

Part 2

PM 1440GT VFD and Solid State Control Conversion

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A. Introduction:

100 A Precision Matthews PM1440GT lathe has been converted from the standard 3-phase Factory Original Control Systems to run on single phase power using bi-polar solid state control electronics and a Variable Frequency Device (VFD). All previously built-in safety features are replicated or exceeded and new ones added. In addition new operational features have been incorporated. The purpose of this document is to provide sufficient detail to enable others to repeat and improve upon this design as well as allowing the author to recall what was done and why!

A major objective of this conversion was to fit the new conversion system into the original lathe cabinet. Hence, solid state circuits were used to eliminate most, if not all, of the original large mechanical relays, power transformer, and other parts.

110 The major objective of this document is to provide a record, but more importantly to provide an organized, detailed technical description for those who decide to try to duplicate or improve upon the conversion design. Simply viewing the Figures and Photos may be the best approach for those who want a short read.

This document is multipart.

120 The Part 1 is a technical description of the factory original PM1440GT electronics and its operation. Some readers may choose to skip Part 1. There it was observed that the 3-phase, 220V, machine electronics were built around the use of relays (contactors) for controlling the on-off, forward-reverse, jog, and "latching" safety features. The purpose of Part 1 is to enable understanding of the original design and should the need ever arise to allow one to reconstruct the original system. It might also be useful in repairing an original system which has failed. While only a few pages long the two Figures may be helpful even without reading the text.

The Part 2 describes the conversion to 220V 1-phase input power plus the addition of variable speed, additional functional features, while maintaining or improving safety features. All mechanical relays have been eliminated. This is accomplished via the use of the WJ200-022SF Hitachi Inverter, VFD, and custom designed solid state control electronics. The document is a detailed technical description of the new system, its features, design, construction, and its operation. Figure 3, which is described in depth, is an overall electronic schematic of the control electronics. Photo 7 & 8 are of the new conversion electronics, interconnections and control panel operational options.

130 The text is long and is primarily for those who wish to actually repeat this build. However, portions of the document can be skipped by those already familiar with VFD conversions. To facilitate searching the document the Table of Contents provides hyperlinks to the topic in the text. Every effort was made to ensure that it is technically correct, but errors usually creep in. Feedback, suggestions, and corrections on the design and this document are welcome.

B. Converted Machine Features: (FP=located at the Lathe Front Panel)

Retained or modified lathe features:

140 On-Neutral-Off Control
Jog (forward direction only at 60Hz, high speed, FP)
Coolant Switch (Off-On, FP)
Active Safety Latching Relay (Neutral Control Position Latches On)
E-Stop (FP)
Cover Interlock (breaks relay latching)
Indicator Lamp (E-Stop & Cover Interlock enabled, breaks latching, FP)

Foot Brake Switch (breaks relay latching)

Added lathe features:

Solid State Design (no-mechanical relays)

Input power: 220Vac single phase, 30Amp

VFD provides 3ph power variable frequency (a few Hertz to 400Hz)

150 Speed Control (Variable via Potentiometer, FP)

Frequency Preview (Digital Voltage Readout, FP, 0-10 volts)

Spindle RPM (Hall Effect, High Resolution Digital Readout, FP)

Jog: Forward & Reverse Momentary Switch (low speed, 6Hz, FP)

Integrated Electronic Braking Resistor (Small, 50 Ohm, 400 Watt)

Dual Rate Electronic Braking Switch (2 position switch, FP)

Automatic-Manual-Off Coolant Switch (3 position switch, FP)

Proximity Stop Sense Input (FP connector)

Proximity Stop Fail Safety Switch Input (FP connector)

160 Latch Ready Indicator Lamp (FP)

Manual Foot Brake & Power Loss Critical Safety Feature

Critical Safety Feature Reset Switch (FP)

C. Short VFD (Inverter) Description and Chosen Design Functions:

1. VFD Introduction:

170 A brief VFD purpose and features description is provided. There are VFD models for different voltage inputs and outputs as well as different size motors. Here, the Hitachi WJ200-022SF Inverter is employed in a small shop environment, where the main features are that it converts from 60Hz, 1-phase ~220 volts to variable frequency, 3-phase ~220 volts and is sized for a 3HP motor. It is priced in the ~\$350 range and is by far the most expensive single component of the conversion. It comes with a physical manual as well as a DVD programing software and a pdf Manual (No. NT325DX, February 2018) of 677 pages! There are several versions of this manual available online, but this 2018 version seems to be the most complete (~13GB) and useful:

http://www.hitachi-iec.cn/ch/product/trans/wj200/images/WJ200_Series_Instruction_manual.pdf

180 For Hitachi model WJ200-022SF, the WJ200 is a model series, while the 022 indicates it will provide 2.2KWatt, 3HP motor. Of the 022SF the S indicates a single phase input while the F indicates the VFD comes with a keypad as well as a USB input for programing.) The device has many more features than are used or discussed here.

190 The basic operational concept of a VFD is that the input line, 220 Volt AC, power is rectified to a DC voltage and stored on high voltage power capacitors. This voltage is then used to create a new 3 phase set of 220 Volt AC line voltages to drive the 3-phase motor. Hence, other than grounding concerns, there are two wires (1-phase) for input power, and three wires for 3-phase power going to the motor (load). In addition, the inverter can provide electronic braking for the motor by diverting the motor's back electromagnetic force (emf) currents to an external dissipating resistor. This energy conversion is achieved with power silicon devices which are controlled and switched via the internal microcomputer logic. (Perhaps one overly simplified way to think of this is as a box with three amplifiers in it, much as a stereo would have two amplifiers used to amplify low level signals.) As such,

the microcomputer can provide features, which can be determined by user defined input variables. These variables are basically just parameters which are applied to the microcomputer's general control code. The VFD also has digital inputs and outputs, a small amount of DC power out, and a couple of analog inputs and outputs and logic drives for external relays to provide other controls. These basically allow for the operation of the inverter to be changed while running. What some of these do will become obvious. (The inverter can also be used to effectively control or interact with additional inverters and, hence, secondary motors. None of which is used here.)

200 2. Terminals or Connector Comment:

Besides those mentioned below, there are both additional analog and digital terminals and VFD features, which are not used in this design and so are not discussed here. Some of these can be conceived of by reviewing the useful "Example Wiring Diagram, pages 4-5 to 4-7, pdf pages 209-211, of the VFD Manual (No. NT325DX, February 2018).

3. Analog terminals:

210 The connectors labeled "H" (10Vdc, maximum 10mA output, manual page 1-10), "O" (input), "La" (analog common) provide a method of applying a voltage at terminal "O" relative to the "La" common, between 0 and 9.8 volts via a potentiometer. This voltage then causes the VFD output frequency to vary somewhat proportionally from zero to the user programmed maximum. The device output frequency can alternatively be controlled via an input current or via a frequency signal. This design utilizes the potentiometer approach. The VFD input impedance is 10K Ohm so the potentiometer should be smaller so as to not be loaded by the input. This design uses a 2K Ohm potentiometer is a reasonable compromise between loading by the input impedance and usage of current from the "H" reference. A settling wait time, filtering time, called the "Analog Input Filter"

220 can be assigned to this input to help with noise immunity. This design used a setting of 31, which is the slowest allow, but no attempt was made to determine if faster settling times could be tolerated. (See Manual programing label A016).

The connectors labeled "AM" (0 to 10 volts DC) and "La" (analog common) provides a voltage output which is somewhat proportional to the active output frequency. This voltage only appears when the VFD is powering the load. Hence, the output of this is zero volts prior to the VFD powering the load (motor). For this reason the use of this output to monitor frequency is diminished in value, but left as an option in this design.

230 4. VFD Logic Control Power:

When the VFD's internal logic power supply is used, the Logic Power connectors are "P24" (24Volts DC), "L" (Digital Common), and "PLC" ("PLC" is connected to either "P24" or to "L" to determine logic sinking or sourcing of current to represent an "active" logic level). This "P24" power source is limited to approximately 100mA and the manual specifically states that it should never be connected directly to "L" as it will damage the device. It is not explained how or what this damage might be. For this reason, this design does not utilize the VFD's internal 24V, "P24", supply at all, but instead an inexpensive external 24V DC supply is provided and used. This design utilizes an active level logic when positive current is flowing into a VFD logic input terminal and so the "PLC" is connected to the common of the external power supply, the external power supply negative output (common). Neither the L nor the

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P24 VFD terminals are directly connected to anything. So the jumper between either of them and PLC must be removed. The VFD manual is somewhat obtuse with respect to the use of the terms sinking and sourcing “inputs”. By “inputs” the manual means the external control “switches” or circuits, not some internal part or terminal of the VFD. However, it may be easier for the user to ignore the manual’s term “inputs” and simply look at the diagrams provided to determine the current flow. Normally, one would say that a terminal with positive current flowing into it is sinking current or that the device supplying current towards this terminal as sourcing the current. This would be consistent with the VFD manual if one understands what the manual means by the term “inputs.” Hence, in the design being used here, the +24V of the external supply is connected to the external controlling devices (i.e. switches) and current that travels through the external device (i.e. switch), when closed, flows into the VFD logic terminal. Hence, the VFD logic terminal is sinking the current. Also, note that the VFD manual states that the Analog Common, La, and the Digital Common, L, are connected together inside the Inverter. Hence, the manual’s diagram for using an external power supply is also a bit confusing as it does not show that the L can be connected to the external supply’s common terminal. For this design, refer to the bottom half of the manual’s page 4-14, pdf page 218.

5. “Intelligent” Digital Input terminals:

The VFD’s digital connector terminal labels, of interest, are numbered from [1] to [7] plus [PLC] (common). This implies that there are a maximum of 7 input functions that can be defined by the user firmware inputs. These are referred to as “Intelligent Terminal Functions” (see manual page 3-83, pdf p165). However, some of these have limitations as to their definition. The normal logic operating voltage is 24Vdc, while the rated maximum input voltage to these is 27Vdc, and their internal impedance (resistance) is listed as 4.7K Ohm. This means that if a switch is connected between the 24Vdc power supply and one of these inputs a maximum current into the terminal would be $24/4.7K=5.1mA$. However, nowhere in the manual is described the minimum current required to cause the logic to be switched. This may be due to the fact that it is situationally dependent upon the noise of the environment. Hence, here, it was measured to determine what would reliably turn on the logic to cause the output to turn on and run a spare 1.5KWatt 3-phase motor. Testing multiple terminals, it was found to be approximately 1.56mA. The difference, between these two current values, $5.1-1.56=3.54mA$ represents the extra current noise tolerance under the worst of noisy environments. That is any incremental current flow greater than 1.56 helps in preventing noise from having ill effects, but the total current from 24 volt sources can never be greater than the 5.1mA that the VFD’s input resistance allows. That is, assuming the signal was at 5.1mA and a noise spike of negative 3.54mA exists on the logic line, then the noise could cause the input current to drop to, or below, the required 1.56mA. If this condition were to occur for a “sufficiently long time” the logic would change state. Likewise, if the signal was 0.0mA and a noise spike were to increase the input current to more than 1.56mA for a “sufficiently long time”, the logic would again change state. A “sufficiently long time” is undefined here as it is an unknown VFD pre-programmed debounce time. It is prudent that the positive level logic current always be greater than 2mA. In the current design, the circuits are designed such that the logic level current is always about or greater than 3.3mA. This provides a

290 practically high signal to noise ratio. (The debounce time does not appear to be specified in the manual. However, a definition of debounce is typically that time a switch must be held in one position before the switched state will be considered to be valid by the reading electronics. The average typist can produce 40 wpm, words per minute, with fewer than 5 errors. The record speed for typists is 216 wpm or ~1080 characters per minute, which would imply 2160 off-on-off transitions per minute. So at 60 seconds/2160 states would mean that this typist would out pace a debounce time of 28 milliseconds. It is highly doubtful that the VFD uses such a short time to interrogate switch positions for control of these large motors. Nevertheless this is a long time for many noise spikes to persist.)

In the current design, the programing parameters assign the 1-7 logic inputs as:

300 **[1]** Forward (FW, Inverter outputs power the motor in the forward direction at programed speed. Active when sinking current, i.e. current is flowing into the VFD terminal # 1.)

[2] Reverse (RV, Inverter outputs power in the reverse direction at programed speed. Active when sinking current. Should both inputs # 1 and # 2 be simultaneously active the Inverter shuts off power to the motor.)

[3] Jog (JOG, Inverter outputs at 6 Hertz, in the direction corresponding to the active input # 1 or # 2. Should both inputs # 1 and # 2 be active the Inverter does not run so Jogging does not occur.)

310 **[4]** Unattended Start Protection (UPS, This works in conjunction with an External Trip event. Example: An External Trip event might be the power being shut off while the Inverter is running. Hence, an active input UPS signal current prevents the Inverter from resuming its previous running state. To return to a run state the run state must be first taken to an off state by taking the active inputs 1 and 2 to off states and then returning to an on state. However, the designed electronics also prevent this. Other trip events might be designed in to the system. Active when sinking current.)

320 **[5]** External Trip (EXT, This input is programmed as normally active, Tripped, when the input current is interrupted. Active when NO current is supplied. This logic input can be referred to as being active when low, whereas all other inputs would be considered active high when current is flowing into the VFD input.) Based upon the VFD programing, a trip will cause the VFD to cut off current to the load. Even if logic current is resumed the VFD will not function until a Reset is initialized.)

330 **[6]** Brake via Channel 2 (Brk, CH2, The electronic breaking time is preprogramed. In this design, the braking time to bring the Inverter from full frequency to zero and so stop the load/motor is programmed to be 1 second. However, if CH2 is active the breaking time is programed to be 3 seconds in this design. That is, the CH2 input is active when sinking current. Since, a 1 second breaking time is hard on the lathe mechanics, especially the motor belts, it is probably best to run the lathe with the 3 second breaking time unless the shorter breaking time is needed for a particular application such as proximity sensing.)

[7] Reset (Rst or RST, Activating the Reset input causes a Trip State to be nullified. After an EXT event, it is recommended to carefully check the lathe settings prior to applying a Reset.)

6. VFD Parameter Coding:

A spread sheet list of all of the Hitachi WJ200-022SF VFD programmed settings were captured and is provided in Table 1. It seemed to be better to supply all of the data to the reader rather than just the entries that were changed during this project. Blue highlighted lines provide column titles while yellow highlighted entries provide an easy comparison to the default values. This is not to say that the default values are not important. However, some of these highlighted differences are determined via the operating VFD at the time of data was capture and so are not really preprogrammed by the user. For example, the first entry, F001 is simply the frequency the VFD was set to via the potentiometer at the time the data was captured. Hence, it might be different the next time one looked. Likewise the motor parameters were VFD determined by the motor tuning process, H001 and H002, which should be performed. Some of these, and many other, entries in this table do not even apply to this application. Nevertheless, once, the VFD parameters are understood it is reasonably straight forward to understand many of the values. For the most part the values chosen are either the default values or are similar to those discussed by others on Hobby Machinist. However, there are a few exceptions such as the acceleration curve, A097, which is probably motor and lathe dependent. The choice of this entry can best be determined by accelerating up to a number of frequency settings to ensure that the motor behaves well for all conditions. Likewise, the digital inputs are assigned via C001-C007 while the active levels are assigned in C011-C017. As mentioned earlier, particularly important for safety is the logic level implementation of C015 as NC, for the EXT TRIP input signal, C005, which causes the logic state to be inverted from those of the other inputs. (Recall that the NC and NO refer to the external switch not the VFD input.)

