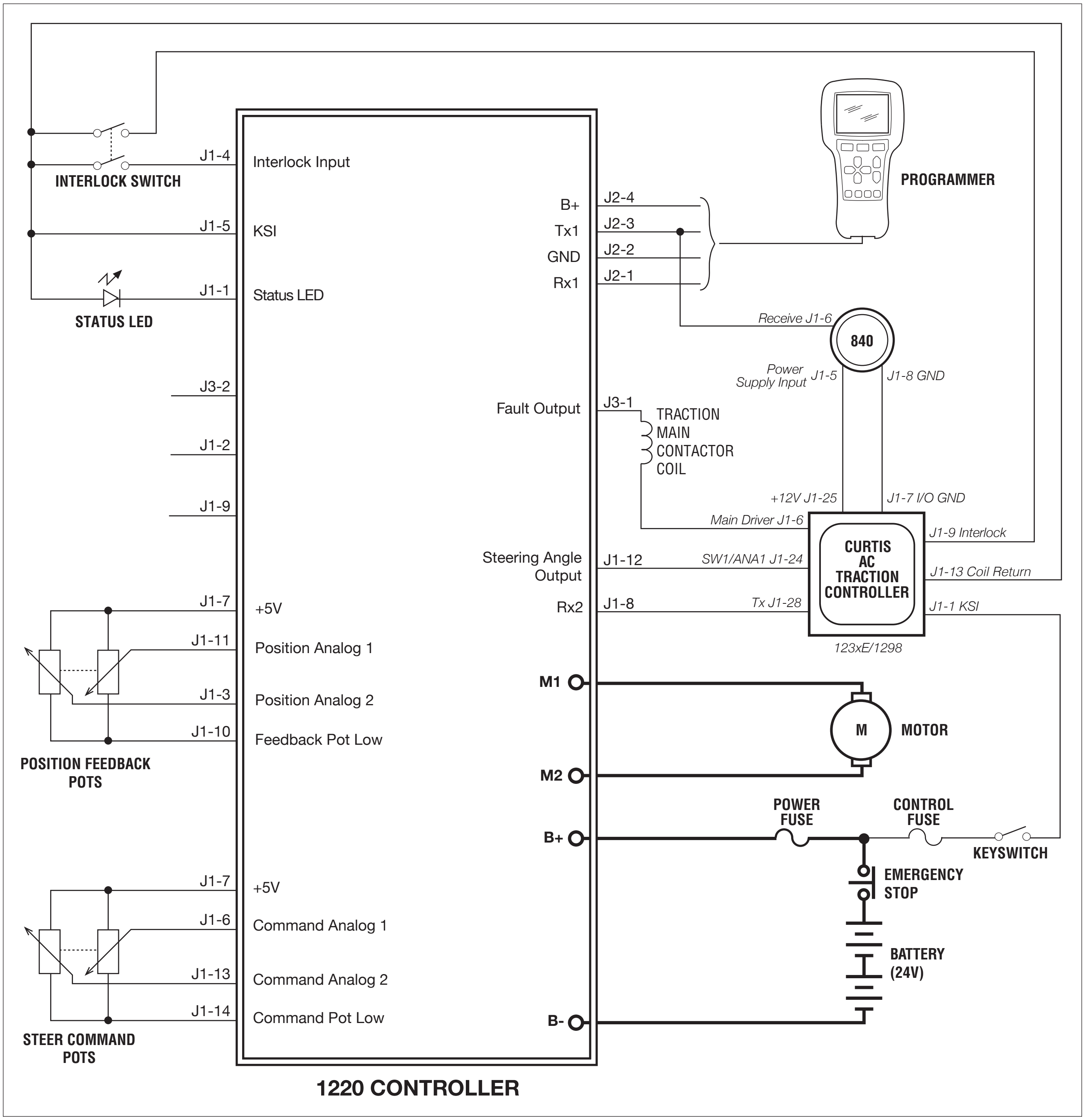


Fig. 3b *Basic wiring diagram, using position feedback pots for feedback device.*

INPUT/OUTPUT SIGNAL SPECIFICATIONS

The electrical characteristics of the input/output signals wired to the J1, J2, and J3 connectors are described below.

KSI (pin J1-5)

The keyswitch (KSI) must be connected to B+ via a switch. This pin feeds the internal power supply and can be used for general on/off and for the power supply to the Fault Output pin.

Input current at Nominal Battery Voltage	(50 – 200 mA) + Fault Output current

Digital inputs (pins J1-4 and J3-2)

The digital inputs must be connected to B+ via a switch, or they can be driven by outputs from other systems.

Input current at Nominal Battery Voltage	approx. 0.2 – 0.7 mA (depending on nominal battery voltage
Input filter R-C time constant	max 5 ms
Max LOW threshold voltage	5.0 V
Min HIGH threshold voltage	12 V
De-bouncing time (in software)	10 – 25 ms

Analog inputs (pins J1-3, J1-6, J1-11, J1-13)

The analog inputs are used for analog input commands from any analog input device, e.g., potentiometer, Hall sensor.

Input resistance (to B- ground)	50 kΩ ± 10%
Input current (wheel in center position)	max 100 µA ± 10%
Input filter R-C time constant	max 5 ms
Voltage range	0 – 5.5 V
Minimum resolution	12 bit

Steer Motor Encoder inputs (pins J1-2, J1-9)

These inputs are used for the A and B signals of the Steer Motor Encoder device.

Input current (to Encoder Ground)	1.5 mA ± 20%
Input filter R-C time constant	1 µs
Max LOW threshold voltage	0.5 V
Min HIGH threshold voltage	2 V

+5V Supply (pin J1-7)

This pin is the power supply connection to the Command Input Device and the Position Feedback Device.

Command supply voltage	+5 V ± 10%
Maximum current draw	70 mA

Pot Low (pins J1-10, J1-14)

The Command and Feedback Pot Low pins are connected to I/O GND. They are not protected against short circuits to B+.

Fault Output (pin J3-1)

The Fault Output has independent supervision via the MCU, and can be used for power supply of the traction main contactor coil. This output has reverse polarity protection.

Max output current	1.5 A
Max voltage drop (to KSI) at 1.5 A	2 V

Steering Angle Output (pin J1-12)

This pin will output an analog signal to the traction controller for traction speed limit.

Analog output range	5–9 V ±10% (2.5 V when not ready)
Max ripple voltage (p-p)	0.2 V
Max output current	5 mA

Programmer connections (J2 connector)

The Curtis programmer plugs into the 4-pin connector, J2.

Rx is the data input connection to/from the programmer.

Input pull down resistance (to B- ground) 5 kΩ ±10%

Tx is the data input connection to/from the programmer.

Logic Level 0:

Min output sink current	2.8 mA
Max output voltage at current <2.8 mA	0.6 V

Logic Level 1:

Min output source current	0.4 mA
Max output voltage at current <0.4 mA	3.5 V

3 PROGRAMMABLE PARAMETERS

The 1220 controller has a number of parameters that can be programmed using a Curtis 1313 handheld programmer or 1314 Programming Station. The programmable parameters allow the steering performance to be customized to fit the needs of specific applications. The programmable parameters are grouped into nested hierarchical menus, as shown in Table 1.

Table 1 Programmable Parameter Menus

- **COMMAND DEVICE** .... p. 11
  - Redundant Input
  - Command Analog Left
  - Command Analog Center
  - Command Analog Right
  - Command Analog Fault Min
  - Command Analog Fault Max
  - **Command Map** .... p. 13
    - Left Stop (deg)
    - P1 Input
    - P1 Output (deg)
    - P2 Input
    - P2 Output (deg)
    - P3 Input
    - P3 Output (deg)
    - P4 Input
    - P4 Output (deg)
    - P5 Input
    - P5 Output (deg)
    - P6 Input
    - P6 Output (deg)
    - Right Stop (deg)

- **FEEDBACK DEVICE** .... p. 14
  - Position Feedback Device
  - **Analog** .... p. 15
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    - Position Left Stop
    - Position Center
    - Position Right Stop
    - Position Fault Min
    - Position Fault Max
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    - Encoder Steps
    - Swap Encoder Direction
    - Encoder Fault Check
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      - Homing Direction Method
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      - Homing Compensation (deg)

- **VEHICLE CONFIGURATION** .... p. 18
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  - Fault Output Control
  - Fault Steering Timeout
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  - Position Kp
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  - Velocity Ki
  - **Sensitivity Map** .... p. 22
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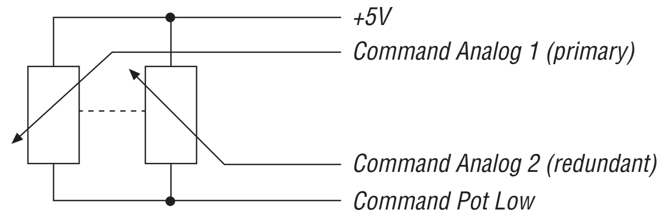
    - HS Sensitivity
    - Low Speed
    - Mid Speed
    - High Speed

CAUTION

We strongly urge you to read Section 5, Initial Setup, before adjusting any of the parameters. Even if you opt to leave most of the parameters at their default settings, **it is imperative that you perform the procedures outlined in Section 5, which set up the basic system characteristics for your application**.

COMMAND DEVICE

PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Redundant Input	Off / On	This parameter determines whether there will be a redundant steer command input. Off = Single input, to Command Analog 1 (pin J1-6) On = Redundant inputs to Command Analog 1&2 (pins J1-6, J1-13). It is best practice to wire the primary and redundant input signals in an “X” configuration (0–5V and 5V–0). When the Redundant Input is programmed Off, only a single steer command device (the Command Input Device) is used and steer command redundancy is disabled.