D. The Design: Control Component Physical Locations:

1. The PM1440GT Stand Rear Enclosure:

Other than the external switches and the Lathe's Front Control Panel, Photo 7, all of the control circuitry is located in the spindle stand rear enclosure, Photo 8. There is also an end panel covering the remaining volume vertically under the gears in the stand (Photo 2, Part I). As also illustrated in Figure 4, to reduce unwanted interactions and noise, the general physical component layout philosophy is that the AC currents, especially the high voltages and currents, were restricted to the right hand side, while the low current, low voltage processes are kept to the left hand side of the enclosure and component plate. The components are:

See Photo 8, Photo13, and Figure 4: Via the original factory design, along the top of the back of enclosure are 10 wire feed through ports. There are 8 ports on the enclosure's rear surface plus 1 at each side surfaces. In addition, not illustrated, there are 2 ports at the top enclosure surface exiting to the outside. As seen at the top of Photo 8, one is used for the Lathe motor cable while the other cable, behind the motor cable in the image, supplies power to a DRO (lathe tool position Digital Read Out). The 8 back side ports feed into the cavity of the stand which is accessible via the end panel. (Not all of these ports were supplied with feed through strain relief clamps.) The cavity appears to have been constructed by cutting openings at the rear stand surface and by welding steel plates to the inside of the lathe stand to form a box. The stand sides were made by rolling a piece of

heavy sheet metal (~4mm thick) into the generally rectangular vertical tube shape before welding. The enclosure cavity is not totally plumb, but is reasonably good. The cavity depth varies a little with position. With considerable effort and lack of precision the critical cavity dimensions were measured. These are illustrated in Figure 5 which also shows the new Al backing plated size and location. The overall measured inside dimensions of this cavity are approximately 13.75"W x 15.75"H x ~4.625"D while the front opening is approximately 11.14"W x 13.3"H, but is shifted with respect to the center of the cavity. At the back surface, 4 tapped bolts holes, arranged as a square pattern of approximately 250mm x 205.25mm, are used to fasten the original electronics control plate as well as the new one to the enclosure back wall. It is unknown if these dimensions, features, or positions are consistent for all PM1440GT lathe stands.

As with the original design, all of the electronics are mounted on a single plate so that by detaching the port wires everything can be removed as a single unit. This overall control electronics mounting plate of this design is made from 0.125"T x 11.937"W x 12.875"H Aluminum. While this fits the opening by sliding in sideways, the height could be reduced (~12.375"H) to facilitate easier insertion of the plate when all of the components mounted. The top port wires tend to be in the way during the component laden plate insertion into the cavity. The specification on the VFD indicates that it is 108mm wide (4.25"). The VFD mounting material total thickness is ~0.25". One might want to check the enclosure depth, especially near the bottom center, below the opening to ensure that the VFD width will fit. Here there was ~ 0.325" to spare. If not it may need to be moved upward when mounted. The plate was tapped and the components or DIN rails were mounted using ~0.25" long 6-32 screws. The plate itself is mounted directly to the back of the steel enclosure via the original metric mounting bolts. For the following description of the component locations see Photo 8.

The original screw terminal strip was replaced with a different style, shorter, screw clamp strip. It is fastened at the top right hand side of the mounting plate, is composed of a 17 pair-screw terminal block strip of heavy duty (30Amp/300V) elevator style screw clamping terminals to handle all of the AC power, but especially the high current carrying wires. The wire assignments to this terminal block are provided in Table 2. A 20 position terminal block was disassembled, cut down to 17 positions, some of the terminals, common connections, were shorted on one side of the terminals or via soldered jumpers mounted directly into the circuit board carrying the screw terminals, and then reassembled. These shorted screw terminals are marked in common colors and can be noted as terminals 01-02, 06-7, 08-09-10, 11-12-13, and 14-15-16 of Table 2 and Photo 8b. After being switched and fused at the wall the single phase 220Vac power lines, neutral, and ground lines enter via the enclosure side port (Lathe Stand End port, Photo 2, Part 1) which is also visible as the large yellow rubber jacketed cable at the right edge of the Photo 8b. These individual wires, inside the enclosure are the large rubber green (ground) (07), white or light orange (neutral) (09), black (-110Vac) (12) and red (+110Vac) (15) wires. This power then travels from the corresponding terminals to the VFD screw terminals. Hardly visible in Photo 8b due to the other wires, just above the power screw terminals and just below the feed through ports, the ground wires (green (06) and yellow-green from the motor) are attached directly to the

original tapped hole at the stand enclosure back. It is also connected to the control electronics mounting plate by #6-32 screw via terminal 07.

The VFD is located at the bottom center of the mounting plate oriented with its screw terminals on the right side, and the 3 phase 220Vac generated by it returns to the power terminal strip terminals 03, 04, 05 positions just to the left of the incoming power and then on out to the motor via the corresponding wires with the white sleeves labeled U, W, and V. This orientation of the VFD also allows for its display to be easily read from the end-backside of the lathe. The single phase 220Vac also travels via 0.4Amp fuse and a solid state relay out to the coolant pump via the wires with labels U1 (17) and V1 (11). The 30 Amp 220Vac solid state relay used for the pump is extremely over rated for this application, but was familiar, inexpensive, known to be very reliable and most importantly, available without waiting to be purchased. Nevertheless, the SSR was mounted using heat sinking thermal paste. However, it could certainly have a smaller current rating and have a smaller foot print and might even be circuit board mountable. Similarly the fuse holder was on hand and the metal mount for it was made by bending some surplus lightweight stainless steel sheet metal, but these could be replaced with an in-line fuse holder. The holder was oriented to enable easy of fuse replacement should the need arise. The solid state relay is switched on an off via the control electronics and, along with the fuse, is located just below the power carrying screw terminals and sort of behind the cover fan when in place. One side of the single phase 220Vac provides 110Vac to a 24Vdc power supply, which is located at the bottom left hand side. In addition, 110Vac is supplied by one side of the incoming 220Vac power to the small cooling fan, which is mounted on the inside of a new transparent Plexiglas enclosure cover, just below the heavy duty screw terminal strip. The electrical installation of the fan required that it remove with the enclosure cover. Hence, an extension cord was cut in half and the two ends attached to the fan leads and the power screw terminals. This left the two plug ends of the cord available to allow the fan to be unplugged when the enclosure cover is removed. The fully insulated extension cord approach is bulky and anything but classy looking, but is simple, inexpensive and safe!

To provide an efficient cooling air flow and to allow one to view the inside and read the VFD display, the enclosure cover was replaced with a 0.25 inch thick clear Plexiglas which is spaced outward about 1 inch from the lathe stand on three sides using solid plastic black bars along the sides and top. This plastic provides both ridged mounting and seals tightly to the Plexiglas cover and the lathe stand to prevent debris cuttings and dirt from entering on these three sides. At the bottom, no plastic bar is inserted leaving a gap for air to enter. (From a depth perspective, all of the components, including the fan, would still fit inside the enclosure even if this standoff geometry were not employed.) The small outward blowing fan mounted on the inside surface of the Plexiglas cover circulates air flow into the enclosure bottom and out the fan port. It is not clear that the outward blowing exhausting fan is even necessary as warm air would rise in the enclosure cavity from the bottom and flow out the fan port by convection, but any elevated temperature of the VFD is known to shorten capacitor lifetime. So why not give it plenty of cooling air? During operation, the exiting air feels only mildly warm, if at all, to the hand.

The VFD heat sink is designed to normally be mounted with the base against a surface so that its internal fan produced air flow is trapped by the mounting surface and forced to pass through the heat sink. However, here the VFD is rotated and mounted with its side to a secondary 0.125" aluminum side plate, which in turn is mounted against the overall control electronics mounting plate. This mounting allowed the VFD to fit into the enclosure with the plastic portion of the VFD housing about 0.125" away from the overall control electronics mounting plate as well as the front wall of the lathe enclosure. Also, yet another aluminum plate, heat sink plate, was attached to the bottom (the normal VFD mounting surface and holes) of the VFD to confine the VFD fan generated air flow through the heat sink. This plate, Photo 8c, extends out to the electronic braking resistor bank to guide the VFD exiting air flow to the braking resistor bank. The bottom of the VFD plate is aligned even to the bottom edge of the overall control electronics mounting plate and these two plates sit approximately 0.5 to 1 inch off the bottom of the enclosure. The side of the VFD heat sink was tapped via #6-32 screw holes in the thicker parts of the heat sink and attached to the mentioned 0.125 inch thick side plate. These screws were counter sunk into the side of this small plate from the face that is next to the overall control electronics mounting plate so that the two plates rested flat against each other. Since the heads of these screws are trapped it is difficult for them to come loose. This side plate is approximately the height of the VFD heat sink, but extends sufficiently longer (left and right) than the heat sink to allow it to be mounted at the ends to the overall control electronics mounting plate. Hence, the VFD is mounted to the control electronics plate. (One might be tempted to mount the VFD directly to the enclosure, but then it would not lift out with the overall control electronics mounting plate and all other components. Furthermore connecting the heavy power carrying wires after the parts are inside the enclosure would be difficult. The VFD side spacing used in this design does not meet those recommended in the manual. However, the manual does not account for the direct fan cooling used in this design. More importantly, the device does not overheat nor appear to be more than warm.)

The internal VFD fan was reversed in its mount at the VFD heat sink to cause air to be blown through the VFD heat sink from left to right rather than to be sucked through it from right to left. In this manner the air flow exits the VFD heat sink towards the right and then flows over and around the braking resistor bank and its aluminum mount heat sink. This air flow then continues upward and out the enclosure panel cover fan when these are in place. Meanwhile some portion of the fresh air also enters the bottom gap and flows through the remainder of the enclosure cooling the other components as well as the air at the top of the VFD. While there is little heat being generated by these components, this geometry provides cooling to them. This overall geometry allows for cool air to enter at the space between the bottom of the cover and the enclosure opening and to be pulled through the VFD and the rest of the enclosure. Hopefully this exhausting fan and bottom air entry geometry limits the amount of lathe made debris that might enter the enclosure compared to if the cover simply had holes in it. A screen filter might be attached at the bottom opening to prevent floor dust from entering, but this has not been implemented yet.

Next to the VFD at the bottom right is a bank of power resistors used as the VFD braking resistor, Photo 9a-b. Figure 6 illustrates its technical construction. The resistor wiring is connected directly to the VFD and to the VFD via the power screw terminals 1 and 2 which are jumpered together at the opposing pair power screw terminals. This jumper wire was employed to allow easy disconnection of the braking resistor if needed. There are a total of 8 resistors, each of value of 25 Ohm by 50 watts. These power resistors are mounted to a secondary 0.125”T x 4.5”W x 4.4”H Aluminum plate. This small plate is then mounted along one edge to a 4.5”L x 0.5” x 0.5” Aluminum bar. This bar is mounted to the control electronics backing plate resulting in the resistors being mounted in the air vertically along the 4.4” depth of the Al plate. Thermal paste was applied between the bar and the backing plate, but this does not seem to be needed. The resistor plate sticks outward about the depth of the VFD. These metal mountings are essentially are heat sinks for the resistors and the resistor orientation exploits the VFD cooling fan air flow pattern. The resistor assembly has a 1/16” thick Plexiglas sheet mounted to it via insulating stand offs which physically isolates and electrically insulates the resistor bank assembly from the power wires at the VFD. At the same time this probably tends to channel the air flow over this portion of the resistors. Electrically, the 8 resistors are connected as two sets of four in series to yield two 100 Ohm circuits and these two sets are then connected in parallel to yield a single 50 Ohm circuit. Since approximately the same current value passes through each resistor, the total wattage of the assembly is 400 Watts. However, due to its typical usage, it is extremely unlikely that this lathe would ever need a 400 Watt braking resistor, even as little as one or two 50 Watt resistor might have been sufficient. Alternatively, a set of only 6 of the 50Ohm resistors would have yielded a 75/2~ 37.5Ohm by 300 watt braking resistor. As a test, the lathe was spun up to high spindle speed with the standard 3 jaw chuck mounted as a load and then shut down with a 1 second electronic braking time. This was done a dozen times as quickly as the lathe could be brought up to speed and then stopped. A finger test to the resistors, right after this procedure, found them to be only slightly warmed. Separate Photos 9c-f shows more detail of the braking resistor assembly. No enclosure cover, nor cover fan, was in place during this test so cooling was not optimized. Due to the air flow pattern any heat generated by the braking resistor flows away from VFD, not towards it.

The 24Vdc supply is mounted to the left of the VFD far enough to allow plenty of air to reach the VFD. It is connected to the power screw terminals at 09 and 11. Its output feeds upward to the control electronics circuit board.

Just to the left of the 17 pair screw terminal strip is the control circuit board mounted to a DIN rail via a special circuit board holder. (Before this board holder became available several other approaches for mounting the board and connectors were tried and found wanting.) The circuits here provide an interface between the outside world to the logic and analog inputs at the VFD. At the top of this board are plug in style screw terminals connecting the circuits to the wires headed outside the enclosure, while at the bottom of this board are also push in style screw terminals for wires going to the VFD as well as to other enclosure components. These connectors allow the wires to be easily be connected and disconnected in groups or individually. Hence, the top connectors are referred to as straight angle connectors while the bottom ones are right angle connectors. The angle refers to

the bend in the metal going into and being soldered at the board side of the connector. The two different connector angles were chosen for minimizing wire strain, ease of installation, and ease of connection of wires based on the wire orientation from the enclosure wire ports.

The control electronics design will be discussed next.

E. The Design: Control Electronics Circuits:

1. Control Circuits General Description:

See Figure 3 (Global Circuit Schematic). For clarity, this schematic shows both logic circuitry and many of the various switches and devices which are not located on the control circuit board. In general, there is somewhat of a locational association between the schematic components and the physical layout of the actual circuit board. Note that at the bottom of the schematic are, for the most part, labels indicating connections to the VFD inputs. Likewise, as shown in Photo 8 & 11, and illustrated in detail in Figure 8, at the circuit board bottom there are two 9 pin plug-in style screw terminals and two 2 pin plug-in style screw terminals with wires leading to the VFD, power supply, and coolant controlling SSR. At the top of the circuit board there are three 9 pin plug-in style screw terminals plus, at the far left, one 2 pin plug-in style screw terminals connected to the wires exiting the enclosure ports. The prototype circuit board has solder holes located on 0.1" centers and the plug-in screw terminals are spaced at 0.2" to match the circuit board holes. The right most two of these top sets of terminals connect to the two 8 wire shielded cables. They are marked in red and black these markings carry over to connectors at the control panel. The rainbow of colored wires from these two 8 wire shield cables connect to the controls at the front panel of the lathe and the colors are useful identifying connections. Hence, there are up to 16 wires plus two shields going to the front panel via these connectors. (The lathe's factory original single cable of control wires has been replaced with these two cables.) By using these plug-in style connectors, the wires can easily be disconnected and connected in groups when the overall panel needs to be removed or installed. The individual wires do not need to be unscrewed. Note that there are several LEDs in the circuits. These are primarily diagnostic in function and provide the user with immediate knowledge about which circuits are carrying current. With the exception of the Proximity Inverter LED, they could each be replaced with a short but the values of the resistors in series with them then might need be adjusted. The individual circuits on this board, and illustrated in Figure 3, are itemized and discussed next.

2. Control Circuit Specifics via Physical Location on the Circuit Board:

24Vdc Supply:

An external 1 Amp, 24 Vdc supply is employed and is labeled, S24. The negative terminal (S24-) is considered a common and is isolated from chassis ground. The majority of its 1Amp capacity is used by the lathe lamp. The 24Vdc power (S24+) and the 24V supply common, S24-, are brought to the control circuit board and then two conductors of the 8 wire cable brings these plus a 12Vdc voltage and the VFD analog common, La, to the front panel.

24V Digital Logic:

With the exception of one, all of the transistors in the control circuit operate either in the off state or the saturated, on, state. Hence, they perform as digital

logic devices. Hence, this is a 24volt bipolar transistor logic circuit which provides the currents to the VFD's current sinking inputs. In this regard, the VFD's PLC input is connected to the negative side of the 24V supply, i.e. its common, (S24-). The VFD's P24 supply terminal is unused and so is unconnected. The VFD's L supply terminal is not explicitly used and so is also shown as unconnected, but the manual states that it is connected inside the VFD to the VFD's analog common La, which is used. See the bottom half of the VFD manual page 4-14, pdf page 218. NOTICE: The factory installed jumper between the PLC and P24 or L is removed.

Shielded Cables:

At the far right in the schematic is a direct connection from the top to the bottom terminals labeled "Cable(s) Shield Gnd". These are the shields of the two 8 wire cables mentioned and they are grounded to the chassis at the Control enclosure. They are left unconnected at the lathe front panel. Hence, they are NOT connected to the 24Vdc common anywhere. As is implied by their name, their purpose is to provide a degree of shielding of noise for the control lines. The large area of the metallic lathe represents considerably large capacitance for any EMI noise which is intercepted by the shield to be absorbed by this large capacitance.

RESET:

At the schematic right, next to the shield connector is a straight through line connected from a momentary contact switch at the lathe front control panel to the VFD Reset terminal [7] input. The other side of the switch is connected to the 24Vdc supply at the front panel. Also, at the front panel, this switch is level (effectively recessed) to the panel surface, and must be pressed inward to be activated. This profile is selected to prevent it from being accidentally tripped. The momentary switch package employed for this has four terminals. Two terminals are the switch while the other two terminals provide contacts to a LED and series resistor. This measured forward LED diode drop is approximately 2.2 volts and the resistance value is slightly larger than 2K Ohm. The LED and resistor are designed to connect to a 9 to 30V supply, which implies that the LED operates for currents ranging from $(9-2.2)/2K=3.4mA$ to $(30-2.2)/2K=13.9mA$. Hence, the switch maybe wired in series with this LED and series resistor terminals, yielding an operation where the LED light would confirm the depression of the switch. To determine the current supplied to the VFD, the VFD internal impedance is added to the LED resistor, $(24-2.2)/(2K+4.7K)=3.25mA$. This is more than sufficient to provide the logic signal. A lower voltage LED indicator from this same product series would have a smaller resistor and so could potentially increase this current if needed.

UPS:

Moving left, to the third circuit board area, is a shorted line from the 24Vdc supply to the VFD UPS [4] terminal. This assures that the VFD is operating with the UPS function active. (see the UPS description above). There is no need for a front panel connection.

CH2, Alternative Braking Rate:

Next over on the schematic is the 4th line which simply activates the CH2 (Channel 2), the longer electronic braking time, via a simple front panel On-Off switch connected directly to the 24Vdc supply. In this design when this switch

670 is closed the lathe electronic braking is 3 seconds rather than 1 second when it is open. To avoid excessive lathe stress and wear of the 1 second electronic braking process, most lathe operations should use the 3 second electronic braking.

Analog Signal to VFD Frequency:

680 The next portion of the circuit is the front panel potentiometer, R14, which is used for setting the analog voltage input to the VFD for selecting the VFD frequency. This is a 10 turn, 2K Ohm potentiometer. One potentiometer terminal is connected to the VFD analog terminal H (nominally 10Volts) while the opposing potentiometer terminal is connected to the VFD terminal La (analog common). The potentiometer wiper is connected to the VFD analog terminal O. At the front control panel's top left hand side is a digital volt meter (shown next to the potentiometer on the schematic) which preferably has its signal input connected to the potentiometer wiper. In making this connection the voltage appearing on the voltmeter read out is the VFD frequency control voltage measured at the potentiometer wiper. This voltage is present and readable even if the VFD is not actively driving a load (a Run State). This enables the operator to approximately know what the VFD frequency will be prior to turning on the drive. While the VFD can be programmed to produce high frequencies of several hundred Hertz, this design uses a maximum frequency of approximately 100 Hertz. Hence, 10 Volts at the pot wiper, and so at the digital voltmeter would indicate the lathe motor would be receiving ~ 100 Hz frequency. Likewise, by setting the pot to output about 2 volts, the volt meter will read 2 volts, producing approximately a 20 Hertz VFD output. Optionally, should someone wish to do so, the Volt meter can be connected to the VFD analog terminal [AM], which is the VFD frequency output indicator voltage produced while running. This too has a full scale output of 10Volts. This arrangement however, has the disadvantage of not providing knowledge of what frequency the VFD will be producing prior to VFD actually producing output drive to the motor. Just above the digital voltmeter in the schematic is shown an inexpensive 12 volt voltage regulator, P1, which is used to drop the 24Vdc input down to the 12Vdc that the voltmeter prefers to see as a supply. There is an associated 1uf capacitor, C4, which is used to reduce any line noise which might be produced by the switching in the digital voltmeter display. This digital voltmeter requires approximately 13.5mA current, mostly for the display. Should the display create unacceptable noise at the potentiometer wiper this would be fed to the VFD. Hence, this is the reason for the optional connection to [AM]. However, noise has not been observed to be a problem so the voltmeter sense connection is at the potentiometer wiper.

RUN LATCH & PROXIMITY SENSOR(S) Circuit Details:

710 Immediately above the voltage regulator, P1, are components labeled Proximity. These are sensor(s) used to set the lathe carriage position limit and prevent motion of the carriage or tooling from crashing into the spindle, spindle chuck, or any object. Most commonly, these are used to stop a z-axis cutting operation such as threading at a specified location, but there is no reason they could not also be available for x-axis motion. These switches would be located at the lathe bed, but their signal feeds into the lathe front panel via cable connectors and then via the cabling are connected to the Proximity Inverter at

the base of Q1 on the control circuit board. As many of these switches (with various technologies such as inductive, capacitive, optical or mechanical are available) as desired may be wired in parallel. Hence, limits in other direction or function could be added. However, before discussing these more, it is convenient to discuss the string of components just to the left of them on the schematic. The heart of several of the safety features of the original factory design was a latching relay. Here, a solid state electronic equivalent, labeled the Run Latch, is employed.

This classic bipolar latch design is composed of two bipolar transistors Q2 (pnp) and Q3 (nnp), capacitors C2 and C3, and resistors R4 and R3 as well as the loads above these. For the moment resistor R5 can be considered the primary load. (For the reader who might not be familiar with bipolar transistors, there are various literature descriptions available for how bipolar transistors function. The letters n and p stand for the electronic doping state of the three physical regions inside the transistor material to make it semiconducting. Hence, for an npn transistor, the outside terminals, the collector and emitter are n type while the base region is p type. The reverse is true for the pnp type transistor. The values of the components are listed with the schematic. However, worthy of comment is that, the 2N3904 and 2N3906 transistor used here have been around for many decades, are very reliable, and are extremely inexpensive. They typically cost only a few cents each. Nevertheless, there are many different transistors that could be used.)

Upon applying power to the latch via the components above it, the latch resistors, R3 and R4 and capacitors, C2 and C3, slow any potential current transients such that both transistors remain in the non-conducting off state. These large valued Run Latch resistors, R3 and R4, also bleed off any leakage current that might occur do to imperfect capacitors or transistors. Hence, when the latch is off, no current flows through transistors Q2 and Q3. The Run Latch will remain in the off state, and so no current flows in the load resistors above the latch. However, should one of these transistors begin to conduct current via the collector to emitter path it would provide current to the base of the second transistor, and so the second transistor would start to conduct. This conduction is regenerative, causing base current at the original transistor and so driving it further into conduction. They both then rapidly go into saturation mode conduction and so the pair latch into conduction. This initiation process can be caused by a small current injected into the base of Q3 via R8 and is used to do so.

These transistors have a current gain >100 when a small current is flowing and even a typical gain of >10 when the transistor is turned on strongly. Hence, a few 10s of microamperes of current into the base of Q3 via R8 results in milli-Amperes of collector current, which must flow from the base of Q2 resulting in the latched on state. Even with the R8 current removed, this latched condition will remain unless the current through R5 feeding the transistors is starved away (terminated). Hence, once latched on, the Run Latch continues to conduct unless the current through the load, i.e. the current through R5, is interrupted.

Looking at the rest of the string of components in series with the Run Latch, one sees several normally closed (NC) switches (E-stop, Lathe gear/ belt

Cover Interlock, Proximity Safety Stop, Q1 called the Proximity Inverter, and the Manual Brake switch). Other than the Proximity Inverter circuit, none of these switches are on the circuit board, but are scattered about the lathe or are in, or connected, via the lathe front panel. If any of these switches are opened the latch formed by Q2 and Q3 is starved of current and the circuit becomes unlatched. It will remain unlatched, even if the interrupting switch is returned to a close position, until current is again injected via R8. This string of components does not interact directly with a VFD input, as the bottom of the Run Latch is connected to the common of the 24volt supply and the VFD common point [PLC], but the latch state does affect the operation of other circuits which drive the VFD. The green Latch LED, which is also in series with the switches is located on the lathe front panel (Active Latch LED) and provides the operator with the knowledge that the latch is on or off. Importantly, the Manual Brake switch is at the top in the string of switches. One side of this switch is connected to the 24V supply voltage at this circuit board while the other side is connected to the switch series as well as to the VFD input [EXT, 5], again at this circuit board. Hence, a manual foot brake action turns off the latch while the VFD is programed such that should the current flowing into the [EXT, 5] be interrupted the VFD shuts down, without not provide electronic braking to the motor. The lathe motor is effectively disconnected from all power so that the mechanical foot brake operation is not in conflict with any electronic braking process. That is, as long as the [EXT, 5] remains connected to the 24V supply, VFD electronic braking is operational. However, if the brake switch is opened, the motor and lathe free-wheels until the brake friction, or other friction, stop these from spinning. Capacitor C1, in combination with R1 and R2 dampens noise at the EXT input as well as suppresses contact bounce from the mechanical brake switch or a proximity switch.

The components, Q1, R1, R2, C1, and LED, at the top of this string are referred as the Proximity Inverter. Since R2 provides a path for the Q1 base current to flow, the Q1 operates in saturation mode. So, Q1 represents simply another of the NC series switches going to the Run Latch. That is, it is conducting between the emitter and collector. However, if a normally open Proximity switch, illustrated at the right of the Inverter, were to close this would pull the Q1 base voltage up towards 24 volts resulting in Q1 turning off. As mentioned multiple proximity sensors can be wired in parallel and can be of mixed technology. Illustrated are both a mechanical switch and an inductive sensor. The only criterial on these sensors is that the voltage drop across the activated Proximity device or switch be less than the total of the forward voltage drops of the Q1 emitter to base plus the LED, i.e ~ 2.6V (how this number is determined is explained in the next paragraph). An inductive sensor, model: LJ12A3-4-Z_CY-G (PNP NO+NC) was tested and found to have an on voltage drop of well less than 2 volts and performs well. These proximity sensor devices, as used in this designed, are NO, so should a wire fail one would not know that the sensor would not function to the stop motor. On the other hand, when not being used one can simply remove the cable from the front panel without affecting the rest of the circuitry's function. For this reason a backup mechanical Proximity Safety, NC, switch was added to the series Switch chain of the Run Latch circuit. If the cable is removed from this safety switch a

shorted plug must be employed to achieve the needed shorted, NC, state. In operation, the mechanical backup switch is physically arranged to not operate until the proximity sensor trip point has been surpassed, hopefully providing for more accuracy and repeatability than a mechanical switch. However, because the Run Latch operation is fast compared to the contact bounce of a mechanical switch, the circuit is unlatched and stays unlatched upon the initial contacting event. It does not wait for the contact bounce to settle out.

At this point it is useful to discussing semiconducting device characteristics briefly in order to allow some circuit analysis. Diode conduction current is exponentially related to the forward voltage across the device, i.e. the voltage across the p - n junction diode terminals (i.e. See Wikipedia, "pn junction diode"). The current through a diode versus the voltage across it is exponential providing a sharp turn on characteristic. A typical Silicon (Si) diode will have about 0.6 to 0.7 Volt drop across it before it conducts significantly and will conduct considerably more for incremental voltage increases. The same is true for the emitter-base junction of the bi-polar transistor. This forward biased volt drop "value" is related to the fact that the diode is made from doped Silicon material. A junction diode is formed at the interface of two semiconducting material regions, where one is p type doped (electron acceptor element like Boron, and the other is n type doped (electron donor element like, Phosphorus). Hence, the diode is formed by the p-n junction where these two types of doped Silicon material join. With voltage applied positive current flows from the p to the n region, but will not flow in the opposite direction. LEDs (Light Emitting Diodes) function similarly, but are made from non-Silicon semiconductor materials. Since the junction materials are different from Si their forward diode voltage drops are larger. However, they are still diodes and as such current only flows in one direction. There are several inexpensive LEDs shown in this circuit and they all have measured forward diode drops of about 2 volts, except for the Latching LED which has a forward diode drop of approximately 2.5 volts. This later value is not a circuit necessity for this design; it is simply due to the LED that was readily available in the small front panel mount package used. Likewise, the npn and pnp bipolar transistors are made from Si and so the voltage drop between the base and emitter, which is again a p-n junction, also has a forward bias voltage drop of about 0.6 to 0.7 Volt. The voltage drop between the collector and emitter is determined by the amount of current flowing through the transistor, but is different from a simple p-n junction and so can be essentially any value. However, when a Si transistor reaches the saturation mode and is fully turned on, the typical collector-emitter voltage is usually only approximately 0.35 to 0.45 volts. Lastly, the voltage across a resistor is determined by Ohm's Law, which is simply $V=I \cdot R$, where R is the resistor value in Ohms and I is the current through the resistor in units of Amperes. One can use these few pieces of knowledge to calculate the voltages at various points in the control circuits and the currents flowing in the various paths of the control circuit.

So, to cause the Proximity Inverter Q1 to shut off, the emitter base current flow must be reduced significantly. That is, the voltage between the base and emitter must be reduced below the forward diode voltage value of 0.6V. The Proximity Inverter LED which is in series with the Q1 emitter,

represents another $\sim 2V$ of forward diode voltage, so to shut off Q1, the base merely needs to be raised above $24V - (2.0 + 0.6) = 21.4$ volts by a proximity switch/sensor circuit. The closed, Proximity sensors/switches can have as much as a couple of volts across them when closed and will still be effective at shutting off Q1. The Proximity Inverter LED provides extra voltage drop just for this purpose, but also provides a visual check to see if current is flowing. It might emit a little light if a small current was flowing out of the Q1 base and through R2, even if this current was insufficient to drive Q1 into saturation. But it would emit much brighter if Q1 is fully in saturation mode. One can simply view the LEDs in the Control Electronics Enclosure to see what is amount of light is being emitted and get a good idea of what is active in the electronics or if a portion of the circuit might have failed. Current through R2 is employed to ensure that Q1 is conducting and saturated when there is no proximity sensor signal. Note that in this case the R2 current is simply $I = 21.4V/R2 = 21.4/10K = 2.14mA$ (for $R=10K$). This is sufficient to cause Q1 to be saturated and to cause the red LED to be somewhat lit. As will be seen below, when the Reverse-Neutral-Forward switch (Rev-Neu-FRW) switch is in the Neutral position the current flowing in the Run Latch is about 2.86mA and so the red LED becomes slightly brighter and the green LED is now turned on. The human eye is much more sensitive to green wavelengths than to red. Hence, the Run Latch current is sufficient to cause the front panel green Run Latch LED to appear quite bright. As will also be seen below, when the switch is placed in one of the RUN positions an additional ~ 3.3 mA current is pulled from the R7, R6 node for the VFD RUN input. So the LED current, and brightness, again increases.

Returning to the latch formed by Q2 and Q3, one can see that if the latch is not turned on then essentially no current is flowing through these transistors and so the voltage across the latch is essentially the power supply value, 24V, less any voltage drop across the proximity inverter LED and the saturated Q1. However, if the Run Latch is turned on, where each of the transistors are fully in the saturation mode, the voltage across the pair, from the top to the bottom of the Run Latch, is approximately equal to one transistor collector to emitter saturation voltage plus one base to emitter voltage drop. This is $\sim 0.4 + 0.6$ volts ~ 1.0 volts. Hence, with respect to all of the other devices in series with the Run Latch, this amount can simply be viewed as reducing the 24 volt power supply voltage by 1 volt. Likewise, since current is flowing, the green Run Latch LED forward voltage drop can be viewed as reducing the overall voltage across the other series elements by about another 2.5V, while the Proximity Inverter LED reduces the overall voltage by about 2Volts and a saturated Q1 reduces it another 0.4 volts. The closed switches can be view as having close to zero resistance and so there is no voltage drop across them. Subtracting these, one see a remaining voltage of $24 - 1 - 2.5 - 2 - 0.4 = 24 - 5.9 = 18.1V$ across the combined resistors R5, R6, and R7. (The small valued R7 was inserted for historic purposes of monitoring current flow and is not really needed. Hence, its value can be 0 Ohm.)

In this design, $R7 < 100$ Ohm and essentially plays little to no role, $R6 = 470$ Ohm, $R5 = 6.2$ K Ohm, and $R8 = 22K$ Ohm. For the following analysis one assumes $R7 = 0$ Ohm. The node at the top of R6 is connected to the Reverse-

910 Neutral-Forward switch (Rev-Neu-FRW) and so could provide current to the circuits to the immediate left of this Latch series string of components. Only if the switch is in the Neutral position will any current flow through R8. One can now analyze the role of the Run Latch on the circuits to the left of the Latch string of components, which form the signals for causing the VFD to go into Run mode.

920 First, assume that the Run Latch is turn off and so not conducting. In this situation, the voltage at the top of the Run Latch was found to be essentially 24 volts, with zero current flowing through R7, R6, or R5. If the Rev-Neu-FRW switch is in either the Reverse (R) or Forward (F) position, the emitter to base voltage of Q4 or Q5 is equal to the voltage drop across R5, which is zero as there is no current flow. So these transistors are off and not conducting. So no current reaches the VFD Run logic inputs, R or F.