Command Analog Input

COMMAND DEVICE, cont'd		
PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Command Analog Left	0–5.00 V	Defines the command analog wiper voltage required to produce a steer position command of full left (Steer Command = -100% = Left Stop).
Command Analog Center	0–5.00 V	Defines the command analog wiper voltage required to produce a steer position command of center (Steer Command = 0% = 0°).
Command Analog Right	0–5.00 V	Defines the command analog wiper voltage required to produce a steer position command of full right (Steer Command = 100% = Right Stop).
Command Analog Fault Min	0–5.00 V	Sets the minimum threshold for the analog pot input. If the command analog wiper voltage goes below this threshhold for 60 ms, a fault is issued.
Command Analog Fault Max	0–5.00 V	Sets the maximum threshold for the analog pot input. If the command analog wiper voltage rises above this threshhold for 60 ms, a fault is issued.

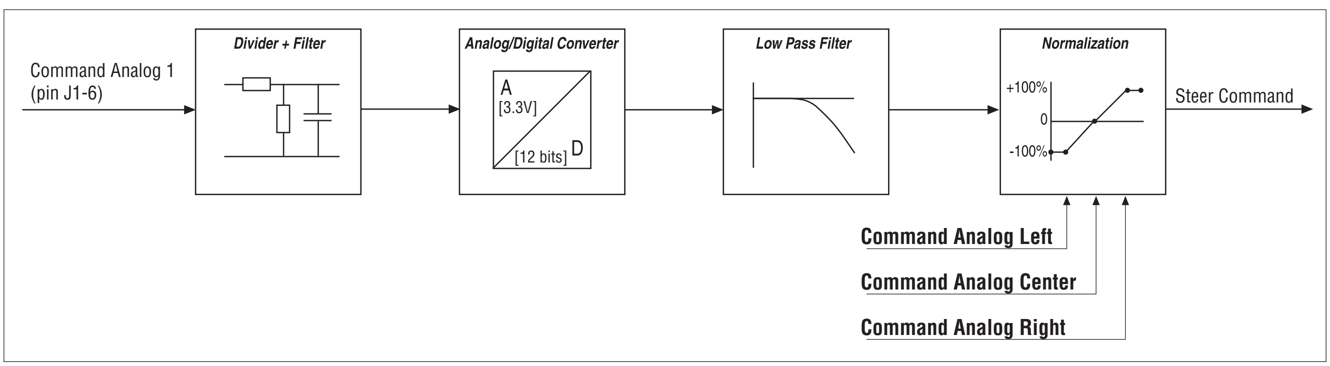


Fig. 4 *Command signal flow.*

The normalization map takes Command Analog 1 in volts and maps it to Steer Command in percent. Command Analog Left may be set higher or lower than Command Analog Right. Command Analog Center must be between Command Analog Left and Command Analog Right. Assuming Command Analog Left is less than Command Analog Right, the three points of the normalization map are defined (from left to right in the diagram above) as:

X = Command Analog Left and **Y** = -100%

X = Command Analog Center and **Y** = 0%

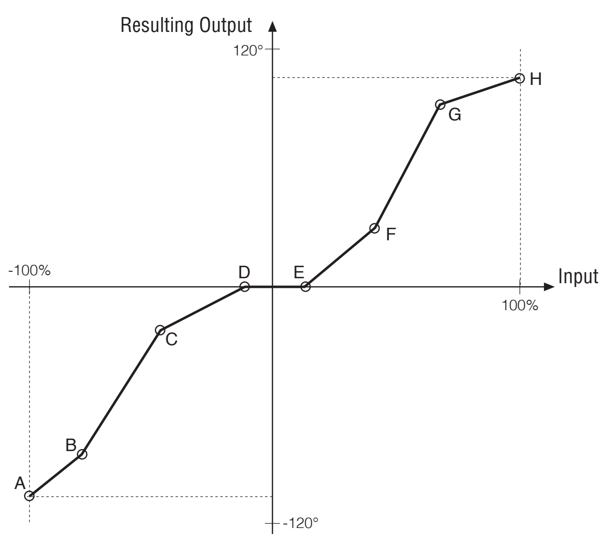
X = Command Analog Right and **Y** = 100%.

A command map is used in the input command signal flow to compensate for steering geometry differences between vehicles (steered wheel on the left side, middle, or right side).

The command map menu contains 14 parameters defining an 8-point map that modifies the steer command input. The first point (Left Stop (deg)) always defines the steer command input of -100% and the last point (Right Stop deg)) always defines the steer command input of 100%.

COMMAND DEVICE: COMMAND MAP

PARAMETER	ALLOWABLE RANGE	DESCRIPTION
P1–P6 Input	-100.0 – 100.0 %	These six parameters individually define the steer command input (in %) for the P1, P2, P3, P4, P5, and P6 Inputs.
Left Stop (deg)	-120.0° – 0.0°	These eight parameters define the steer command output (in degrees) of the steer command map. Left Stop (deg) P1 Output (deg) P2 Output (deg) P3 Output (deg) P4 Output (deg) P5 Output (deg) P6 Output (deg) Right Stop (deg)
P1–P3 Output (deg)	-120.0° – 0.0°	
P4–P6 Output (deg)	0.0° – 120.0°	
Right Stop (deg)	0.0° – 120.0°	



The steer command map is shaped by points A – H.

	X	Y
A	-100%	Left Stop (deg)
B	P1 input	P1 Output (deg)
C	P2 input	P2 Output (deg)
D	P3 input	P3 Output (deg)
E	P4 input	P4 Output (deg)
F	P5 input	P5 Output (deg)
G	P6 input	P6 Output (deg)
H	100%	Right Stop (deg)

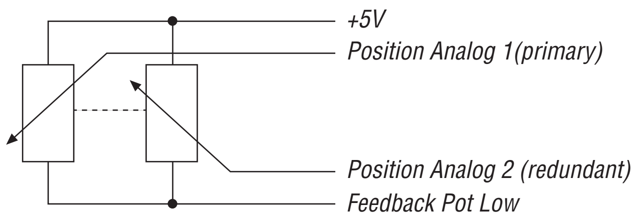
The map in this example is set up to provide a deadband in the center (points D and E) and less sensitivity at the ends (between A and B, and between G and H).

Fig. 5 *Steer command map.*

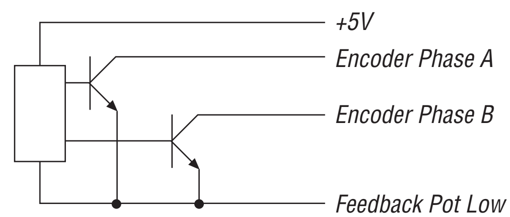
Although any map shape can be set up, **it is recommended that the map always be set so that a Steer Command of zero % equals a Steer Command (deg) of zero**.

FEEDBACK DEVICE

PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Position Feedback Device	0–2	Set this parameter to match the type of device you will be using for position feedback: 0 = Analog sensor. 1 = Polarity encoder. 2 = Quadrature encoder.



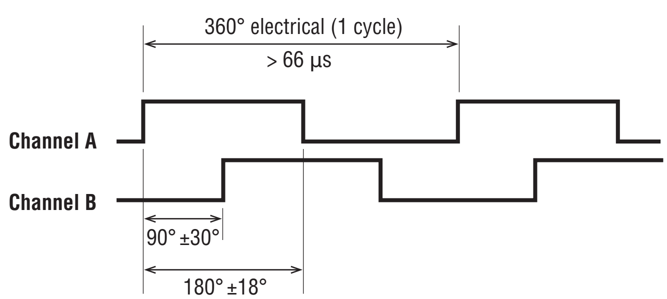
Position Analog Input
(Position Feedback Device = 0)



Position Encoder Input
(Position Feedback Device = 1 or 2)

If encoder position feedback is used, an encoder and a home switch are required.

The electrical requirements for the encoder are as shown.



The wheel position is aligned to the current steer command position upon interlock. The left stop, center, and right stop points are programmable parameters. Angular rotation is limited by means of programmable left stop (deg) and right stop (deg) parameters in the Command Map.

FEEDBACK DEVICE: ANALOG

PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Redundant Input	Off / On	Defines whether the primary (J1-11) or both (J1-11 and J1-3) position feedback inputs will be used; see Command Redundant Input, page 11.
Position Left Stop	0–5.00 V	Defines the position analog wiper voltage when the steer position feedback is at the left stop (Wheel Position = Left Stop).
Position Center	0–5.00 V	Defines the position analog wiper voltage when the steer position feedback device is at the center position (Wheel Position = 0°).
Position Right Stop	0–5.00 V	Defines the position analog wiper voltage when the steer position feedback device is at the right stop (Wheel Position = Right Stop).
Position Fault Min	0–5.00 V	Sets the minimum threshold for the position feedback analog pot input. If the position wiper voltage goes below this threshhold for 60 ms, a fault is issued.
Position Fault Max	0–5.00 V	Sets the maximum threshold for the position feedback analog pot input. If the position wiper voltage rises above this threshhold for 60 ms, a fault is issued.

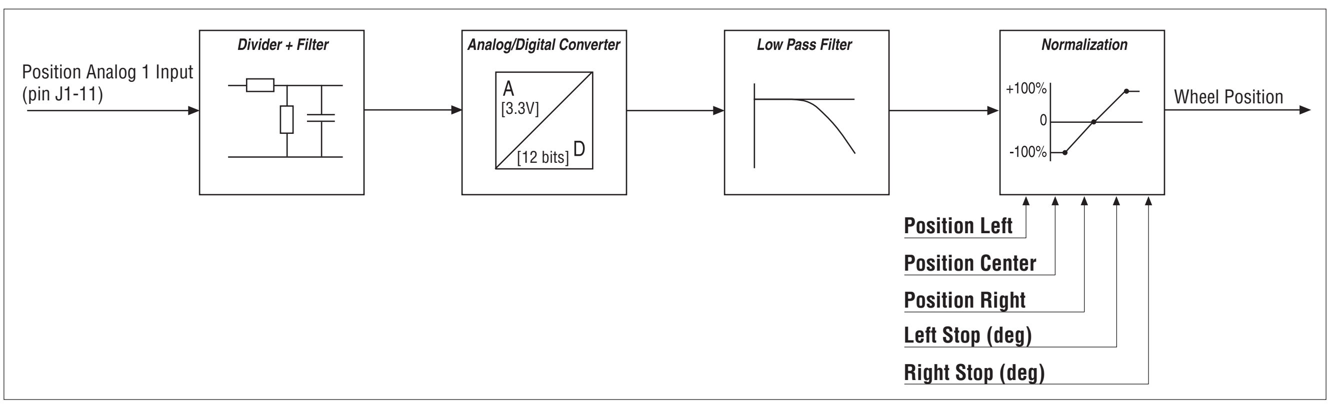


Fig. 6 *Position feedback signal flow, with analog pot.*

The normalization map takes Position Analog input in volts and maps it to Wheel Position in percent.

Position Left Stop may be set higher or lower than Position Right Stop. Position Center must be between Position Left Stop and Position Right Stop. Assuming Position Left Stop is less than Position Right Stop, the three points of the normalization map are defined (from left to right in the diagram above) as:

X = Position Left Stop and **Y** = Left Stop (deg)
X = Position Center and **Y** = 0%
X = Position Right Stop and **Y** = Right Stop (deg).

FEEDBACK DEVICE: ENCODER

PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Encoder Steps	2.0–256.0	Sets the number of encoder pulses per revolution of steering motor rotor.
Swap Encoder Direction	Off/On	This parameter changes the encoder's effective direction of rotation. It must be set such that when the tiller head is turning right, the steer motor speed is positive.
Encoder Fault Check	Off/On	The Encoder Fault Check parameter applies only to quadrature encoders (Position Feedback Device = 2). It disables/enables the encoder fault check function, which can be used to detect single wire open of Encoder Phase A or B.
Center Offset (deg)	-180.0°–180.0°	The Center Offset is the difference between the zero position (center) for the application and the home reference position (found during homing). During homing, the home position is found and once the homing is completed the zero position is offset from the home position by adding the Center Offset to the home position. All subsequent absolute moves shall be taken relative to this new zero position, including Auto Center. If the home switch is at the same position as center, set Center Offset to zero.

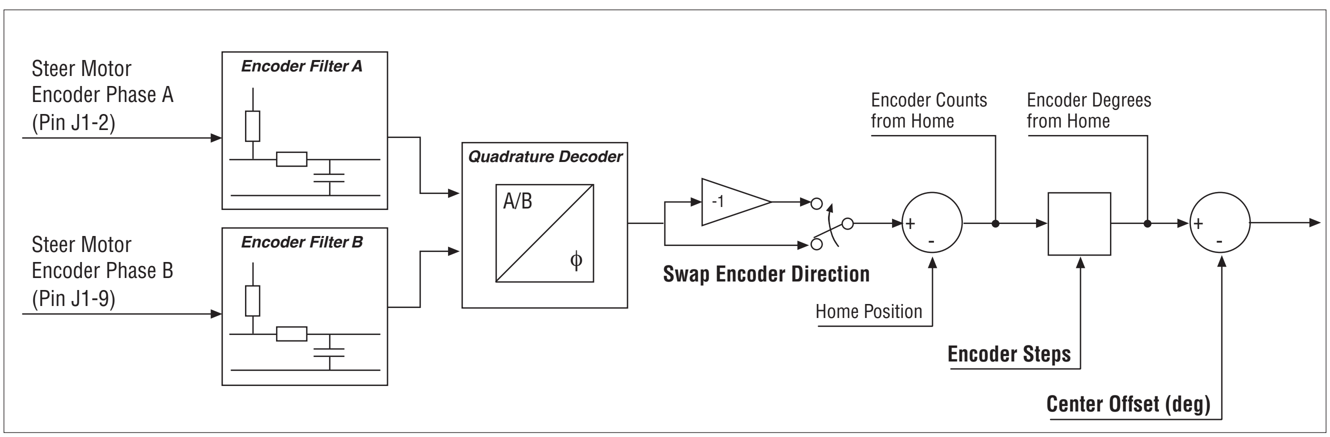
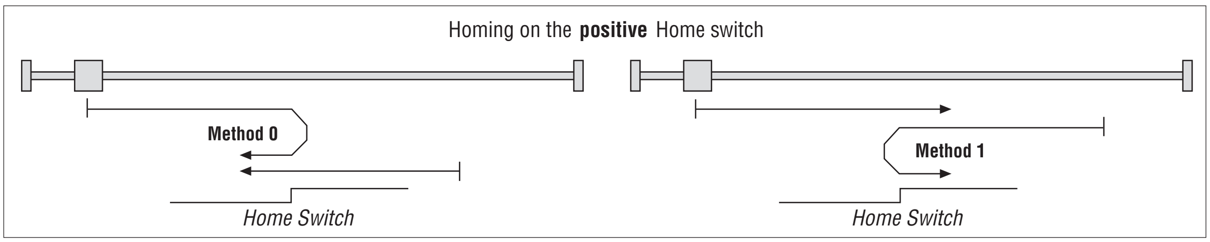


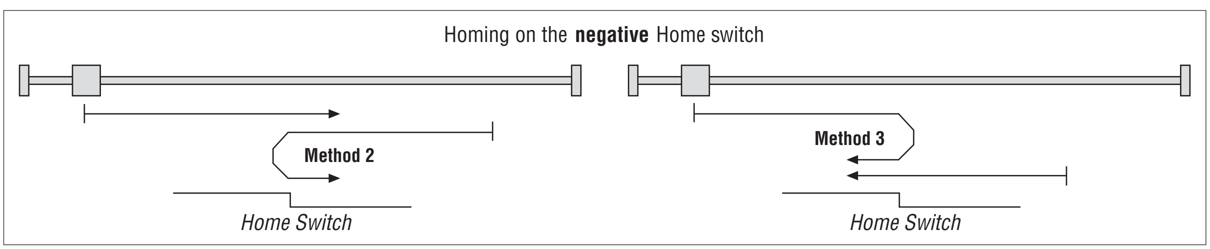
Fig. 7 *Position feedback signal flow, with motor encoder.*

FEEDBACK DEVICE: HOMING

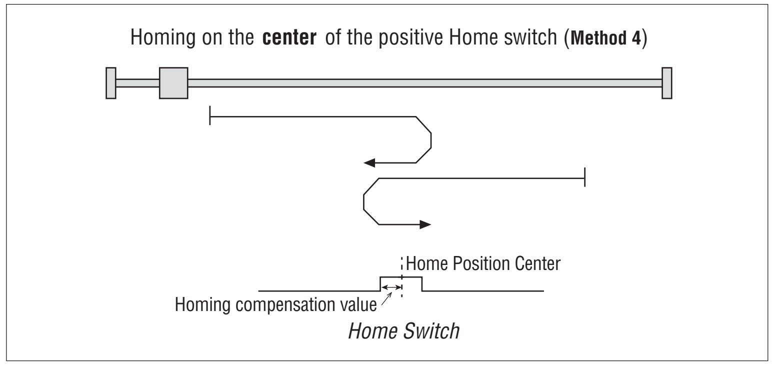
PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Homing On Interlock	Off / On	Defines when the homing function is activated. Off = Home when keyswitch is turned on. On = Homing on first Interlock. If the interlock signal is turned off during homing, the homing procedure is paused and will resume when the interlock becomes active again.
Homing Direction Method	0 – 4	Defines which method is used to find Home position. The method determines the initial direction the homing function takes and on which edge the homing function is complete. 0 = Left of positive Home switch. 1 = Right of positive Home switch. 2 = Right of negative Home switch. 3 = Left of negative Home switch. 4 = Center of positive Home switch. Methods 0 and 1 use a Home switch that is On if the wheel is to the right of it and Off if the wheel is to the left of it. At the start of homing the wheel will move to the left if the Home switch is On and to the right if it is Off. The home position is just to the left of the switch transition in method 0 and just to the right of the switch transition in method 1.



Methods 2 and 3 use a Home switch that is On if the wheel is to the left of it and Off if the wheel is to the right of it. At the start of homing the wheel will move to the right if the Home switch is On and to the left if it is Off. The home position is just to the right of the switch transition in method 2 and just to the left of the switch transition in method 3.



Method 4 uses a Home switch that is On if the wheel is just on it and Off if the wheel is not on it. At the start of homing the wheel will move in the

FEEDBACK DEVICE: HOMING, cont'd		
PARAMETER	ALLOWABLE RANGE	DESCRIPTION
		direction saved in EEPROM at the last shutdown. The home position is just at the switch transition period. 
Homing Speed	0–100 %	Defines the speed of the steering motor during the homing function, as a percentage of the steer motor Max Speed. The lower the set value of Homing Speed, the more accurate the homing will be; it is therefore recommended that Homing Speed be set as low as tolerable. Although higher values will allow the homing function to be completed more quickly, the results will be less consistent than with lower values.
Homing Compensation (Deg)	-5.0°–5.0°	This parameter is active only when the Homing Direction Method = 4. It compensates for homing to zero position from either direction.