930 On the other hand if this switch is in the Neutral position the voltage at the R7 and R6 node is applied to R8 causing current from Q1 to be injected at the base of Q3. Hence, this switch position causes the Run Latch to turn on. (Once turned on the latch remains turned on even if the switch position is changed and the R8 current ceases.) Until the Run Latch starts to conduct, the current through R8 is essentially $(24 - 2 \cdot 4 - 2.5)V / R8 = 19.1 / 22K \text{ Ohm} = \sim 1\text{mA}$. This condition only lasts for a small fraction of a second as the current turns on Q3 causing the Run Latch to switch on. Once, the Run Latch has turned on the current through R8 is determined by the voltage across R6+R5+Latch on voltage drop less the forward voltage drop of Q3. The voltage at the top of R6 would be 24V less the two LED and the saturated Q1 voltage drops $(24 - 2 \cdot 4 - 2.5 \sim 19.1V)$. So the applied base current remains about the same, $(19.1 - 0.6)V / R8 = 18.5 / 22K \sim 1\text{mA}$. Hence, the Run Latch trigger current is sufficiently large. Should the switch be moved to one of the RUN positions the current via R8 ceases. To determine the current in R5, or the Run Latch, when the Run Latch is on, one must include the current from both R6 and from the base of Q4 or Q5.

940 This essentially completes the analysis of the Run Latch circuit, except for the calculation of the current values in R6 and R5. When the Run Latch is off, but the REV-Neu-FRW switch is not in the Neutral position the current through R5 and R6 is essentially zero. So, Q4 and Q5 have no base current and so are off. Hence, Q4 or Q5 provides no current to turn on the VFD.

950 When the Run Latch is on and the Rev-Neu-FRW switch is in the Neutral position the current through R8 was found to be $\sim 1\text{mA}$. The current in R6 and R5 is $19.1V / (6.2K \text{ Ohm} + 470 \text{ Ohm}) \sim 2.86 \text{ mA}$. Hence, the voltage across R5 is $2.86\text{mA} \cdot 6.2K \text{ Ohm} \sim 17.73V$ and the voltage across R6 is $2.86\text{mA} \cdot 0.47K \text{ Ohm} \sim 1.34V$. This value is important in determining if the emitter base voltage at Q4 and Q5 is sufficient to turn on these transistors. It is, as it is significantly greater than a forward diode voltage drop of 0.6V, but not so large that it would destroy the transistors (The maximum 2N3906 allow V_{EB} is 5 volts). When the REV-Neu-FRW switch is in the REV or FRW position the voltage across R6 is clamped to approximately 0.6 volts by the transistor base-emitter forward diode voltage drop and this base current is essentially stolen from R6, but returned to R5. One now sees why the R6 value is chosen to be in the 470 Ohm range, but one can also see that the values being used have considerable latitude. If the

Latch LED were not going to be included or had a different voltage drop one could simply change the values of R6 and R5 a bit. Likewise, if one found that one of the switches in the chain had significant contact resistance, the resistors could again be adjusted to compensate.

RUN Signals and Neutral Signal Dampening:

The circuits to the left of the Run Latch control the Forward and Reverse signals to the VFD. The ganged lathe micro switches forming the Rev-Neu-FRW switch are located at the tail stock end of the Lathe and the wires via the plastic conduit run to the Control Electronics Enclosure. Analysis of this portion of the circuit is straight forward. The role of the Neutral position has already been discussed. Via R8 it provides the trigger current to cause the Run Latch to engage. Should the Run Latch be turned off then the Rev-Neu-FRW switch must be returned to the Neutral position to activate the Run Latch. This is the Latching safety feature preventing accidental lathe start up after any of the safety switches are activated. If the Run Latch is activated and the REV-Neu-FRW switch is move to either the REV or FRW position current flows from the latch circuit to the switch, to Q4 or Q5, and then via R9 or R10 and LED-R and LED-F on to the VFD logic terminal RVo [2] or FWo [1], respectively. The two LEDs are not needed, except to provide indication of the activity and to assure the user that this portion of the circuit is actually working. Likewise, the resistors R9 and R10 are not essential to operation. They have a value of 330 Ohm, which is small compare to the VFD logic input impedance, 4.7K Ohm, and could be left out. However, they are a safety feature to protect the transistors of the circuits. Should one of these outputs become shorted during assembly etc. the maximum current that could flow via Q3 or Q4 would be $\sim 19.1V/330 \sim 58$ mA. This is below the maximum current ratings for Q3, Q4, or Q1 and would protect from being destroyed. (The maximum 2N3906 collector current rating is 200mA) However, this current might destroy the resistors or the LEDs. The current into the VFD logic terminals by these transistors is about $(24V-(2.5-2-0.4-2-.4))/(4.7K\text{ Ohm}+330\text{ Ohm}) \sim 16.7V/5.03K\text{ Ohm} \sim 3.3mA$. Removing the LED would increase this by $\sim 2V/5.03K\text{ Ohm} \sim 0.4mA$. However, the 3.3mA into the VFD logic terminal yields quite reliable results. (Recall: It took less than 1.56mA current to cause switching at the VFD terminal inputs while the current is limited by the 4.7K input impedance to be 5.1mA when 24V is applied directly.) Increasing the value of the 330Ohm resistor to, say 1.5K to protect the LEDs or the resistor itself is a possibility, but would decrease the current to the VFD logic input to $16.7V/6.2K \sim 2.7mA$, while the shorted current would be reduced to $16.7V/1.5K \sim 11mA$ at which point a 0.25 watt resistor and the LED would not burn out. However, for now, this larger resistor value has not been tested.

There was a concern that the wire coming from the Neutral position of the REV-Neu-FRW switch is a bit of an antenna for the collection of noise. This noise would then tend to appear at R8 on the circuit board and represent a possible cause to inadvertently provide Q3 base current when the latch was off, but the switch is in one of the two RUN positions. This is not a common situation, but would represent a safety concern that the lathe motor might turn on when the operator was not expecting it to. An example of such an event would be: A proximity event has turned off the Run Latch, the Proximity switch

is then reset to the open circuit position, but the REV-Neu-FRW has not yet been returned to the Neutral position. However, any noise that then appears at the input of R8 would be significantly damped out by C3. The voltage across C3 must approach the Q3 emitter base forward diode voltage before Q3 starts to conduct. The RC time constant is essentially $22K \cdot 1\mu f \sim 22mSec$. Hence, it would require an extreme large and noise spike of significant duration to cause this event. This is very unlikely to occur, but if one is still concerned then shielding the wires with a metallic conduit from the switches to the enclosure cavity would be another possibility. In the current implementation these wires are in the original plastic conduit and no problem event has been observed. It is not anticipated to ever be a problem.

JOG Signal:

The next control circuit to the left provides the ability to Jog the spindle in either the Forward or Reverse directions. The front panel switch is a three position momentary double throw switch, which directs current, via LEDs to both the VFD JOG [3] logic terminal and via a second set of LEDs to the VFD RUN logic terminals RVo [2] or FWo [1]. They are necessary to prevent a RUN signal from activating the JOG mode. This second set of LEDs could be replaced by conventional Si signal diodes, but again having the emitting light is sometimes useful. These latter diodes are required to isolate the REV-Neu-FRW signals from activating the JOG logic input. Noteworthy is that the Jog signals do not require an active Run Latch condition. Hence, one can JOG the spindle even if the Run Latch is turned off. This allows one to use the JOG as a By Pass signal to move the lathe carriage even when a Proximity sensor has closed and is causing Run Latch to be turned off. There is a potential hazard that a forgetful operator might Jog in the forward direction after the proximity sensor has tripped, causing a crash into the sensor. It would be possible to design a bit more logic to prevent this by using the signal from the Proximity Inverter circuit, but it has not been implemented here. The VFD programing calls for a JOG signal to cause the output frequency to be 6 Hz. Hence, VFD jogging is far more controllable than that of the original factory design. This Jog frequency is independent of the frequency selecting potentiometer setting. There are no short current fault protection resistors in series with the JOG diodes, but they could/should be inserted between the JOG switch and the LEDs. Using a 3.5mA activation current then one finds a resistance value of $R + 4.7K = (24-2)/(3.5mA) \sim 6.3K$, or $R \sim (6.3K - 4.7K) \sim < 1.6K\Omega$ would protect the transistors and the LEDs from an accidental short.

Coolant Signals:

Looking to the left of the Jog circuits the schematic shows the control for the Coolant pump. The lathe front panel switch is a three position double throw for Off, Manual On, and Automatic On states. This switch and circuit provides current to a solid state relay (SSR) used to turn the 220Vac pump motor off or on. In the Manual switch position the pump motor is directed to run all of the time and so is similar to that of the original factory design. In the Auto position, the pump runs when there is a RUN signal. The SSR logic input requires a maximum DC voltage of no more than 30V and about 7.5mA DC current to be activated. Hence, in series with the switch is a 330 Ohm resistor, R13, along with an indicator LED. To dampen any possible noise, wired across the SSR

control inputs, at the SSR, are a 22K resistor and a 1uF capacitor. In the Automatic switch position, the current is provided via Q6 and the coolant pump is activated any time the lathe receives a Run signal. Hence, the resistor R13 has been inserted as over current protection for Q6 in case of a wire shorting to ground. At this time, the SSR input has not been characterize well and so R13 was set to 330Ohms, but this is probably not large enough to protect Q6 from a shorted fault condition. In the Automatic switch state, the circuit containing Q7 inverts signals that might arrive from the Run Forward or Run Reverse circuits. These arrive via diodes D1 and D2 to prevent any possibility of current from the coolant circuits from turning on the spindle accidentally. Jumpers JF and JF are shown and either could be cut if one wanted to eliminate coolant flow while the spindle was turning in one particular direction, say reverse. R11 (22K Ohm) and R12 (10K Ohm) are simply biasing resistors for Q7 to prevent Q6 from being turned on if the Run condition is not met. They drain any leakage current away from the base of Q7 when the Run signals are off, while being large enough to effectively not take any significant current from the Reverse or Forward Run current paths nor the base of Q6. The combination of Q7 and R11 are referred to as an emitter follower circuit and as such is the only transistor on this board which is not operated in saturation! Hence, the voltage across R11 always essentially remains the same as the base voltage less the forward diode drop of Q7. The transistor current gain adjusts to cause this, effectively controlling the base current from Q6. In the Run state, it was found earlier that the Q4 or Q5 collector voltage is ~ 19.1V. Hence the voltage at the base of Q7 is ~18.5V and the voltage applied to R11 is 17.9V. So the current flowing through R11 to the 24V common is ~ $17.9/22K \text{ Ohm} \sim 0.81\text{mA}$, which is small. R11 also provides protection from a short fault. The SSR AC load current capacity is extreme over kill for the application. It can switch up to 30A at 220Vac, but here is being used to switch only the ~0.3A drawn by the Coolant pump motor. To protect the pump when in a stalled state, but to allow it to run at full load, the circuit to the pump is fused at ~0.4A.

PM1440GT Supplied Work Light Connection:

The label on this lamp says it runs on 24Vac or 24Vdc. As a matter of convenience, the work light connection occurs via the control circuit board at the far left. It is connected to the 24Vdc supply and is switched at the actual light. This eliminates the need to run separate power lines directly to it and to the circuit board. Push-on screw terminal connectors at both the circuit board top and bottom are employed.

3. **RPM Sensor and Indicator:**

The RPM (revolutions per minute) of the spindle is also measured and displayed at the lathe front panel, but since none of its components are located there it is not shown on the Control Circuit Schematic. A 6 digit RPM digital display is located in the lathe front panel and a Hall Effect sensor is located under the gear and belt cover next to the spindle. 10 magnets, space uniformly at 36 degree intervals around the spindle, are attached to the spindle via a nylon clamping holder. The holder is deigned to squeeze the spindle rather than to have the magnets simply glued or stuck to the spindle. As a magnet passes under the Hall sensor, a pulse is generated and counted at the display via a signal line. Hence, there are 10 counts occurring per revolution. The Digital display can measure 0-999,999 counts

per minute, so, for example, when the display shows 50 the spindle is turning at 5 RPM. Clearly one does not need such a high RPM nor the high resolution for typical lathe functions. The primary reason for using this particular digital RPM meter is its smaller display footprint and its short depth. It fit into the lathe front panel area and cavity easily. However, the ability to accurately measure low RPM values is useful if one needs very low spindle speeds. This is sometimes handy for winding bobbins for thread on sewing machines, wire for electromagnet coils... or for fishing lines! However, having a total revolution count would also be valuable if available. The RMP display and the Hall sensor are powered from the 12Vdc that is available at the digital volt meter which is also located in the lathe front panel. Hence, this RPM wiring runs only between the lathe front panel cavity and the spindle gear/belt enclosure.

Photo 10 and Figure 7 shows the hockey puck shaped magnet mount and the Hall device's Aluminum sensor mount. The magnet mount is made from stocked nylon and so does not interfere with the magnetic fields of the permanent magnets. However, other non-magnetic materials could be used. Slots for each of the Nd-Magnets were milled at 36 degree intervals just below the nylon outer diameter surface. They are secured in the slots via slot geometry as well as with #6-32 nylon screw heads. By moving the magnets away from the magnetic steel of the spindle surface the magnetic fields extend farther out into space providing a stronger field signal at the Hall sensor. The nylon hockey puck was made sufficiently thick in the diameter direction to allow a future pipe shaped spider to be fitted inside of a resized inner diameter. The nylon inner diameter could then be clamped either to the spindle or the spider depending upon how the puck was reshaped. On the PM1440GT there was an unused threaded bolt hole near the spindle bearing ring. The Aluminum Hall effect sensor mount is attached by this bolt hole via bolt and it pivots about this bolt to bring the sensor surface parallel to the magnets. A second screw is provided in the mount to extend through the mount and press against the bearing ring to brace and tighten the mount into position relative to the magnets. The spacing between the sensor and the magnets is also adjusted via the threaded sensor and its nuts.

4. Proximity Sensor Mechanics:

Both the inductive proximity sensor and the mechanical proximity limit switch are built into a 0.5 inch thick aluminum plate that is attached to the PM Micrometer Carriage Stop. There have been several descriptions provided on Hobby-Machinist for this style device and this design to a considerable degree replicates these.

The Inductive Proximity sensor chosen for this design is the model LJ12A3-4-Z_CY-G (PNP NO+NC) which has both NC and NO output options. It is widely available and inexpensive. As described in the control circuit analysis the NO connection is appropriate. This sensor has a specified detection distance of approximately 4mm. However, this varies considerably with the material being sensed and its mounting. It was found that for the 1440GT carriage the distance was more like 2.5 to 3 mm. This is sufficient for many spindle rotation rates and z-axis travel rate, but not the very fast ones. The carriage travel distance after the sensed signal is provided is dependent upon the 1 second electronic braking time and the inertia of the spindle, spindle chuck, work material and shape as well as the motor, gears, etc. Hence, for some conditions the carriage or tool could still crash the spindle even after the sense signal is provided.

1150 The sensing distance can be significantly increased. This sensor uses a
ferromagnetic ferrite core in a coil driven at approximately 600 KHz (measured).
When coming in proximity of the steel carriage the inductance is altered and this
causes the sensor electronics to trip. Hence, as stated, its sensitivity is highly
dependent upon the sensed material. Steel, being a somewhat of a soft magnetic
material, does this to some degree. However, at 600 KHz also, induces Eddy
currents in the carriage probably prevent the material from being as effective as it
would be if the frequency was less than say 100 Hz. However, a low frequency
causes other sensor performance problems. However, by placing a permanent
magnet at the surface of the carriage to create a field inside the proximity sensor
1160 as it approaches the sensing distance can be essentially doubled to greater than
5mm. Two 12mm diameter by x 4mm thick ~>35MGOe Neodymium Iron Boron
magnets were spaced away from the steel carriage by about 0.125 inches of
Aluminum and directly in the line of motion of the proximity sensor. The
magnetization is oriented through the thickness. This field, when approached by
the sensor, magnetizes the ferrite core, changing its magnetic permeability, to
lower the sensors inductance. The extent of the field from the magnets is improved
by mounting them into a non-magnetic material, such as Aluminum or plastic, to
both hold them in place, but more importantly to space them from the carriage steel
surface a bit. Covering them a bit also makes them easier to clean of any
1170 magnetic cutting debris collected on them. However, if one is going to employ this
permanent magnet technique, perhaps the sensor should be changed to a Hall
Effect device. Given the speed of the Run Latch and associated electronics, it is
not clear that and electrically active sensor, such as the inductive proximity sensor,
even yields better repeatability than a good mechanical switch. The delay time
between when the sensor threshold is reached and when the signal is provided has
not yet been measured.