VEHICLE CONFIGURATION MENU		
PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Interlock Type	0/1	Defines which inputs will be used to determine an interlock: 0 = KSI (interlock turns on with keyswitch). 1 = Single NO switch Input.
Sequencing Delay	0–5.0 s	The sequencing delay feature allows the interlock switch to be cycled within a set time (the sequencing delay), thus preventing inadvertent deactivation of the steering control. This feature is useful in applications where the interlock switch may bounce or be momentarily cycled during operation.
Fault Output Control	0/1	Set this parameter to match your wiring configuration: 0 = Fault output connects to traction controller interlock input. 1 = Fault output connects to traction controller main contactor coil.
Fault Steering Timeout	0.0–8.0 s	This parameter applies only when a steer fault action of either "Warning then Shutdown" or "Hold then Shutdown" is triggered (see Table 4, Troubleshooting Chart). When one of these faults is detected, the Fault Steering Timeout sets a delay from when either of these fault actions is set to when the fault output turns off.

VEHICLE CONFIGURATION: RELAY DRIVER

PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Main on Interlock	Off / On	Determines when the main relay is activated. Off = Main relay is activated when keyswitch is turned on. On = Main relay is activated when interlock is on.
Pull-in Voltage	0 – 100 %	The relay pull-in voltage parameter allows a high initial voltage when the relay driver first turns on, to ensure contactor closure. After 1 second, the pull-in voltage drops to the holding voltage. The voltage is a percentage of the nominal voltage.
Holding Voltage	0 – 100 %	The relay holding voltage parameter allows a reduced average voltage to be applied to the relay coil once it has closed. The voltage is a percentage of the nominal voltage. This parameter must be set high enough to hold the relay closed under all shock and vibration conditions the vehicle will be subjected to.
Open Delay	0 – 40 s	The open delay can be set to allow the steer relay to remain closed for a period of time (the open delay) after the interlock is turned off. The delay is useful for preventing unnecessary cycling of the relay and for maintaining power to auxiliary functions that may still be used for a short time after the interlock has turned off.

VEHICLE CONFIGURATION: TRACTION SETTINGS

PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Traction Motor Max Speed	0 – 8000 rpm	Defines the maximum speed of the traction motor in revolutions per minute.
Interlock Enable Speed	0 – 100 %	Sets the traction motor speed above which the interlock will automatically be enabled, thus enabling steering. It is a percentage of the Traction Motor Max Speed A setting of zero disables this function.
Speed Limit Angle (deg)	0 – 90°	The traction controller continuously monitors the Steering Angle Output (pin J1-12). When this angle is greater than the threshold set by the Speed Limit Angle (deg) parameter, the traction controller will reduce the traction motor speed.
Steering Angle Output Interlock	Off / On	When a 1313 programmer is connected to the traction controller, a Communication Lost fault (code 63) is issued on the 1220. If Steering Angle Output Interlock = On, the Steering Angle Output (pin J1-12) is fixed at 10V to limit the traction motor speed. If Steering Angle Output Interlock = Off, the Steering Angle Output (pin J1-12) has its full of 5–9V range according to the actual steered wheel angle regardless of the status of the Communication Lost fault. This parameter is useful during commissioning and will be set to On automatically at every startup.

CURRENT MENU

PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Drive Current Limit	0–40 A	Defines the maximum current the controller will supply to the steer motor during drive operation.
Regen Current Limit	0–40 A	Defines the maximum current the controller will supply to the steer motor during regen operation.
Boost	On / Off	Enables/disables the boost feature. When set to On, the current limit is boosted to 50A.

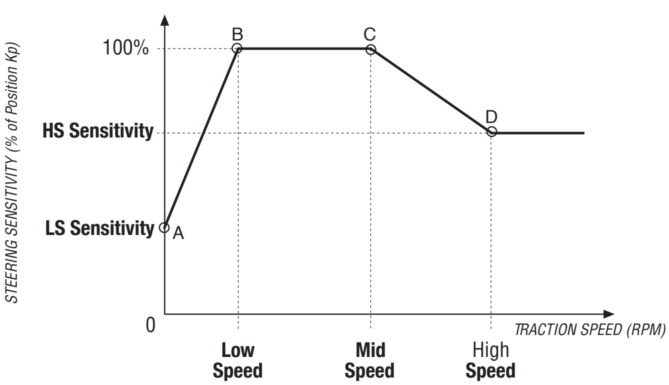
MOTOR MENU

PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Gear Ratio	0–500.0	Defines the total gear ratio of the gearbox, including its speed reducing mechanism.
Max Speed	0–8000 rpm	Defines the maximum allowed steer motor rpm.
Stall Steering Speed	0–500 rpm	These parameters are used by the motor stalled fault check. The Stall Steering Speed defines the speed below which the steer motor will be considered stalled if it remains below this speed longer than the length of time defined by the Stall Timeout parameter while the target PWM > Stall PWM or the motor current > 95% Drive Current Limit. Setting of the Stall Steering Speed = 0 turns off the motor stalled fault check.
Stall PWM	25–80 %	
Stall Timeout	0–2000 ms	
Current Rating	0–25 A	Set this parameter to the motor current rating provided by the motor manufacturer.
Max Current Time	0–120 s	Defines the maximum time the motor is allowed to run at the drive current limit.
Cutback Gain	0–100 %	When the motor overheats, the drive current is cut back until it reaches the programmed Current Rating. The Cutback Gain determines how quickly this cutback will be initiated once the programmed Max Current Time has expired. A higher setting provides faster cutback.

MOTOR CONTROL TUNING MENU

PARAMETER	ALLOWABLE RANGE	DESCRIPTION
Following Error Tolerance (deg)	0.0–5.0°	Defines the maximum difference allowed between command inputs and position feedback.
Following Error Time	0.0–20.0 s	Defines the maximum following time allowed during steering and homing operations.
Position Kp	0–100.0 %	Determines how aggressively the steer controller attempts to match the steer position to the commanded steer position. Larger values provide tighter control. If the gain is set too high, you may experience oscillations as the controller tries to control position. If it is set too low, the motor may behave sluggishly and be difficult to control. Position Kp can be fine-tuned using the Steering Sensitivity parameters.
Velocity Kp	0–100.0 %	Determines how aggressively the steer controller attempts to match the steer velocity to the determined velocity to reach the desired position. Larger values provide tighter control. If the gain is set too high, you may experience oscillations as the controller tries to control velocity. If it is set too low, the motor may behave sluggishly and be difficult to control.
Velocity Ki	0–100.0 %	The integral term (Ki) forces zero steady state error in the determined velocity, so the motor will run at exactly the determined velocity. Larger values provide tighter control. If the gain is set too high, you may experience oscillations as the controller tries to control velocity. If it is set too low, the motor may take a long time to approach the exact commanded velocity

MOTOR CONTROL TUNING: SENSITIVITY MAP		
PARAMETER	ALLOWABLE RANGE	DESCRIPTION
LS Sensitivity	0–100 %	Defines the steering sensitivity at very low traction speeds (i.e., near zero traction rpm), as a percentage of the programmed Position Kp. Sensitivity is typically reduced at low speeds to prevent excessive hunting for the commanded position.
HS Sensitivity	0–100 %	Defines the steering sensitivity at high traction speeds, as a percentage of the programmed Position Kp. Sensitivity is typically reduced at high speeds to make the vehicle easier to drive.
Low Speed	0–100 %	Defines the percentage of Traction Motor Max Speed at which 100% sensitivity will start to be applied as the vehicle accelerates.
Mid Speed	0–100 %	Defines the percentage of Traction Motor Max Speed at which 100% sensitivity will start to decrease as the vehicle decelerates.
High Speed	0–100 %	Defines the percentage of Traction Motor Max Speed at and above which the programmed HS Sensitivity value will be applied.



The steering sensitivity map is shaped by the settings of the five parameters in the Steering Sensitivity menu, with the two sensitivity parameters along the Y axis and the three speed parameters along the X axis.

	X (RPM)	Y (%)
A	0	**LS Sensitivity**
B	**Low Speed**	100%
C	**Mid Speed**	100%
D	**High Speed**	**HS Sensitivity**

The map adjusts the proportional gain (Position Kp) as a function of traction speed.

Fig. 8 *Steering sensitivity map.*

Table 2 Functions Menu		
FUNCTION	RANGE	DESCRIPTION
Restore Parameters	Yes/No	When set to Yes, will reset all programmable parameters to their factory default settings.
Clear Hourmeter	Yes/No	When set to Yes, will set the hourmeter to zero hours.

4 MONITOR MENU

Through its Monitor menu, the handheld programmer provides access to real-time data during vehicle operation. This information is helpful during diagnostics and troubleshooting, and also while adjusting programmable parameters.