5. Lathe Wires to the Front Panel:

1180 There are three cables that enter the front panel cavity from the small side hole
under the gear/belt cover. They are the already discussed RPM sensor cable plus
the two 8 wire shielded cables that feed up from the rear control panel enclosure.
To distinguish between the two shielded cables, the white jacketed cables are
tinted red and black at the lathe front panel as well as along the way from the
control enclosure. These colors are also marked at the push on connectors at both
ends of the cables. With a little effort, all three cables easily squeeze through the
original factory design wire port at the left side of the front panel cavity and then, as
was the original cable, are folded tight and clamped against the gear housing so as
to avoid the gears. Once, inside the lathe front panel cavity the wires are attached
to 0.15 in. (3.51mm) centered elevator screw terminals located on a small circuit
board with solder holes space to match. These push screw terminals are then
1190 connected to other sets of push screw terminals via the circuit board, which
connect to the individual switches and devices associated with the front panel. An
extra length of the cable wiring is folded into the cavity to enable removal of the
front panel and extension of the wires for access to all of the connections and
panel devices when the panel is removed. The PVC cover on the 8 wire cables
extend almost to the right hand side of the front panel cavity, then the individual
wires continue and bend outward to the connectors. The 8 shield cables are
composed of 8 colored ~ 20 AWG, multi-stranded (10 small strands) signal wires

plus the shield. The individual strands were advertised as Ni plated copper (silver color), but they are actually an alloy which is perhaps Ni and Cu and is a bit stiffer than most annealed Cu wire. (Scraping a strand surface does not change the silver color. Small lengths of the strands were carefully weight and measure to determine the material density. The density would indicate an alloy of more than just Cu and Ni. It is not uncommon in metal alloys to add additional components to reduce corrosion. (Cheaper wires are sometimes made of Al with a Ni coating. While Ni will solder the Al will not. Also, Al tends to corrode especially when exposed to solder flux. These should be avoided.) Inside the PVC jacket the 8 wires are wrapped with a metal coated plastic film which also has a bare, 10-stranded wire, wrapped to it to form the noise shield. It is a decent cable which should hold up even to vibration and oil contamination. The cable is supposedly made for the salty marine environment. Approximately 25 foot of cable was purchased via an Amazon. The ends of each wire maybe tinned with solder or crimped with 20-22 AWG ferrules before being inserted into the screw terminals. Because of the multi-colored characteristic, the wires from pieces this cable were also used to connect at various locations such as between the control circuit board screw connectors and the VFD spring loaded push-in clamp connectors. Approximately 18 ft. of the cable was consumed during the project.

6. DRO (Digital position Read Out):

A self-contained Precision Mathews two axis magnetic DRO was installed, which requires 110Vac power. Its power cable was routed via one of the rear enclosure ports and connected to one side of the 220Vac terminals. The DRO specifications claim 1 micron cross feed resolution and 5 micron z- axis resolution. Of course accuracy is less.

F. Control Electronics Circuit Board Layout:

The Control Electronics Circuits were built around a classic 0.10 inch (2.54mm) centered double sided solder holes board which is mounted in a special DIN board carrier. (Having a custom designed printed circuit board would be advantageous.) After enlarging the circuit board holes slightly by re-drilling to accommodate the square pins, the plugin style elevator screw connectors were soldered at both the top and the bottom edges of the circuit board. The carrier is designed for a 72mm wide circuit board so the circuit board was cut to fit. The carrier and circuit board lengths were cut down to fit the mounting position. The overall final length is about 162mm (~6.38"). Photo 11 is provided, as well as a representative scale drawing, Figure 8, of the layout of the wires and components. Similarly to Figure 3, but corresponding to Figure 8, Figure 9 provides the Control Circuit Schematic with interconnection labels.

Along the top plug in style elevator style screw connectors provide connection to the wires that pass through the enclosure's ports, such as the wires from the Reverse-Neutral-Forward switches, Foot Brake switch or the multiple front panel components. The top connector screw heads face downward so that it is easy to see and reach the wire insertion holes even when in the lathe enclosure. This connector style is used as there in limited room above and between the circuit board and the enclosure ports. The bottom plugin style connectors provide connection to the internal enclosure components such as the VFD etc. (If this board is ever remade, the bottom plugin style screw connectors should be moved up a circuit board hole row so as to not interfere with the edge of the circuit board carrier.) The bottom edge connector screw heads face directly outward,

perpendicular to the circuit board, and the wires are inserted from the bottom. For the most part the layout of the components is similar, left to right, to the layout in the circuit schematic. One obvious exception is the Coolant control lines and its connections which were moved to the far right on the circuit board. Also, because the Run Latch component section is spatially long, the Proximity Inverter circuit components are inverted and moved to the right of the Run Latch. The colors of the wire connections on the board are essentially irrelevant. However, the wire colors from the screw connectors outward, for the most part, are the same as the colors used in the pair of cables going to the lathe Front Panel. In fact, it was very convenient to simply pull the colored wires from short segments of the cable for the wires going to the VFD etc.

Above the circuit board sketch are representative sketches of the control switches etc. which lie outside the enclosure. Wire connections between these Front Panel devices occur at the front panel. Below the circuit board are some connection listings as well as some additional external wiring and device sketches. Some reasonably accurate dimensions are also provided. The green regions at the ends of the circuit board sketch represent the DIN clamps. A large hole through the circuit board and board carrier was cut on the left hand side to allow one of the 4 control electronics mounting plate bolts to pass through and clamp the Aluminum plate to the lathe cavity back wall. By removing the top and bottom plugin style screw connectors and releasing the circuit board DIN latches the entire circuit board may be easily removed.

G. Front Panel and Component Physical Layout:

The front panels of the factory original lathe are shown in Photo 3, Part 1. The region behind where the E-Stop, T(Jog), white indicator light, and the coolant switch are located is a hollow cavity to provide space for the switches etc. and this provides space for this design's switches and wires. Hence, the panel must be removed. The original aluminum panel also encompasses the upper gear knobs with long handles. These are firmly glued into the knobs and could not be removed without damage to the appearance. They do not easily unscrew. The shaft side pinch pins can be driven out of the knobs and then the handles slide off the shafts. Caution must be taken when removing the three position (H, M, L) gear knob as there are a spring, plastic insert, and ball bearing pushing out the back against the handle shoulder at the gear box, which is used to provide positioning detents, Photo 14. Because of the spring, the small parts can easily fly out and be lost during the knob removal. The pressure on these parts is adjusted via a set screw that is hidden behind the glued on arrow label. The arrow label can be peeled back and removed, but this aluminum label can easily be wrinkled or damaged. This detent feature of the lathe design is poor as the detent/spring strength is insufficient to always hold the center (M) gear position during the lathe startup acceleration. This is especially true after the VFD conversion as the motor is not specifically designed for variable speed and the motor's acceleration tends to pulsate at certain acceleration settings causing the gears to become unengaged. (This problem is the subject of a You-Tube video! However, the VFD design program parameters ameliorated a good portion of this pulsation and once up to speed the motor seems to stabilize.) Once the front panel is removed it can be cut off just below the lathe gear threading direction knob and then the lower portion replaced with a new panel layout, Photo 15. (There is one proximity connector hole missing in this photo.) Note that the additional corner bolt mounting holes have been drilled and tapped into the lathe which simultaneously fixes the top corners of the new panel and the bottom corners

of the cut off original panel. The new functions shown on the replacement panel Photo 7 are, from left to right, top row followed by the next row:

1. LED Digital Voltmeter:

The VFD analog input frequency setting is displayed on the 5 digit green LED Digital Voltmeter indicating a voltage between 0-10V corresponding the applied VFD frequency control voltage. The VFD frequency response to input voltage is not perfectly linear. It was desired not to have to do a mental calculation each time this meter was viewed, so the VFD was programed to provide ~ 60Hz when a voltage of 6 volts was applied. In order to achieve this the VFD maximum frequency was set to be about 108Hz at 10 volts input. Clearly all of the voltmeter digits are not necessary, but this display was chosen for its smallish size and electrical properties. It is unlikely that the motor would ever be run at over 100Hz as this would imply the maximum spindle speed would approach 3000 RPM.

2. RESET Switch:

A recessed momentary contact USP Reset switch is provided. A recessed switch was chosen to prevent its being accidentally depressed. This particular switch contains an LED, which can be connected to confirm the switch's closure.

3. RPM Digital Meter:

The 6 digit red LED Digital RPM meter indicates the spindle speed from a Hall sensor and 10 magnets per revolution located on the spindle. Hence, a reading of 10 would imply 1 revolution per minute. Clearly 6 digits are over kill and the resolution maybe questionable, but the meter is inexpensive and physically smaller than other RPM meters allowing it to fit the panel space. At a rather high spindle speed of 3000 RPM the meter will read 030,000 with the highest digit on the display will still being 0. Overall it works pretty well and is quite visible.

4. Run Latch Active LED:

The top right position is the green Run Latch LED indicator. A lit LED indicates that the lathe will turn if activated by the Forward or Reverse switch signal. The LED is quite visible. An off LED indicates that the lath will not start as the Run Latch is off. However, JOG mode is still active.

5. Three Position Coolant Switch:

The bottom left switch controls the Coolant. Up is the Automatic Coolant position, the middle position represents Coolant being turned off, and the bottom position is the Manual On operational condition.

6. Two Position Electronic Braking:

To the right of the Coolant switch is the two position Electronic Braking switch which provides two alternatives. The downward position implies that the lathe spindle will brake to a stop in 3 seconds. In the upward position, the electronic braking occurs in 1 second. (One can use the 1 second braking when employing the proximity sensing.)

7. Momentary Two Direction JOG Switch:

The next switch is a momentary switch for JOG. Up is the Reverse JOG position (clockwise rotation when viewing the spindle from the tail stock) and down is the Forward JOG position (counter clockwise rotation). JOG is programed to occur at 6 Hertz motor frequency. This function runs independent of the RUN Latch state and so can be used to move the carriage away from the proximity sensor without disengaging the carriage feed gearing. (This prevents losing the carriage lead screw phase when thread cutting.)

8. GX12 Aviation Proximity Safety Switch Cable Connector:

To the right of this is a standard 4 pin male GX12 Aviation cable connector for the mechanical NC Proximity Safety limit switch. Only two of the wires, of this 4 pin connector, are connected to this mechanical NC switch. These two proximity cable connectors are, intentionally, mechanically incompatible. If the lathe carriage-stop, and so proximity sensor, is not used, the cables can be removed. However, a shorting connector must then be placed on this GX12 cable connector to ensure that a NC circuit is in place.

9. M12 Proximity Sensor Cable Connector:

The next position is a male 4 pin M12 sensor cable connector for the NO inductive Proximity sensor cable connection. Three wires supply power, ground, and signal connections via a right angled connector. It looks a bit like a standard aviation connector, but is not mechanically compatible with such. The M12 style pins are smaller and match those of the M12 style proximity sensor. A straight, non-angled, cable connector for the GX12 connection makes it easy to distinguish between it and the right angled M12 cable connector.

10. VFD Frequency Setting Potentiometer:

A 10 turn, 2K Ohm potentiometer, used to set the VFD Motor frequency, holds the next position on the panel. Internally, the potentiometer wiper terminal is connected both to the VFD input via the 8 wire cable and directly to the Digital voltmeter signal input.

11. E-Stop Switch:

Finally, at the bottom right, just below the Run Latch indicator LED, is the conventionally large NC Emergency-Stop (E-Stop) switch button.

H. Front Panel Wiring:

There are two 8 conductor shielded cables plus the Hall Sensor cable (3 wires) feeding the front panel from the lathe's left gearing wall entry hole. In addition, the two front panel proximity connector cables (3+2 wires) must be connected. This represents a total of $2 \times (8 + \text{shield}) + 3 + 3 + 2 = 26$ wires that feed into or out of the front panel cavity. Even with the redundancy of power and ground leads there are 44 needed wire connections. Hence, these wires would be a considerable rat's nest of wires if not organized in some manner. Also, permanently attaching each of these wires to their respective devices would represent a tedious process if the connections needed to be modified. Hence, a circuit board was constructed with robust wire screw-push on connectors for this transition. Figure 10 and Photo 12 illustrates the circuit board layout of these which easily fits, along with the wires, in the front panel cavity. To limit the length and size of this set of connectors mounted on a circuit board with 0.15 inch spaced connector pins (3.81mm centers) are used. These are smaller than the 0.2 inch spaced (5.08mm centers) used on the control electronics circuit board in the electronics control enclosure. (One maybe tempted to use the smaller 0.1 inch centered connectors as are commonly used in microprocessor systems, such as Arduino, but these are insufficiently strong in such an environment.) In total there are 4 nine pin connectors and 2 four pin connectors employed to make the 44 connections.

The 9-pin and 4-pin connectors are soldered to the circuit board in two parallel rows so that 22 screw terminals exit on each side (The 9-pin connectors maybe cut down to make the 4-pin connectors) . For most of the terminals pairs a wire is soldered straight across between the two rows. However there are a few exceptions which are shown in Figure

1390 10. A small space remains between the two rows to allow for multiple solder connections
or redirection of connections. After the soldering is completed, a compliant insulator such
as polymer foam board or rubber is attached to the back of the circuit board to cover all of
the solder points without applying excessive stress to the connections. The attachment
was made by leaving extra circuit board at the ends of the rows of connectors where wire
is fed through the circuit board holes and the insulator material and then twist tied
together. This clamps the insulator material firmly in place against the solder side of the
circuit board. The cable wires and device wires are attached to the elevator screws
clamps and then plugged into the corresponding circuit board connectors. There are no
obvious mechanical connection points inside the front panel cavity so the wires and this
board are simply folded into the center of the panel cavity to allow one to access it in the
1400 future. Drilling new holes was avoided out of some concern of hitting internal components
or the oil reservoir. Even though the circuit board is essentially insulated and the screw
heads are inside the plastic, the nest of device wires and the cable wires should be
arranged so that they tend to hold the free floating circuit board in place, restricting it from
contacting the cavity body, wire ends, panel devices or any other electrical conductor. The
overall length and width of the board should be kept small to easily fit into the cavity along
with all of the panel devices.

I. Potential Improvements:

1410 The Control Electronics circuit board, as well as the Front Panel interconnect circuit
board, should be made as custom printed circuit boards. They might be more reliable,
save a lot of soldering time, and in the case of the Control Electronics board could be
made more compact and hence shorter. In doing so the plug-in connectors could be
reduced to 0.15" center spacing rather than the current 0.20" devices and so the overall
length of the board could be shorter. The proto-board used for this current design has
0.10" solder hole centers and there is considerable open space on the board. This saved
length would allow a separate (electrically isolated) board section in the same carrier
providing a mount for a smaller Coolant SSR and fuse. This would further simplify the
overall wiring and physical construction. Putting such a device on the current board was
contemplated, but ruled out in order to avoid placing 220Vac and the associated switching
1420 on the same board with the logic and analog signals. However, with a reduced size, the
physical spacing would be greater.

The RPM meter could possibly be replaced with an electronic counter, which is
available from the same vendor. Adding this, plus a small amount of timing electronics
would allow for having revolution counting or RPM measurements with the addition of a
small start switch. This concept is being investigated.

The front panel potentiometer has a 10-turn, locking, dial reading, which with the
digital volt meter to indicate the potentiometer output voltage is no longer needed. In fact,
one does not really even need the resolution of a 10 turn potentiometer.

1430 Having the proximity sensor at the mechanical carriage stop is not good as it is
susceptible to cutting debris and coolant splattering. At the least it should have a cover
over the electrical parts. Likewise, its dangling cables represent a reliability issue and this
fact drove the need for the proximity safety mechanical switch. These cable materials
need to be oil tolerant or extra shielding should cover them. The pair of proximity cables,
rather than one cable with extra internal wires, was used to reduce the risk of a single
cable failure. Alternatively, obtaining a DRO, which could be pre-programed to output a
signal when a programed position has been reached, could potentially remove the need

for the proximity sensors all together. Does such a DRO even exist? This would seem to be trivial feature to be added to most DROs, but one might need access to the DRO programming and wiring to alter a currently available unit. A signal cable from the DRO could be run directly to the Rear Panel Control Circuit Board and would not need to go to the Front Panel.