Table 3 Monitor Menu

COMMAND INPUT . . . . p. 24
- Steer Command
- Target Position (deg)
- Speed Request
- Command Analog 1 Input

POSITION FEEDBACK . . . . p. 24
- Wheel Position (deg)
- Stop Position Reached
- Encoder Counts from Home
- Position Analog 1 Input

VOLTAGE . . . . p. 25
- Battery Voltage
- Capacitor Voltage
- Motor Voltage
- 5V Out

INPUTS and OUTPUTS . . . . p. 25
- Main Driver
- Main Coil Feedback
- Fault Output
- Fault Output Feedback
- Interlock Switch
- Home Switch

CONTROLLER . . . . p. 26
- Temperature
- Motor RPM
- Motor Current
- Motor Temp Cutback
- Traction Motor RPM
- Hour Meter
- **Status** . . . . p. 26
  - Interlock
  - Traction Controller Connected

Monitor Menu: COMMAND INPUT

VARIABLE	DISPLAY RANGE	DESCRIPTION
Steer Command	-100 – 100 %	The operator's steer command (in percent) that is input into the command map. the output of the command map is the Target Position (deg).
Target Position (deg)	-120.0° – 120.0°	Wheel position target for the position control loop.
Speed Request	-100 – 100 %	The calculated speed PWM command.
Command Analog 1 Input	0 – 5.50 V	Command Analog 1 input voltage.

Monitor Menu: POSITION FEEDBACK

VARIABLE	DISPLAY RANGE	DESCRIPTION
Wheel Position (deg)	-120.0° – 120.0°	Final wheel position (in degrees).
Stop Position Reached	Off / On	Flag indicating the Stop position has been reached.
Encoder Counts from Home	-2147483648 – 2147483648	Encoder counts from home position.
Position Analog 1 Input	0 – 5.50 V	Position feedback Analog 1 input voltage.

Monitor Menu: VOLTAGE

VARIABLE	DISPLAY RANGE	DESCRIPTION
Battery Voltage	0–36.3 V	Voltage of battery.
Capacitor Voltage	0–36.3 V	Voltage of steer controller's internal capacitor bank.
Motor Voltage	0–36.3 V	Voltage measured between the steer motor connectors.
5V Out	0–9.00 V	Voltage measured at the +5V output.

Monitor Menu: INPUTS and OUTPUTS

VARIABLE	DISPLAY RANGE	DESCRIPTION
Main Driver	Off/On	Flag indicating the main relay driver status.
Main Coil Feedback	Off/On	Flag indicating the main relay coil feedback status. If it does not match the main relay driver status, a fault is issured.
Fault Output	Off/On	Flag indicating the Fault Output status.
Fault Output Feedback	Off/On	Flag indicating the Fault Output feedback status. If it does not match the Fault Output status, a fault is issured.
Interlock Switch	Off/On	Flag indicating the interlock switch status.
Home Switch	Off/On	Flag indicating the home switch status.

Monitor Menu: CONTROLLER

VARIABLE	DISPLAY RANGE	DESCRIPTION
Temperature	-50°C – 100°C	Controller's internal temperature.
Motor RPM	-8000 – 8000 rpm	Steer motor speed in revolutions per minute.
Motor Current	-60 – 60 A	Current of the steer motor.
Motor Temp Cutback	0 – 100 %	Current cutback, as a percentage of max current, during motor over-temperature. 100% = no cutback.
Traction Motor RPM	-8000 – 8000 rpm	Traction motor speed in revolutions per minute.
Hour Meter	0 – 1000000.0 h	Number of hours KSI has been active.

Monitor Menu: CONTROLLER → Status

VARIABLE	DISPLAY RANGE	DESCRIPTION
Interlock	Off / On	Flag indicating the interlock status.
Traction Controller Connected	Off / On	Flag indicating the status of communcation between the steer controller and the traction controller.

5 COMMISSIONING

The 1220 steer controller can be used in a variety of vehicles, which differ in characteristics and in their input and feedback devices. Before driving the vehicle, it is important that the commissioning procedures be carefully followed to ensure that the controller is set up to be compatible with your application.

The 1220 controller must be used in conjunction with a Curtis AC traction controller with VCL. The Curtis traction controller must implement special software (VCL) to communicate with the 1220 controller, in order to support safe vehicle operation.

A single main contactor can be used to support both traction and steer controllers. **All vehicles must use the Fault Output connection** (J3-1) to allow the 1220 to disable the traction controller's main contactor coil or interlock input during certain fault conditions.

> Before starting the commissioning procedures, **jack the vehicle drive wheels up off the ground** so that they spin freely and steer freely from stop to stop. **Manually disable the Interlock** (traction and steer) so that the 1220 will not begin steering and the traction wheel will not turn. Double-check all wiring to ensure it is consistent with the wiring guidelines presented in Section 2. Make sure all connections are tight. Turn on the controller and plug in the handheld programmer.

The commissioning procedures are grouped into four sections, as follows.

The first section covers the initial setting of various parameters, before the actual commissioning begins.

① Preparation for commissioning

The procedures in the second section set up the steer command. The 1220 interlock and the traction interlock both remain Off.

② Command Map setup.

③ Command Input Device setup

The procedures in the third section require the steer motor to turn, so the 1220 interlock (the steer interlock) must be set to On. The vehicle drive wheels continue to be jacked up off the ground to they can spin freely and steer freely from stop to stop.

④ Position Feedback Device setup
 “0” — Setup for Pot feedback
 “1/2” — Setup for Encoder feedback

⑤ Set the Motor Control Tuning parameters

⑥ Verify the Position Feedback Setup

⑦ Resolve any existing faults

Last, the vehicle drive wheels are lowered to the ground and the final procedures are conducted. For these procedures, the traction interlock must also be set to On.

⑧ Set the Center Offset parameter

⑨ Set the remaining Motor parameters

⑩ Adjust the Sensitivity Map.

① Preparation for commissioning

Lower these five parameter values to force low steering performance and stable response (with the wheel off the ground) while the setup procedures are performed:

MOTOR
Max Speed = 1000 rpm or lower

CURRENT
Drive Current Limit = 20%

MOTOR CONTROL TUNING
Position Kp = 5%
Velocity Kp = 5%
Velocity Ki = 5%.

Verify that the 1220 interlock = Off (Monitor » Inputs & Outputs » Interlock Switch) and the traction controller interlock = Off. If either interlock is On, either change the interlock input to the controllers or adjust the **Interlock Type** parameter until the interlock variables are both Off. If the interlock is accidentally set to On during commissioning, the steered wheel may turn without warning.

Set the following parameters based on the vehicle configuration and your desired performance characteristics.

MOTOR
Gear Ratio
Current Rating

VEHICLE CONFIGURATION
Interlock Type
Sequencing Delay
Fault Output Control
Fault Steering Timeout

VEHICLE CONFIGURATION → Relay Driver
Main On Interlock
Pull-In Voltage
Holding Voltage
Open Delay

VEHICLE CONFIGURATION → Traction Settings
Traction Motor Max Speed
Interlock Enable Speed
Speed Limit Angle (deg)
Steering Angle Output Interlock

Verify that the correct VCL software is loaded into the Curtis AC traction controller to support the 1220. Resolve any problems with the traction software before continuing on to the commissioning procedures.

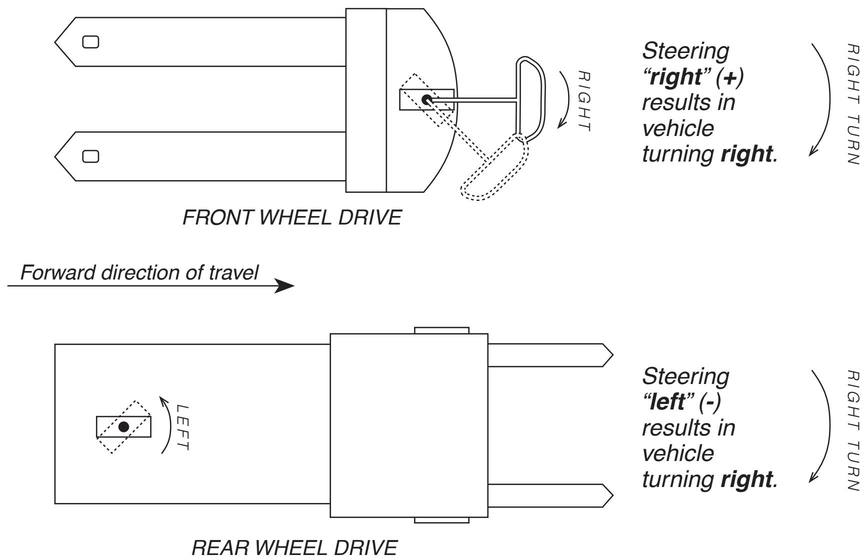
Steer Direction

Parameter and monitor values for wheel position and steer motor speed are signed (i.e., they are positive and negative values).

Right wheel positions (positive values) are such that when traveling in the forward vehicle direction in a vehicle with the steered wheel in the front the steer direction is to the driver's right.

Left wheel positions (negative values) are such that when traveling in the forward vehicle direction in a vehicle with the steered wheel in the front the steer direction is to the driver's left.

In vehicles where the steered wheel is in the back, these directions are reversed.



② Command Map setup *(see page 13)*

The fourteen parameters in the Command Map menu define an 8-point map, as described on page 13. The *input* to the Command Map (in units of %) can be observed in Monitor » Command Input » *Steer Command*. The *output* to the Command Map (in units of degrees) can be observed in Monitor » Command Input » *Target Position (deg)*.

The **Left Stop (deg)** parameter is paired with a value of -100%, and the **Right Stop (deg)** parameter is paired with a value of 100%. The **P1-P6 Output** values fill in the continuum between the two stops; these values should get positive when center is crossed. Similarly, the **P1-P6 Input** parameters should start with negative percent values and increase to positive percent values. The settings of the point pairs can be customized to shape the map according to the needs of the application. In general, starting with a linear command map without any deadband is recommended for vehicles that have the steered wheel in the center.

IMPORTANT

Setting the **Left Stop (deg)** and **Right Stop (deg)** to the correct angle is critical to the setup of the vehicle as these two parameters set the maximum steering angle. They must be set before continuing on to set up the position feedback.

Although any map shape can be set up, it is recommended that the map always be set so that a *Steer Command* of zero equals a *Target Position (deg)* of zero.

③ Command Input Device setup *(see page 11)*

Your steering command input device will be a dual potentiometer (using pins J1-6 and J1-13). Most applications will have a primary command input device and a redundant input device. For applications with only a primary command input device, you will need to set the **Redundant Input Device** parameter to Off.

Set the **Redundant Input** parameter to the type of input you will be using:

Redundant Input
Off = Single input only
On = Redundant input

Setup for Analog Pot input

Note: The steer motor should not respond to this command input because the Interlock is Off. If the steer motor shows any movement (or if the Interlock is On), stop and resolve the issue; see Preparation for Commissioning, page 29.

a. Move the steer command pots to the Left position (not to the actual physical stop, but a small amount away, to allow for pot tolerance variation) and observe the voltage shown in the Monitor » Command Input » *Command Analog 1 Input* variable. Set the parameter **Command Analog Left** to the observed voltage.

b. Move the steer command pots to the Center position and observe the voltage shown in the *Command Analog 1 Input* variable. Set the parameter **Command Analog Center** to the observed voltage.

c. Move the steer command pots to the Right position (not to the actual physical stop, but a small amount away, to allow for pot tolerance variation) and observe the voltage shown in the *Command Analog 1 Input* variable. Set the parameter **Command Analog Right** to the observed voltage.

d. Set the two fault parameters (**Command Analog Fault Min**, and **Command Analog Fault Max**). Set these to voltages that will not be reached during normal operation, but will be reached when the steer command inputs become faulty (e.g., should there be an open or short circuit).

The **Command Analog Fault Min** setting must be below the minimum voltage seen on *Command Analog 1 Input* when steered to the maximum left or right positions.

The **Command Analog Fault Max** setting must be above the maximum voltage seen on *Command Analog 1 Input* when steered to the maximum left or right positions.

IMPORTANT

> Continuing with the commissioning procedures will require the steer motor to turn, so you will have to enable the steer interlock (interlock = On). The vehicle drive wheels should continue to be jacked up off the ground so they can spin freely and steer freely from stop to stop. **Enabling the steer interlock can result in erratic movement of the steer motor.**

④ Position Feedback Device Setup *(see pages 14–16)*

Manually enable the steer interlock, so that the 1220 will begin steering; the traction interlock can remain Off. Verify that the 1220 interlock is now On (Monitor » Inputs&Outputs » *Interlock Switch*). If *Interlock Switch* = Off, resolve the fault condition that is causing this, change the interlock input to the steer controller, or adjust the Interlock Type parameter (Vehicle Configuration » **Interlock Type**) until the *Interlock Switch* variable = On.

Your position feedback device will be a potentiometer (using pin J1-11) or a motor encoder with a Home switch (using pins J1-2 and J1-9 for the motor encoder and J3-2 for the Home switch).

Set the **Position Feedback Device** and **Redundant Input** parameters to match your input type:

Position Feedback Device Type	**Redundant Input** Type
0 = Analog pot.	**Off** = Single input.
1 = Polarity encoder.	**On** = Redundant inputs.
2 = Quadrature encoder.	

Use the appropriate setup procedure for the type of device you have chosen.

Setup for Analog Pot feedback *(see page 15)*

a. Use the tiller to move the steered wheel to the Left stop and observe the voltage shown in the Monitor » Position Feedback » *Position Analog 1 Input* variable. Set the **Position Left Stop** parameter to the observed voltage.

b. Similarly, move the steered wheel to the center and observe the voltage shown in the *Position Analog 1 Input* variable. Set the parameter **Position Center** parameter to the observed voltage.

c. Finally, move the steered wheel to the Right stop and again observe the voltage shown in the *Position Analog 1 Input* variable. Set the parameter **Position Right Stop** parameter to the observed voltage.

d. Set the two fault parameters (**Position Fault Min** and **Position Fault Max**). Set these to voltages that will not be reached during normal operation, but will be reached if the steer position feedback becomes faulty (e.g., should there be an open or short circuit).

   The **Position Fault Min** setting must be below the minimum voltage seen on *Position Analog 1 Input* when steered to the maximum left or right positions.

   The **Position Fault Max** setting must be above the maximum voltage seen on *Position Analog 1 Input* when steered to the maximum left or right positions.

Setup for Encoder feedback and Home Switch *(see pages 16–17)*

a. Verify that the feedback position encoder is working in the correct direction. Steer to the right, and observe the Monitor » Controller » *Motor RPM* variable. In a vehicle traveling forward with the steer motor in front, this value should be positive; see diagram on page 30. If necessary, change the Program » Feedback Device » Encoder » **Swap Encoder Direction** parameter.

b. Set the **Homing Direction Method**, **Home on Interlock**, and **Homing Speed** parameters. **Homing Speed** can be set to a lower speed than required as the final setting will be performed in Step ⑤-a.

c. Review the diagrams in the **Homing Direction Method** parameter description on page 17. Then determine the correct **Homing Direction Method** by observing the Monitor » Inputs and Outputs » *Home Switch* variable while also observing the position of the steered wheel and the Home switch.

If *Home Switch* = On and the steered wheel is to the right of the Home switch (or *Home Switch* = Off and steered wheel is to the left), setting **Homing Direction Method** to either 0 or 1 will result in the correct direction toward the Home switch during homing. Choose 0 or 1 depending on which side of the Home switch you prefer the steered wheel to be when homing is complete.

If *Home Switch* = On and the steered wheel is to the left of the Home switch (or *Home Switch* = Off and steered wheel is to the right), setting **Homing Direction Method** to either 2 or 3 will result in the correct direction toward the Home switch during homing. Choose 2 or 3 depending on which side of the Home switch you prefer the steered wheel to be when homing is complete.

If *Home Switch* = On and the steered wheel is just on the Home switch (and when *Home Switch* = Off when the steered wheel is not on the Home switch), set **Homing Direction Method** to 4. Then set **Homing Compensation (deg)** to the value shown in the Monitor » Command Input » *Target Position (deg)* variable after steering the tiller head and making the steered wheel just on the center of the Home switch.

After setting the **Homing Direction Method**, verify that the homing function works correctly starting from either side of the Home switch.

d. The correct settings for **Encoder Steps** (pulses per revolution, or PPR) can be calculated as follows.

(1) If the encoder is installed *before* the motor gearbox (i.e., attached to the steer motor rotor),

Encoder Single Pulse Period = $60*10^6$/(Max Steer Motor RPM*Encoder PPR) should be > 66µs.

Example: Max Steer Motor RPM = 3000.

$60*10^6$/(3000*Encoder PPR) > 66
Encoder PPR < 303

(2) If the encoder is installed *after* the motor gearbox,

Encoder Single Pulse Period = Gearbos Ratio*60*10^6/(Max Steer Motor RPM*Encoder PPR) should be > 66μs.

Example: Max Steer Motor RPM = 3000.
Gearbox ratio = 40:1.

40*60*10^6/(3000*Encoder PPR) > 66
Encoder PPR < 12120

In either case, we recommend setting **Encoder Steps** to a value greater than 16 to avoid possible sampling error which will lead to poor following accuracy.

⑤ Set the Motor Control Tuning parameters *(see page 21)*

a. Restore these two parameter values to their desired performance settings:

Motor » **Max Speed**
Current » **Drive Current Limit**.

If **Position Feedback Device** = 2, set **Homing Speed** (which is a percentage of **Max Speed**) to the desired setting.

b. Temporarily set Steering Sensitivity » **LS Sensitivity** and **HS Sensitivity** = 100%.

With this setting, and the drive wheels still jacked up off the ground, set the three parameters in the Motor Control Tuning menu (see page 21) to get correct responsiveness to the steer command input.

Note: Setting these values too high will result in unstable responsiveness. Increase these values as high as possible without becoming unstable:

Motor Control Tuning » **Position Kp**
Motor Control Tuning » **Velocity Kp**
Motor Control Tuning » **Velocity Ki**.

After setting these three parameters, return **LS Sensitivity** and **HS Sensitivity** to their proper values.

⑥ Verify the position feedback setup

To verify the setup thus far, observe Monitor » Position Feedback » *Wheel Position (deg)* while exercising the steer command input device over the entire operational steer range. If the signal gives an undesired output, go back and resolve this problem before continuing.

⑦ Resolve any existing faults

Cycle the Keyswitch input to reset the vehicle controllers. Check the active faults in the controller and resolve any faults until all have been cleared. All faults must be cleared before lowering the vehicle drive wheels to the ground. Use Section 6 for help in troubleshooting. Contact your Curtis customer support engineer to resolve any remaining issues about faults before continuing.

CAUTION

Do not take the vehicle down off the blocks until both the steer and traction motors are responding properly. Once the motors are responding properly, lower the vehicle to put the drive wheels on the ground.

⑧ Set the Center Offset parameter *(see page 16)*

While driving the vehicle, initiate a homing action and note the home reference position reached. Set the Center Offset to the difference between this value and the true center (zero) position for the application.

⑨ Set the remaining Motor parameters *(see page 20)*

Set Motor»**Stall Steering Speed**, **Stall PWM**, and **Stall Timeout** to appropriate values that will not cause a fault during normal operation, but will trigger a fault during a real stall condition.

Set Motor»**Max Current Time** and **Cutback Gain** as desired.