J. Conclusions and Performance:

Other than the final versions of the proximity mounts and the Hall magnet mounts, the conversion implementation has now been in used since the late fall of 2020 without any observed problems. All features function as described in this document.

K. Parts List and Sources (approximately complete):

General Parts:

1. PM1440GT Plus Accessories: Precision Mathews
2. PM Accessory: PM Micrometer Carriage Stop.
3. PM Magnetic Rule DRO, 1um (cross slide) & 5um (saddle) resolutions.
4. Casters, 4: 4"dia, Swivel, 1000#/ea. Steel, Service Caster Corporation,
<https://www.amazon.com/Service-Caster-Swivel-Casters-Capacity/dp/B07JXC2XK8> , \$26/ea. Nov. 2019.
5. Wall Switch: ON-OFF, 220V 30A or greater, external/wall switch for incoming power. Preferably with built in breakers or fuses, 220V, 30A in addition to house main breaker, 220V, 30A from a 30A double pole.
6. Wire, 3 conductor plus ground, 10 AWG, for 220V, 30A, from 30A double pole breaker at main house breaker box to lathe wall switch box.
7. Wire, Power, 3 conductor plus ground, AWG 10, from power wall switch to lathe. Preferably flexible stranded wire to allow for lathe movement when servicing.
8. Strain relief clamps for wire entry into the lathe.

REAR PANEL/ENCLOSURE & MISC. Parts

9. VFD: Hitachi Inverter model WJ200-022SF, www.driveswarehouse.com, \$310.
10. Wire, heavy gauge stranded, various AWG for high current distribution between VFD and the screw terminals for the incoming power, the motor or to the breaking resistor.
11. Plexiglas Cover Panel, 0.25" thick by >~ Original Panel dimensions.
12. Plexiglas cover spacers, 1x1" by panel perimeter length. Virtually any material. Preferably, one which is reasonably impregnable against oil, but which will be flexible enough to seal against the Plexiglas cover panel and the steel lathe stand.
13. Cooling fan, exhausting, 80mm x 80mm x 25mm, EC-multi-Voltage AC and DC, <https://www.amazon.com/gp/product/B07H8TQ7B1> , by GDSTIME, \$14
14. Aluminum plate: 0.125x12x24", 6061 T6 (4 plates, backing, brake-R, VFD-2) <https://www.amazon.com/gp/product/B01CITAC4Y> .
15. Screws, #6-32 by 0.25" plus other Misc. sizes, metric screws. Drill bits and taps.
16. Cable-Shielded (Marine cable): 8+1, 20AWG Tinned-Cu conductors, ~18' was used, White PVC Jacket, Black/Red/Green/Blue/Brown/Orange/Purple/Yellow <https://www.amazon.com/gp/product/B088JZR9N> , by Common Sense Industries: ~ \$52 / 25' roll. Upon recently checking the 25' purchase length had changed.

17. DIN Rail Slotted Aluminum, 12" x 35mm W x 7.5mm H.
<https://www.amazon.com/gp/product/B0814M8FC3> ,by Keadic \$16.39/15pcs +\$0 shipping.
18. Ferrule Crimping Tool Kit AWG 23-10 w/1200 wire end Ferrule pcs,
<https://www.amazon.com/gp/product/B07MZXWTVQ> , by Sanuke, \$25.99/kit+\$0 shipping.
- 1490 19. Ferrules Terminals, 1000 PCS AWG 20,
<https://www.amazon.com/gp/product/B07H2968LW> , by XHF store \$8.89/bag+\$0 shipping.
20. Power Supply, 24V, 1A, 24W, MDR-20-24 AC to DC, DIN-Rail
<https://www.amazon.com/gp/product/B005T6RB16> , by MEAN WELL, \$17.95/ea.+\$0 shipping.
21. SSR-30DA Solid State Relay Module 3-32V DC Input 24-480VAC SSR-30DA 30A,
<https://www.amazon.com/Fotek-Solid-Module-24-480VAC-SSR-30DA/dp/B08DF8KXPL> , ~\$13 (Coolant)
22. Fuse Holder and 0.4A slow blow Fuse (Coolant)
- 1500 23. Resistors, Power: 50W, 25Ohm, wire wound, Al Hose style,
<https://www.amazon.com/gp/product/B07G75GJWF> , by BESUNTEK, \$18/8pcs. (Braking Resistor Bank)
24. Screw Terminal Block, DIN Rail, 20 Position 30A /300V,
<https://www.amazon.com/gp/product/B07BFXRBNY> , by Electronics-Salon, \$19.99/ea+\$0 shipping. Electronics-Salon, <https://cjh-labs.com> , supplies a large number of various, DIN based specially electronic connectors and components.
25. PCB Carrier-Bracket, DIN Rail Mount, for 200mm x 72mm PCB, by Electronics-Salon, <https://www.amazon.com/gp/product/B017B90NPE> , \$13/ea+\$0 shipping
26. Prototype Circuit Board, cut from 15x20cm Double Sided, 2.54mm pitch solder holes, <https://www.amazon.com/gp/product/B07FK41NG8> , by Uxcell,
 1510 \$25.79/5pcs.+0shipping.
27. Pluggable Terminal Block Connectors, 2EDG, 5.08 mm Pitch Right Angle 20Sets 2-pin PCB <https://www.amazon.com/gp/product/B077GTYZVM?th=1> , by Willwin \$8.70/20pcs +\$0 shipping. (search phrase 2EDG)
28. Pluggable Terminal Block Connectors, 2EDG, 5.08 mm Pitch Right Angle 10Sets 9-pin PCB <https://www.amazon.com/gp/product/B077GTYZVM?th=1> , by Willwin \$9.00/10pcs. +\$0 shipping. (search phrase 2EDG)
29. Screw Terminal Block STRAIGHT-Angle-PLUGGABLE 9-Pin 5.08mm Pitch Male+FemalePair PCB 10Pair, <https://www.amazon.com/gp/product/B07793ZSZJ> by Willwin, \$9.20/10pair+\$0 shipping.
- 1520 30. Screw Terminal Block STRAIGHT-Angle-PLUGGABLE 2-Pin 5.08mm Pitch Male+FemalePair PCB 20Pair, <https://www.amazon.com/gp/product/B07793ZSZJ> by Willwin, \$8.70/20pair+\$0 shipping
31. Voltage Regulator, +12V 1.5A, L7812 TO-220 (20 pcs),
<https://www.amazon.com/gp/product/B07XTDB7LJ> , \$6.99+\$0 shipping.
32. Transistor PNP+NPN 2N3904+2N3906 TO-92
<https://www.amazon.com/gp/product/B089K9R8D6> , by Todiys \$9.95/(50Pairs)+\$0 shipping.
33. Resistors,1/4 watt, 5%, generic, See figures for values and number.

- 1530 34. LED Light Emitting Diode Assortment, Round 5mm, 450pcs/box (5 Colors x 90pcs), 2 volt, by DiCUNO, <https://www.amazon.com/DiCUNO-450pcs-Colors-Emitting-Assorted/dp/B073QMYKDM?> , \$12.99+\$0 shipping.
35. Capacitors, 1uF, >~ 30Vdc, polymer, generic, see figures. Example: Capacitor FILM 1UF 5% 63VDC RADIAL, Metallized, Polyester, PET, ~\$1/ea. <https://www.digikey.com/en/products/detail/kemet/r82dc4100dq60j/1930801> , preferably not dielectric capacitors.
36. Diode Axial IN4001, 1A 50V, <https://www.amazon.com/gp/product/B079JPMW9H> by Chanzon, \$5.83/100pcs+\$0 shipping
- 1540 37. PCB Connection wires, solder, misc. etc. The left over shielded 8 conductor wire, when stripped from its outer casing, should provide for colored connections wires between the circuit board and the VFD etc.

FRONT PANEL/ENCLOSURE & MISC. Parts

38. Aluminum plate:~0.071 x12x?", 7075 T6 www.onlinemetals.com (front panel)
39. Proximity Inductive Sensor Switch, Air Plug MX12, sense distance~4mm, DC, PNP, NO+NC, with 2M cable w/ single right angle connector. <https://www.aliexpress.com/item/1005001520492108.html> , FuChuang Tech Co., Ltd., \$5 /ea. (Proximity Inductive Sensor) Supplier, HEYI Electrical Co.Ltd., and data sheet at http://www.control-electrical.com/Catalogue/Inductive_Proximity_Sensor_LJ12A3-397.html .
- 1550 40. Proximity Cable, Double Right Angle Female/Female Connector, 4P, Type A MX12, 2M length. <https://www.aliexpress.com/item/32861398824.html> byMHCN United Co. Ltd., \$2.45 ea.+\$4.60 shipping. (Proximity Inductive Sensor)
41. Sensor Panel Plug Male, 12mm Metal, 4pin, Type A MX12, <https://www.aliexpress.com/item/32838956281.html> , by Electrical Kingdom Store, \$0.81/ea + \$1.55 shipping. (Proximity Inductive Sensor)
42. Aviation Panel Plug+Cap Female GX12 12mm Metal 4pin, <https://www.aliexpress.com/item/32831408251.html> , by ATOPELEC Store, \$0.75/ea +\$1.74 shipping. (Proximity Safety)
- 1560 43. Switch Momentary Push Button DPDT NO NC 6Pcs, by Cylewet <https://www.amazon.com/gp/product/B07FWSZRNX> . (Proximity Safety, poor choice)
44. LED Metal Panel Signal Lamp, 6mm, <https://www.aliexpress.com/item/4000039417563.html> by Brandtop First Store \$0.55/ea + \$0.82 shipping. (Active Lathe, Run Latch Monitor)
45. Switch Momentary Fixed Push Button Flat Switch w/ Ring LED, by BrandTop First Store, <https://www.aliexpress.com/item/32996630889.html> , \$1.46/ea+\$0.82 shipping. (USP, Reset)
46. Switch Connector Cable for Momentary Fixed Push Button Switch, by BrandTop First Store, <https://www.aliexpress.com/item/32996630889.html> , \$0.32/ea+\$0.82 shipping. (Proximity Safety)
- 1570 47. Prototype Circuit Board, cut from 9x15CM, Single Side, 3.81mm Pitch Hole Centers, 3 pcs. (Front Panel Connector Bd) <https://www.amazon.com/gp/product/B07C9YFTG> , 3x\$4.59/ea +\$8.65 shipping, Hard to find item due to 3.81mm centers. Google search phrase: "3.81mm" Prototype Circuit Board

- 1580 48. Screw Terminal Block RIGHT-Angle-PLUGGABLE PIN HEADER SOCKETS & CONNECTORS, 9pin, 15EDG 3.81MM pitch, 2 x 5SETS by Alinsin Store, <https://www.aliexpress.com/item/32877650255> , \$2.73/5sets + \$1.03 shipping. (search phrase 15EDG)
49. Tachometer Digital, 6 Digit Panel, 999999 RPM, OD 60x29x25mm, Hole size 58.5 x 27.5mm, <https://www.aliexpress.com/item/32974138466.html> , by DIGITEN Official Store, \$13.49/ea+\$0 shipping. (RPM). This vendor also sells the same size 6 digit counter, <https://www.aliexpress.com/item/2043949572.html> .
50. Hall Effect Sensor NJK-5002AB, M12 DC PNP NO+NC 10mm Detection distance, <https://www.aliexpress.com/item/32822461023.html> , \$5.74/ea+\$1.05 shipping. (RPM)
- 1590 51. Potentiometer, 10Turn, 2K Ohm 2W, Wirewound, 6mm Shaft, w/ Precision Rotary Dial, by JANSANE <https://www.amazon.com/gp/product/B07D8JWZ7> , \$9.99/ea+\$0 shipping. (Frequency setting)
52. Voltmeter DC 0-4.3000-33.000V LED Digital 5 digit 4wires Green, OD 48x29mm, hole size 45.5x26.5mm, No longer available but similar to: <https://www.aliexpress.com/item/4000636185594.html?spm> , SeeSensor Store, ~\$5.17/ea+\$3.59 shipping. (Frequency monitor)
53. Switches Latching Toggle, Metal, 3 Pin 3 Position ON/Off/ON SPDT, Waterproof Cap+Terminal Wires, TEN-1122MZX-B103, 3pcs, TWTADE <https://www.amazon.com/gp/product/B082QRJT76> , \$12.99/3pcs+\$0 shipping. (Coolant)
- 1600 54. Switches Momentary Toggle SPDT (ON)/Off/(ON) 3Terminal 3Position, metal, 3pcs, by Mxuteuk, <https://www.amazon.com/gp/product/B07TYLWKWN> , \$8.99/3pcs+\$0 shipping. (Jog)
55. Switch Latching Toggle, Metal, 2 pin 2 positions, On/Off SPST, generic (e-brake, 2CH)
56. E-Stop Switch, Original PM1440GT Part.

L. Comments on Parts Sources:

Example Electronic Component Sources:

www.aliexpress.com , www.amazon.com , <https://czh-labs.com> (Electronics-Salon) , www.onlinecomponents.com , www.newark.com , www.jameco.com , www.digikey.com , www.mouser.com , www.sparkfun.com , www.microcenter.com , www.banggood.com .

1610 Many of the smaller electronic parts were purchased via www.aliexpress.com , and in some cases are only available there. AliExpress now takes PayPal payments so the transaction is relatively secure. The standard air shipping from China is commonly free, but shipments to the US seem to be grouped and so delivery can still take from 4-8 weeks for delivery. Amazingly, many of the smaller parts are shipped free. While AliExpress and its suppliers were found to be quite reliable, because of the long delivery time and the low cost, multiple units were commonly ordered for potential future projects. Of the many items ordered, only twice were there issues. In one case the wrong cable style was sent, but was replaced without additional cost. In the other case, a digital volt meter failed after a few hours of use.

1620 Shipping for small quantities can cost more than the part. For this reason, many parts were purchased via Amazon Prime and AliExpress. For some parts, Amazon and AliExpress suppliers are the same.