⑩ Set the Sensitivity Map parameters *(see page 22)*

Drive the vehicle through a wide range of turning and speed scenarios, and adjust the Motor Control Tuning»Sensitivity Map»**Low Speed**, **Mid Speed**, and **High Speed** parameters to create the desired sensitivity map.

6

DIAGNOSTICS & TROUBLESHOOTING

The 1220 controller detects a wide variety of fault conditions. Faults with the steering controller typically affect the traction controller as well, as shown in the troubleshooting chart.

Faults are displayed on the handheld programmer. If you have a LED device attached to the Status LED driver (pin J1-1), the fault codes will be flashed by that device. The numerical codes used by the LED are listed in the troubleshooting chart (Table 4),

The troubleshooting chart, Table 4, provides the following information about each controller fault:

- fault code
- fault name as displayed on the programmer's LCD
- possible causes of the fault
- fault clear conditions
- steer fault action (effect of fault on steering)
- traction fault action (effect of fault on traction)

For each fault, the chart shows one of these six **Steer Fault actions:**

Warning Only — The 1220 still operates normally.

Shutdown — Immediate shutdown of the 1220 and turn-off of the fault output (pin J3-1).

Warning and reduced current limit — Steer motor current is reduced, to protect the controller.

Warning and maximizing steering angle output voltage — Steering angle output voltage (pin J1-12) is maximized, which limits the traction motor RPM.

Warning then Shutdown — The 1220 continues to operate until the traction motor comes to a stop or the timer (set by Fault Steering Timeout) expires. After this occurs, the Shutdown action takes place.

Hold then Shutdown — The 1220 tries to hold the existing wheel position regardless of operator input until the traction motor comes to a stop or the timer (set by Fault Steering Timeout) expires. After this occurs, the Shutdown action takes place.

Whenever a fault is encountered and no wiring or vehicle fault can be found, shut off KSI and turn it back on to see if the fault clears. If it does not, shut off KSI and remove the J1, J2, and J3 connectors. Check the connectors for corrosion or damage, clean them if necessary, and re-insert them.

Table 4 TROUBLESHOOTING CHART

FLASH CODE	NAME	POSSIBLE CAUSE	CLEAR CONDITION	STEER FAULT ACTION	TRACTION FAULT ACTION
12	Controller Overcurrent	1. Steer motor wires shorted. 2. Controller defective.	Cycle KSI.	Shutdown.	Stop.
13	Current Sense Fault	1. Controller defective.	Cycle KSI.	Shutdown.	Stop.
14	Precharge Fault	1. Controller defective.	Cycle KSI.	Shutdown.	Stop.
15	Controller Severe Undertemp	1. Controller is operating in extreme low temperature environment. 2. Temperature sensor broken.	Bring heatsink temperature above -35°C.	Warning Only.	No action.
16	Controller Severe Overtemp	1. Excessive load on vehicle. 2. Controller is operating in an extreme high temperature environment. 3. Improper mounting of controller..	Cycle KSI.	Warning then Shutdown.	Stop.
17	Severe Undervoltage	1. Battery or battery cables or battery connections defective. 2. Excessive non-controller hydraulic system drain on battery. 3. Battery discharged or improper battery.	Cycle KSI.	Shutdown.	Stop.
18	Severe Overvoltage	1. Battery or battery cable resistance too high for a given regen current. 2. Battery disconnected while regen braking.	Cycle KSI.	Shutdown.	Stop.
21	Motor Temp Hot Cutback	1. Excessive load on vehicle. 2. Controller is operating in an extreme high temperature environment.	Bring estimated steering motor temperature back within range.	Warning and reduced current limit.	No action.
22	Controller Overtemp	1. Excessive load on vehicle. 2. Controller is operating in an extreme high temperature environment. 3. Improper mounting of controller.	Bring heatsink temperature below 85°C.	Warning Only.	Speed reduced.
23	Motor Polarity Fault	1. Motor polarity reversed. 2. Position feedback device polarity reversed.	Cycle KSI.	Shutdown.	Stop.
24	5V Output Failure	1. +5V output overloaded. 2. Controller defective.	Cycle KSI.	Hold then Shutdown.	Stop.
31	Main Driver Fault	1. Internal relay coil is broken. 2. Internal relay driver is open or shorted.	Cycle KSI.	Warning then Shutdown.	Stop.
32	Relay Welded	1. Internal relay welded. 2. Controller defective.	Cycle KSI.	Shutdown.	Stop.
33	Relay Did Not Close	1. Internal relay was commanded to close but it did not. 2. Internal relay tips oxidized.	Cycle KSI.	Shutdown.	Stop.
34	Hardware Fault	1. Hardware error detected. 2. Motor voltage out of range. 3. IIC communication failed. 4. Power MOSFETs shorted.	Cycle KSI.	Shutdown.	Stop.

Table 4 TROUBLESHOOTING CHART, cont'd

FLASH CODE	NAME	POSSIBLE CAUSE	CLEAR CONDITION	STEER FAULT ACTION	TRACTION FAULT ACTION
35	Fault Output Failed	1. Incorrect Fault Output wiring. 2. Controller defective.	Cycle KSI.	Shutdown.	Stop.
36	Motor Stalled	1. Stalled steer motor. 2. Steer motor encoder failure or wires open. 3. Steer motor wires open. 4. Related parameters do not match with steer motor.	Cycle KSI.	Shutdown.	Stop.
37	Motor Open	1. Steer motor wires open. 2. Faulty motor cable wiring. 3. Controller defective.	Cycle KSI.	Warning then Shutdown.	Stop.
38	Motor Short	1. Steer motor wires shorted.	Cycle KSI.	Shutdown.	Stop.
41	Command Analog1 Out of Range	1. Command Analog input 1 (J1-6) is out of range. 2. Incorrect parameter settings.	Cycle KSI.	Hold then Shutdown.	Stop.
42	Command Analog2 Out of Range	1. Command Analog input 2 (J1-13) is out of range. 2. Crosscheck on Command Analog Input 1 and Command Analog Input 2 failed. 3. Incorrect parameter settings.	Cycle KSI.	Hold then Shutdown.	Stop.
43	Feedback Analog1 of Range	1. Position Analog input 1 (J1-11) is out of range. 2. Incorrect parameter settings.	Cycle KSI.	Hold then Shutdown.	Stop.
44	Feedback Analog2 Out of Range	1. Position Analog input 2 (J1-3) is out of range. 2. The crosscheck on Position Analog input 1 (J1-11) and Position Analog input 2 (J1-3) failed. 3. Incorrect parameter settings.	Cycle KSI.	Hold then Shutdown.	Stop.
45	Parameter Change Fault	1. A parameter value was changed that requires a power cycle. 2. Parameters were restored to their original vslues.	Cycle KSI.	Shutdown.	Stop.
46	EEPROM Failure	1. The CRC of the parameters in EEPROM does not calculate correctly. 2. Controller defective.	Cycle KSI.	Hold then Shutdown.	Stop.
47	Encoder Fault	1. Encoder data is outside the allowed range. 2. Encoder Phase A or B on the quadrature encoder is open. 3. Encoder Phase B on polarity encoder is open.	Cycle KSI.	Warning then Shutdown.	Stop.
53	Home Position Not Found	1. Home switch defective. 2. Mounting or wiring defective.	Cycle KSI.	Shutdown.	Stop.
62	Communication Fault	1. Handshake with traction controller failed at startup.	Cycle KSI.	Shutdown	Stop.

Table 4 TROUBLESHOOTING CHART, cont'd

FLASH CODE	NAME	POSSIBLE CAUSE	CLEAR CONDITION	STEER FAULT ACTION	TRACTION FAULT ACTION
63	Communication Lost	1. Broken wiring on Rx (J1-8). 2. Programmer (1313/1314) is connecting with traction controller.	Receive the Spyglass message.	Warning and maximizing steering angle output voltage.	Speed reduced.
71	Software Fault	1. Software defective. 2. Controller defective.	Cycle KSI.	Shutdown.	Stop.
73	Following Error	1. Incorrect parameter settings. 2. Position feedback device defective. 3. Steer motor defective.	Cycle KSI.	Warning then Shutdown.	Stop.
75	Parameter Conflict	1. Parameter settings are in conflict with each other.	Cycle KSI.	Shutdown.	Stop.

7 MAINTENANCE

There are no user serviceable parts in Curtis 1220 controllers. **No attempt should be made to open, repair, or otherwise modify the controller.** Doing so may damage the controller and will void the warranty.

It is recommended that the controller and connections be kept clean and dry and that the controller's fault history file be checked and cleared periodically.

CLEANING

Periodically cleaning the controller exterior will help protect it against corrosion and possible electrical control problems created by dirt, grime, and chemicals that are part of the operating environment and that normally exist in battery powered systems.

CAUTION

When working around any battery powered system, proper safety precautions should be taken. These include, but are not limited to: proper training, wearing eye protection, and avoiding loose clothing and jewelry.

Use the following cleaning procedure for routine maintenance. Never use a high pressure washer to clean the controller.

1. Remove power by disconnecting the battery.
2. Remove any dirt or corrosion from the power and signal connector areas. The controller should be wiped clean with a moist rag. Dry it before reconnecting the battery.
3. Make sure the connections are tight.

FAULT HISTORY

The handheld programmer can be used to access the controller's fault history file. The programmer will read out all the faults the controller has experienced since the last time the fault history file was cleared. Faults such as contactor faults may be the result of loose wires; contactor wiring should be carefully checked. Faults such as overtemperature may be caused by operator habits or by overloading.

After a problem has been diagnosed and corrected, it is a good idea to clear the fault history file. This allows the controller to accumulate a new file of faults. By checking the new fault history file at a later date, you can readily determine whether the problem was indeed fixed.

APPENDIX A

VEHICLE DESIGN CONSIDERATIONS
REGARDING ELECTROMAGNETIC COMPATIBILITY (EMC)
AND ELECTROSTATIC DISCHARGE (ESD)

ELECTROMAGNETIC COMPATIBILITY (EMC)

Electromagnetic compatibility (EMC) encompasses two areas: emissions and immunity. *Emissions* are radio frequency (RF) energy generated by a product. This energy has the potential to interfere with communications systems such as radio, television, cellular phones, dispatching, aircraft, etc. *Immunity* is the ability of a product to operate normally in the presence of RF energy.

EMC is ultimately a system design issue. Part of the EMC performance is designed into or inherent in each component; another part is designed into or inherent in end product characteristics such as shielding, wiring, and layout; and, finally, a portion is a function of the interactions between all these parts. The design techniques presented below can enhance EMC performance in products that use Curtis motor controllers.

Emissions

Signals with high frequency content can produce significant emissions if connected to a large enough radiating area (created by long wires spaced far apart). Contactor drivers and the motor drive output from Curtis controllers can contribute to RF emissions. Both types of output are pulse width modulated square waves with fast rise and fall times that are rich in harmonics. (Note: contactor drivers that are not modulated will not contribute to emissions.) The impact of these switching waveforms can be minimized by making the wires from the controller to the contactor or motor as short as possible and by placing the wires near each other (bundle contactor wires with Coil Return; bundle motor wires separately).

For applications requiring very low emissions, the solution may involve enclosing the controller, interconnect wires, contactors, and motor together in one shielded box. Emissions can also couple to battery supply leads and throttle circuit wires outside the box, so ferrite beads near the controller may also be required on these unshielded wires in some applications. It is best to keep the noisy signals as far as possible from sensitive wires.

Immunity

Immunity to radiated electric fields can be improved either by reducing overall circuit sensitivity or by keeping undesired signals away from this circuitry. The controller circuitry itself cannot be made less sensitive, since it must accurately detect and process low level signals from sensors such as the throttle potenti-ometer. Thus immunity is generally achieved by preventing the external RF energy from coupling into sensitive circuitry. This RF energy can get into the controller circuitry via conducted paths and radiated paths.

Conducted paths are created by the wires connected to the controller. These wires act as antennas and the amount of RF energy coupled into them is generally proportional to their length. The RF voltages and currents induced in each wire are applied to the controller pin to which the wire is connected. Curtis controllers include bypass capacitors on the printed circuit board's throttle wires to reduce the impact of this RF energy on the internal circuitry. In some applications, additional filtering in the form of ferrite beads may also be required on various wires to achieve desired performance levels.

Radiated paths are created when the controller circuitry is immersed in an external field. This coupling can be reduced by placing the controller as far as possible from the noise source or by enclosing the controller in a metal box. Some Curtis controllers are enclosed by a heatsink that also provides shielding around the controller circuitry, while others are partially shielded or unshielded. In some applications, the vehicle designer will need to mount the controller within a shielded box on the end product. The box can be constructed of just about any metal, although steel and aluminum are most commonly used.

Most coated plastics do not provide good shielding because the coatings are not true metals, but rather a mixture of small metal particles in a non-conductive binder. These relatively isolated particles may appear to be good based on a dc resistance measurement but do not provide adequate electron mobility to yield good shielding effectiveness. Electroless plating of plastic will yield a true metal and can thus be effective as an RF shield, but it is usually more expensive than the coatings.

A contiguous metal enclosure without any holes or seams, known as a Faraday cage, provides the best shielding for the given material and frequency. When a hole or holes are added, RF currents flowing on the outside surface of the shield must take a longer path to get around the hole than if the surface was contiguous. As more "bending" is required of these currents, more energy is coupled to the inside surface, and thus the shielding effectiveness is reduced. The reduction in shielding is a function of the longest linear dimension of a hole rather than the area. This concept is often applied where ventilation is necessary, in which case many small holes are preferable to a few larger ones.

Applying this same concept to seams or joints between adjacent pieces or segments of a shielded enclosure, it is important to minimize the open length of these seams. Seam length is the distance between points where good ohmic contact is made. This contact can be provided by solder, welds, or pressure contact. If pressure contact is used, attention must be paid to the corrosion characteristics of the shield material and any corrosion-resistant processes applied to the base material. If the ohmic contact itself is not continuous, the shielding effectiveness can be maximized by making the joints between adjacent pieces overlapping rather than abutted.

The shielding effectiveness of an enclosure is further reduced when a wire passes through a hole in the enclosure; RF energy on the wire from an external field is re-radiated into the interior of the enclosure. This coupling mechanism can be reduced by filtering the wire where it passes through the shield boundary.

Given the safety considerations involved in connecting electrical components to the chassis or frame in battery powered vehicles, such filtering will usually consist of a series inductor (or ferrite bead) rather than a shunt capacitor. If a capacitor is used, it must have a voltage rating and leakage characteristics that will allow the end product to meet applicable safety regulations.

The B+ (and B-, if applicable) wires that supply power to a control panel should be bundled with the other control wires to the panel so that all these wires are routed together. If the wires to the control panel are routed separately, a larger loop area is formed. Larger loop areas produce more efficient antennas which will result in decreased immunity performance.

Keep all low power I/O separate from the motor and battery leads. When this is not possible, cross them at right angles.

ELECTROSTATIC DISCHARGE (ESD)

Curtis motor controllers contain ESD-sensitive components, and it is therefore necessary to protect them from ESD (electrostatic discharge) damage. Most of these control lines have protection for moderate ESD events, but must be protected from damage if higher levels exist in a particular application.

ESD immunity is achieved either by providing sufficient distance between conductors and the ESD source so that a discharge will not occur, or by providing an intentional path for the discharge current such that the circuit is isolated from the electric and magnetic fields produced by the discharge. In general the guidelines presented above for increasing radiated immunity will also provide increased ESD immunity.

It is usually easier to prevent the discharge from occurring than to divert the current path. A fundamental technique for ESD prevention is to provide adequately thick insulation between all metal conductors and the outside environment so that the voltage gradient does not exceed the threshold required for a discharge to occur. If the current diversion approach is used, all exposed metal components must be grounded. The shielded enclosure, if properly grounded, can be used to divert the discharge current; it should be noted that the location of holes and seams can have a significant impact on ESD suppression. If the enclosure is not grounded, the path of the discharge current becomes more complex and less predictable, especially if holes and seams are involved. Some experimentation may be required to optimize the selection and placement of holes, wires, and grounding paths. Careful attention must be paid to the control panel design so that it can tolerate a static discharge.

MOV, transorbs, or other devices can be placed between B- and offending wires, plates, and touch points if ESD shock cannot be otherwise avoided.

APPENDIX B
PROGRAMMING DEVICES

Curtis programmers provide programming, diagnostic, and test capabilities for the 1220 controller. The power for operating the programmer is supplied by the host controller via a 4-pin connector. When the programmer powers up, it gathers information from the controller.

Two types of programming devices are available: the 1314 PC Programming Station and the 1313 handheld programmer. The Programming Station has the advantage of a large, easily read screen; on the other hand, the handheld programmer (with its 45×60mm screen) has the advantage of being more portable and hence convenient for making adjustments in the field.

Both programmers are available in User, Service, Dealer, and OEM versions. Each programmer can perform the actions available at its own level and the levels below that—a User-access programmer can operate at only the User level, whereas an OEM programmer has full access.

PC PROGRAMMING STATION (1314)

The Programming Station is an MS-Windows 32-bit application that runs on a standard Windows PC. Instructions for using the Programming Station are included with the software.

HANDHELD PROGRAMMER (1313)

The handheld programmer is functionally equivalent to the PC Programming Station; operating instructions are provided in the 1313 manual.

PROGRAMMER FUNCTIONS

Programmer functions include:

Parameter adjustment — provides access to the individual programmable parameters.

Monitoring — presents real-time values during vehicle operation; these include all inputs and outputs.

Diagnostics and troubleshooting — presents diagnostic information, and also a means to clear the fault history file.

Programming — allows you to save/restore custom parameter settings files and also to update the system software.

Favorites — allows you to create shortcuts to your frequently-used adjustable parameters and monitor variables.

APPENDIX C

SPECIFICATIONS

Table C-1 SPECIFICATIONS: 1220 CONTROLLERS

Nominal input voltage	24 V
PWM operating frequency	15.6 kHz
Electrical isolation to heatsink	500 V (minimum)
Storage ambient temperature range	-40°C to 85°C (-40°F to 185°F)
Operating ambient temperature range	-40°C to 50°C (-40°F to 122°F)
Package environmental rating	IP65 for electronics
Weight	0.3 kg (0.7 lbs)
Dimensions, W×L×H	72 × 131 × 39 mm (2.8" × 5.2" × 1.5")
EMC	Designed to the requirements of EN 12895:2000

Note: Regulatory compliance of the complete vehicle system with the controller installed is the responsibility of the vehicle OEM.

MODEL NUMBER	NOMINAL BATTERY VOLTAGE (V)	2 MIN RATING (A_{rms})	1 HOUR RATING (A_{rms})	BOOST (A_{rms})
1220-22XX	24	40	20	50

Note: Conditions for thermal ratings are as follows: Controller mounted on 150 mm square, 6 mm thick aluminum plate, with 5 km/h perpendicular air flow. Initial heatsink temperature = 25°C. Motor current held at rating being tested for a minimum of 120% of rated time before start of thermal limiting.