M. Figures, Tables and Photos:

(See attachment documents)

1630

Figure 3 (Part 2)

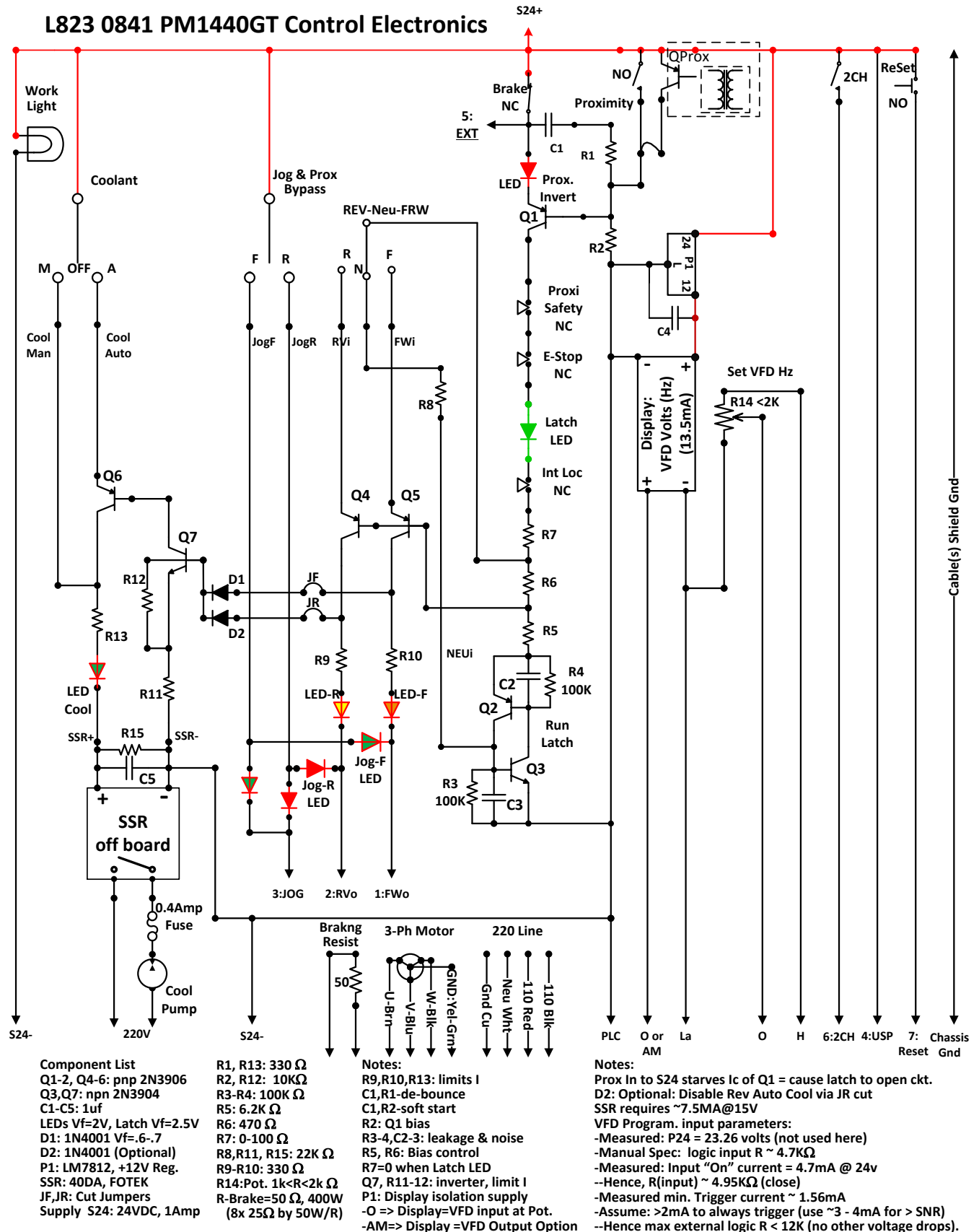


Figure 4 (Part 2)

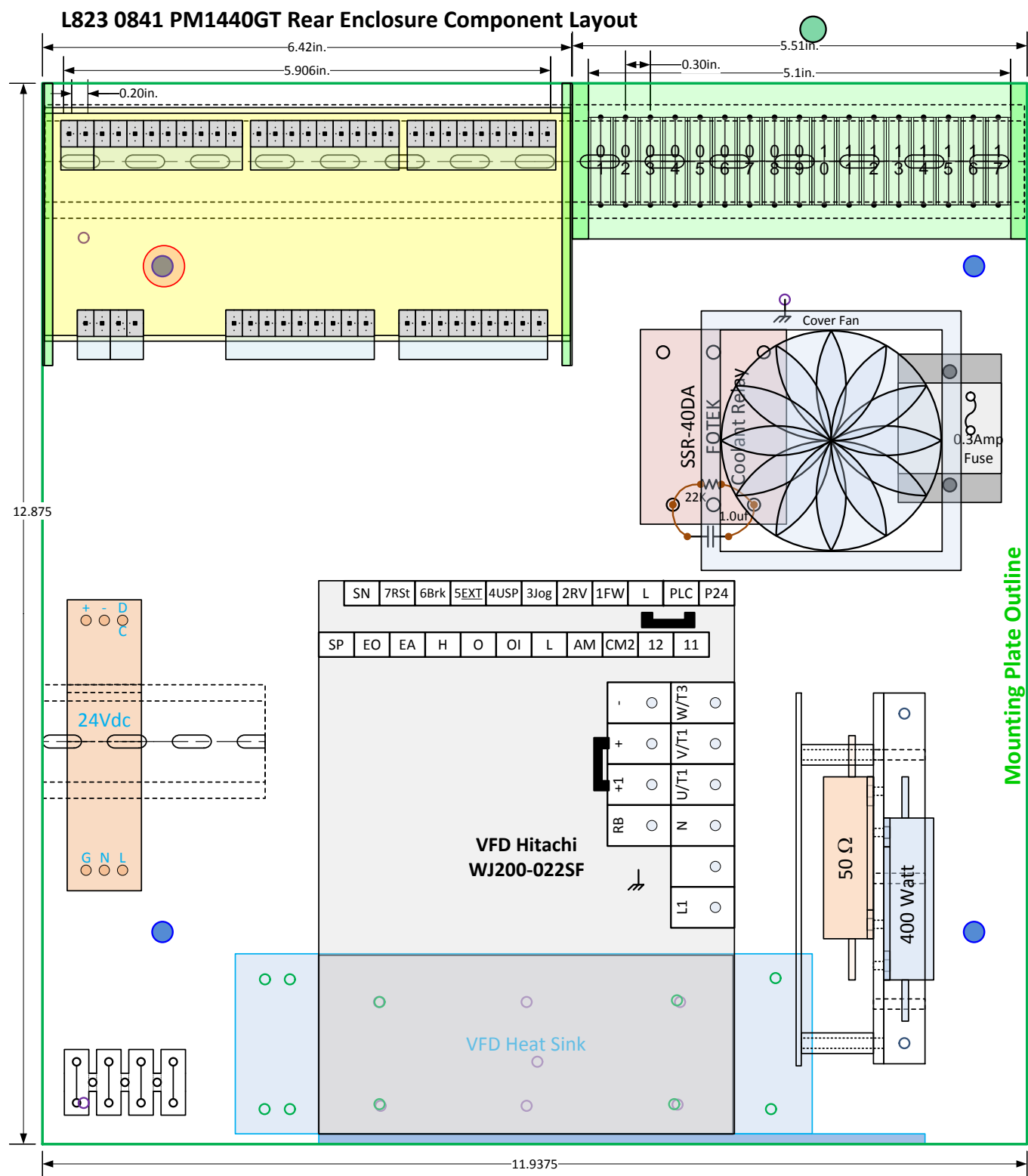


Figure 5 (Part 2)

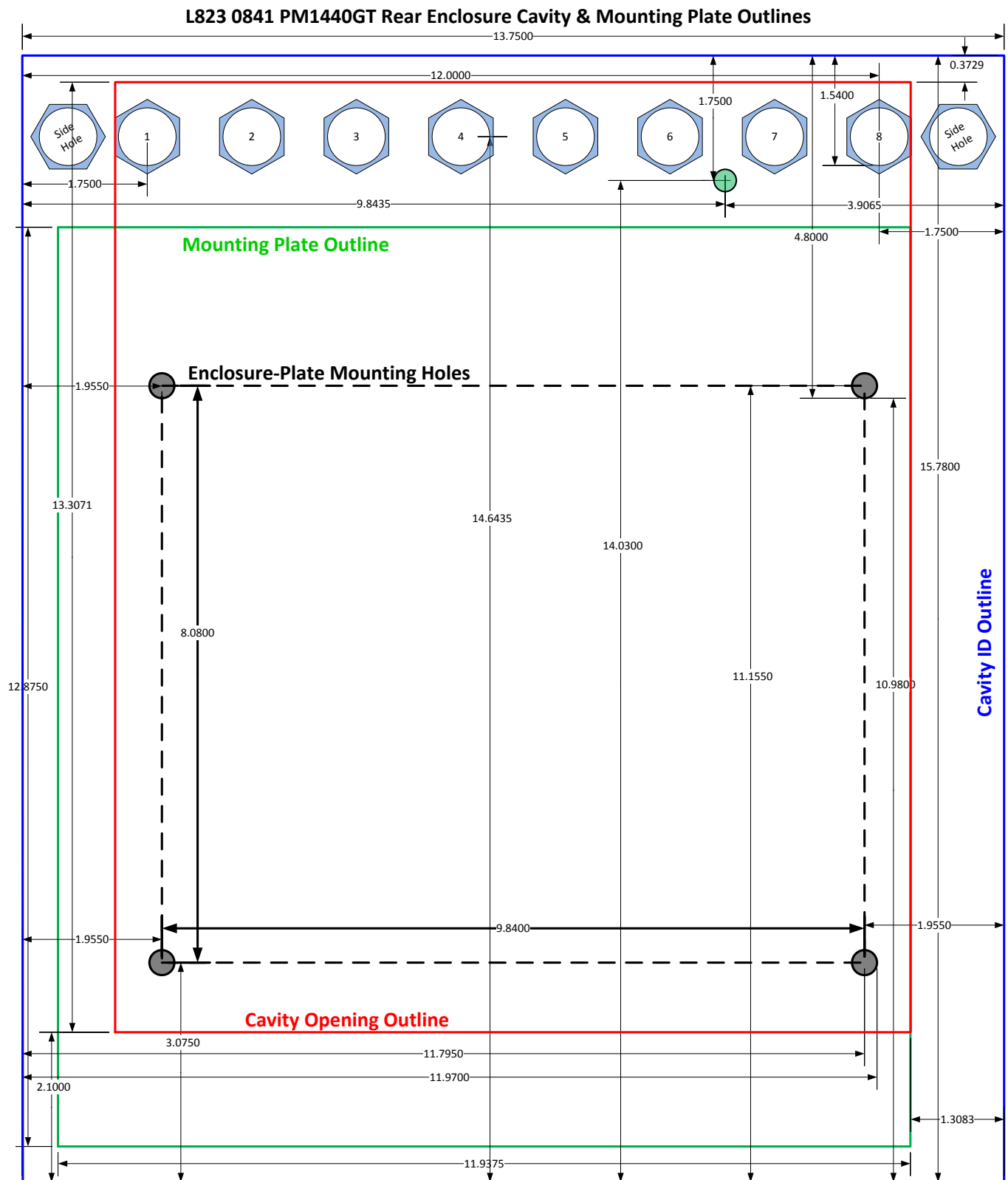
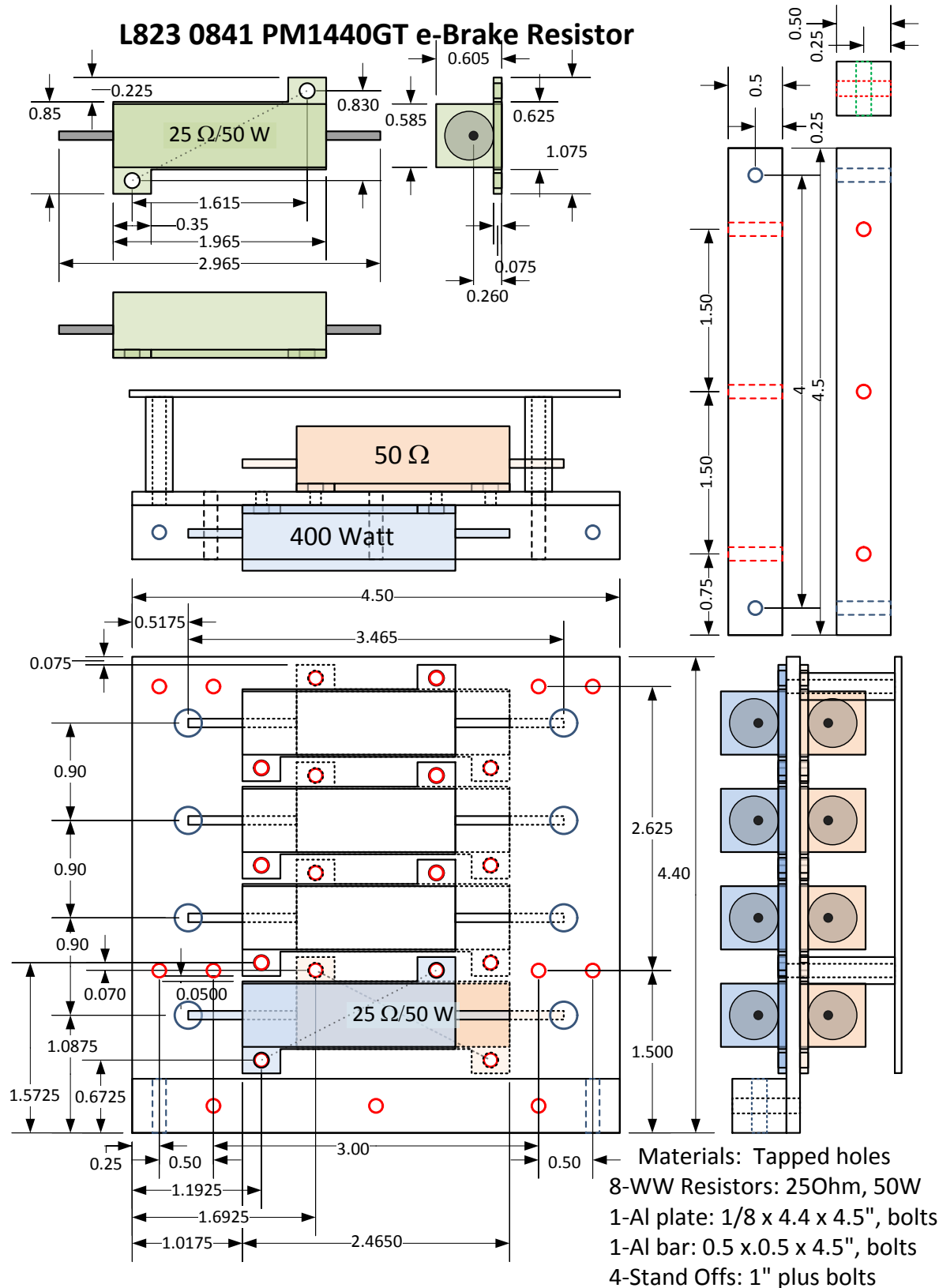


Figure 6 (Part 2)



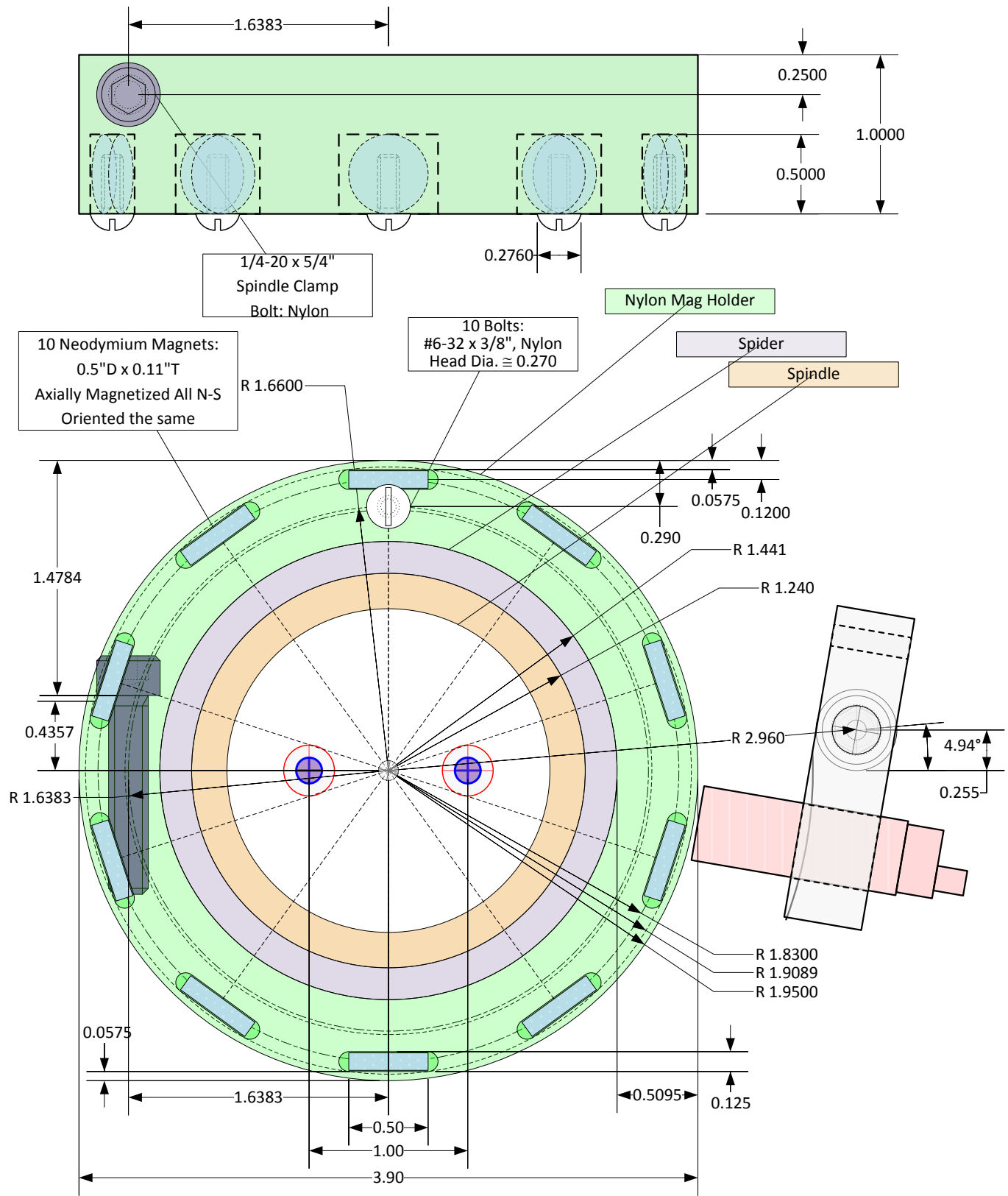
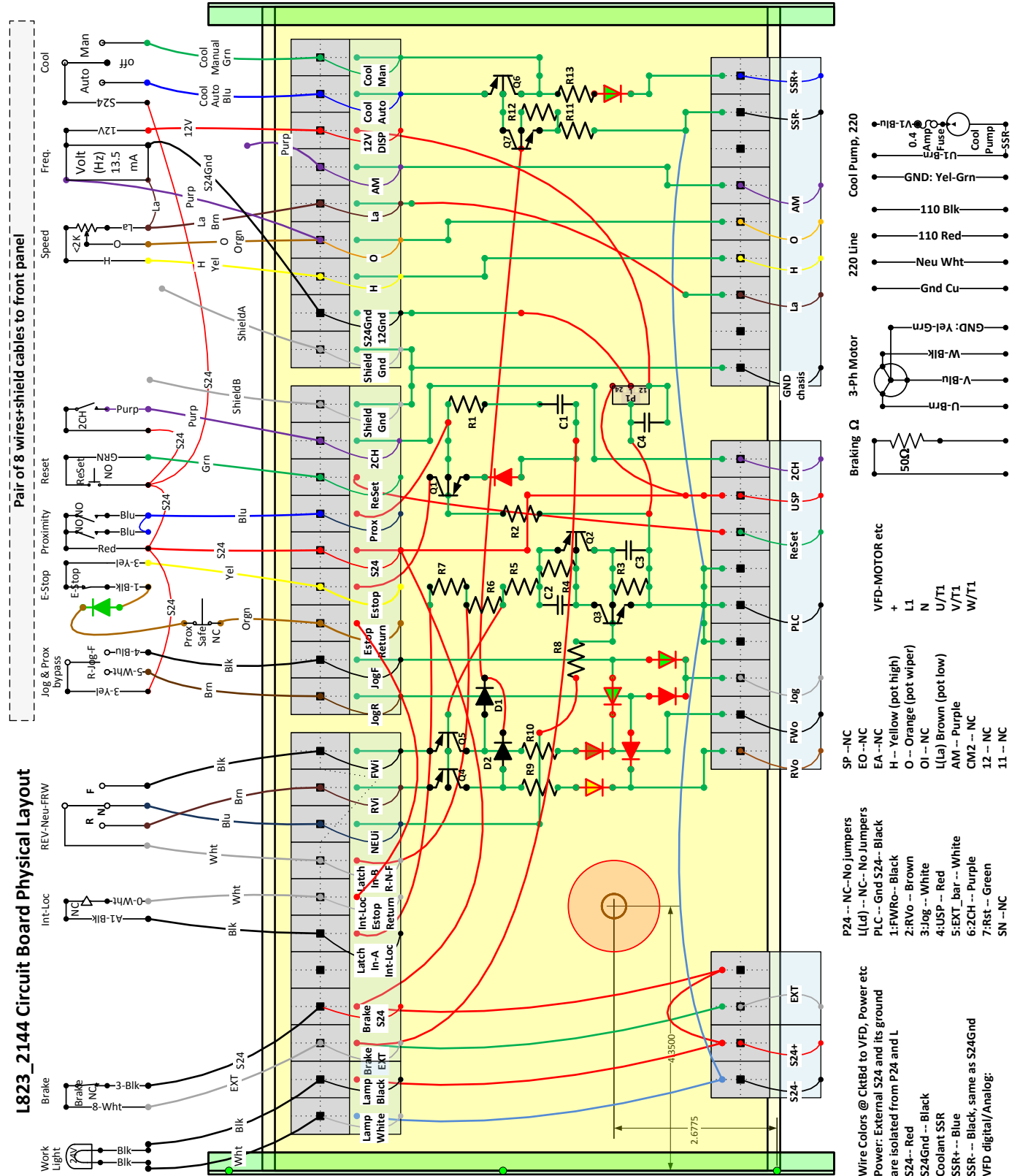
1650 **Figure 7 (Part 2)**

Figure 8 (Part 2)



1660

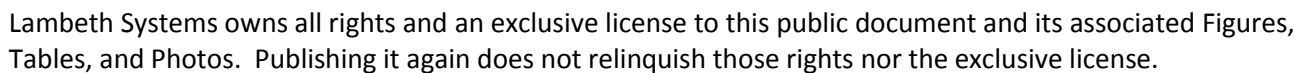


Figure 10 (Part 2)

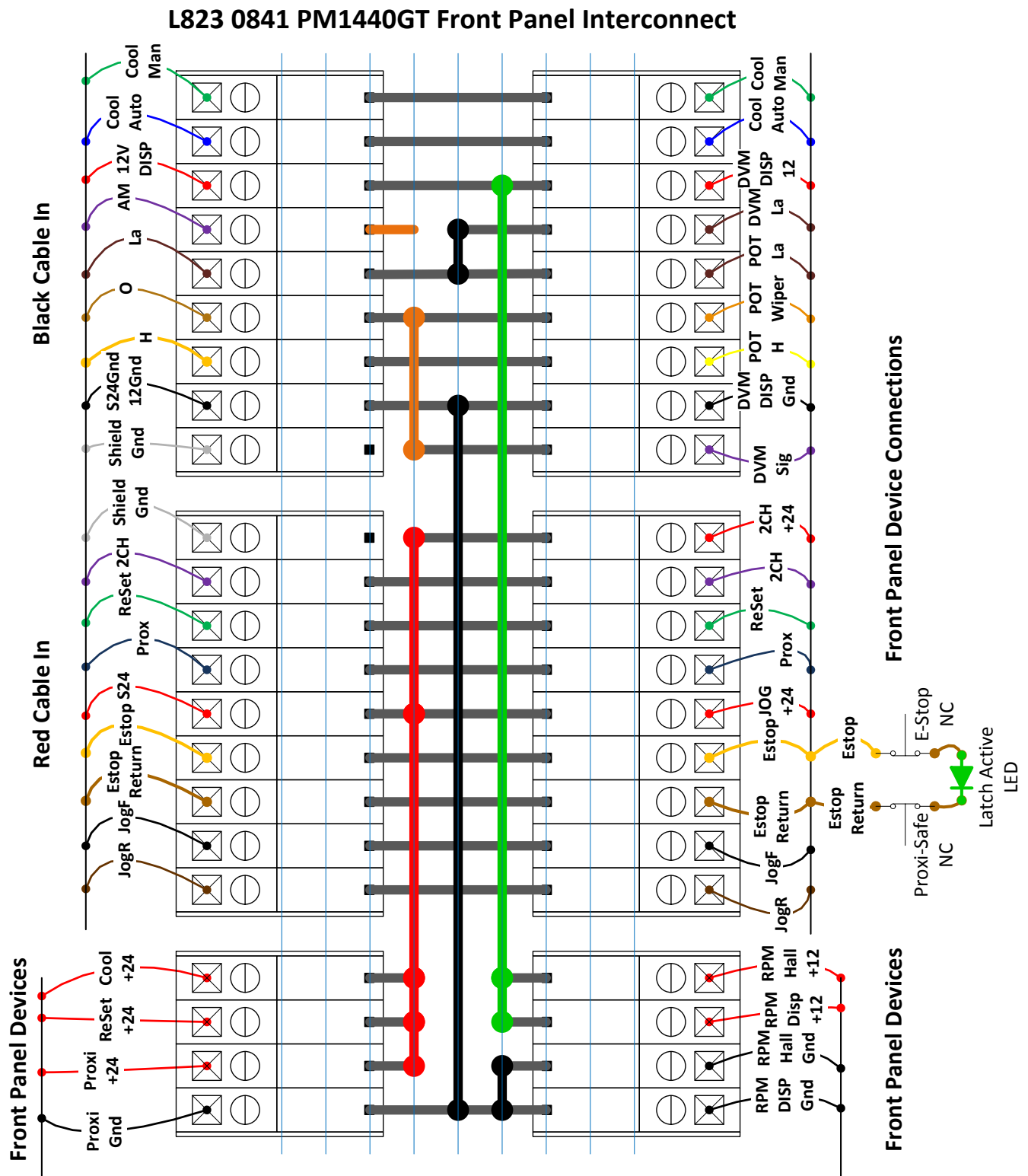






























































Table 2

Power Screw Terminal Assignments								
TOP WIRES	Wire Color	JUMPER Color	TOP Connector #	JUMPER Color	BOTTOM Connector #	JUMPER	Wire Color	BOTTOM WIRES
V1 (Coolant Pump)			17		17			FUSE (Coolant)
			16		16			SSR (Coolant)
+110 (220 Line)			15		15			VFD Power IN
+110 (DRO)			14		14			
			13		13			VFD Power IN
-110 (220 Line)			12		12			VFD Power IN
U1 (Coolant Pump)			11		11			110 Line (S24)
Neutral (DRO)			10		10			
Neutral (220 Line)			09		09			Neutral Line (S24)
			08		08			
Ground (220 Line)			07		07			Chasis Gnd
Ground (DRO)			06		06			
V (3PH Motor)			05		05			VFD OUT
W (3PH Motor)			04		04			VFD OUT
U (3PH Motor)			03		03			VFD OUT
Jumper			02		02			E-Brake Resistor
Jumper			01		01			VFD E-Brake
Wire Color Key:								
								White
								Black
								Brown
								White-Red Stripes
								Blue
								Green-Blue
								Green
								Red

1670

DNL L906_0730

PM14440GT

LAMBETH SYSTEMS

Table 1, Part2

VFD Settings Comparisons A4 print KC04_1333

WJ200(Ver.3.x,3.xE)

DNL's PM1440 Settings: ALL

12/3/2020 7:11:46 PM

ALL

Data ID	Data Name	Current value	Unit	Default value	Range
F001	Output frequency setting	60.01	Hz	0	0.00, 0.50 ... 108.20
F002	Acceleration time (1)	3	s	10	0.00 ... 3600.00
F202	Acceleration time (1),2nd motor	10	s	10	0.00 ... 3600.00
F003	Deceleration time (1)	1	s	10	0.00 ... 3600.00
F203	Deceleration time (1),2nd motor	10	s	10	0.00 ... 3600.00
F004	Keypad RUN key routing	00:(Forward)		00:(Forward)	
A001	Frequency source	01:(Control terminal)		02:(Function F001 s...	
A201	Frequency source,2nd motor	02:(Function F001 s...		02:(Function F001 s...	
A002	Run command source	01:(Control terminal)		02:(Run key on key...	
A202	Run command source,2nd motor	02:(Run key on key...		02:(Run key on key...	
A003	Base frequency	60	Hz	60	30.0 ... 108.2
A203	Base frequency, 2nd motor	60	Hz	60	30.0 ... 60.0
A004	Maximum frequency	108.2	Hz	60	60.0 ... 400.0
A204	Maximum frequency, 2nd motor	60	Hz	60	60.0 ... 400.0
A005	[AT] selection	02:(Select between ...		00:(Select between ...	
A011	[O] input active range start frequency	0	Hz	0	0.00 ... 400.00
A012	[O] input active range end frequency	100	Hz	0	0.00 ... 400.00
A013	[O] input active range start voltage	0	%	0	0 ... 100
A014	[O] input active range end voltage	100	%	100	0 ... 100
A015	[O] input start frequency enable	01:(Use 0Hz)		01:(Use 0Hz)	
A016	Analog input filter	31		8	1 ... 30, 31
A017	EzSQ selection	00:(disabling)		00:(disabling)	
A019	Multi-speed operation selection	00:(Binary operatio...		00:(Binary operatio...	
A020	Multi-speed freq. 0	0	Hz	0	0.00, 0.50 ... 108.20
A220	Multi-speed freq. 0, 2nd motor	0	Hz	0	0.00, 0.50 ... 60.00
A021	Multi-speed freq. 1	0	Hz	0	0.00, 0.50 ... 108.20
A022	Multi-speed freq. 2	0	Hz	0	0.00, 0.50 ... 108.20
A023	Multi-speed freq. 3	0	Hz	0	0.00, 0.50 ... 108.20
A024	Multi-speed freq. 4	0	Hz	0	0.00, 0.50 ... 108.20
A025	Multi-speed freq. 5	0	Hz	0	0.00, 0.50 ... 108.20
A026	Multi-speed freq. 6	0	Hz	0	0.00, 0.50 ... 108.20
A027	Multi-speed freq. 7	0	Hz	0	0.00, 0.50 ... 108.20
A028	Multi-speed freq. 8	0	Hz	0	0.00, 0.50 ... 108.20
A029	Multi-speed freq. 9	0	Hz	0	0.00, 0.50 ... 108.20
A030	Multi-speed freq. 10	0	Hz	0	0.00, 0.50 ... 108.20
A031	Multi-speed freq. 11	0	Hz	0	0.00, 0.50 ... 108.20
A032	Multi-speed freq. 12	0	Hz	0	0.00, 0.50 ... 108.20
A033	Multi-speed freq. 13	0	Hz	0	0.00, 0.50 ... 108.20
A034	Multi-speed freq. 14	0	Hz	0	0.00, 0.50 ... 108.20
A035	Multi-speed freq. 15	0	Hz	0	0.00, 0.50 ... 108.20
A038	Jog frequency	6	Hz	6	0.50 ... 9.99
A039	Jog stop mode	04:(Controlled decel...		04:(Controlled decel...	
A041	Torque boost select	01:(Automatic torqu...		00:(Manual torque b...	
A241	Torque boost select, 2nd motor	00:(Manual torque b...		00:(Manual torque b...	
A042	Manual torque boost value	1	%	1	0.0 ... 20.0
A242	Manual torque boost value, 2nd motor	1	%	1	0.0 ... 20.0
A043	Manual torque boost frequency	5	%	5	0.0 ... 50.0
A243	Manual torque boost frequency,2nd ...	5	%	5	0.0 ... 50.0
A044	V/f characteristic curve	00:(Constant torque)		00:(Constant torque)	
A244	V/f characteristic curve,2nd motor	00:(Constant torque)		00:(Constant torque)	
A045	V/f gain	100	%	100	20 ... 100
A245	V/f gain, 2nd motor	100	%	100	20 ... 100
A046	Voltage compensation gain for autom...	100		100	0 ... 255
A246	Voltage compensation gain for autom...	100		100	0 ... 255
A047	Slip compensation gain for automatic...	100		100	0 ... 255
A247	Slip compensation gain for automatic...	100		100	0 ... 255
A051	DC braking enable	00:(Disable)		00:(Disable)	
A052	DC braking frequency	0.5	Hz	0.5	0.00 ... 60.00
A053	DC braking wait time	0	s	0	0.0 ... 5.0
A054	DC braking force for deceleration	80	%	50	0 ... 100
A055	DC braking time for deceleration	0	s	0.5	0.0 ... 60.0
A056	DC braking / edge or level detection ...	01:(Level detection)		01:(Level detection)	
A057	DC braking force at start	0	%	0	0 ... 100
A058	DC braking time at start	0	s	0	0.0 ... 60.0
Data ID	Data Name	Current value	Unit	Default value	Range
A059	Carrier frequency during DC braking	8	kHz	5	2.0 ... 15.0

A061	Frequency upper limit	108.2	Hz	0	0.00 ... 108.20
A261	Frequency upper limit,2nd motor	0	Hz	0	0.00 ... 60.00
A062	Frequency lower limit	0	Hz	0	0.00, 0.50 ... 108.20
A262	Frequency lower limit,2nd motor	0	Hz	0	0.00, 0.50 ... 60.00
A063	Jump freq. (center) 1	0	Hz	0	0.00 ... 400.00
A064	Jump freq. width (hysteresis) 1	0.5	Hz	0.5	0.00 ... 10.00
A065	Jump freq. (center) 2	0	Hz	0	0.00 ... 400.00
A066	Jump freq. width (hysteresis) 2	0.5	Hz	0.5	0.00 ... 10.00
A067	Jump freq. (center) 3	0	Hz	0	0.00 ... 400.00
A068	Jump freq. width (hysteresis) 3	0.5	Hz	0.5	0.00 ... 10.00
A069	Acceleration hold frequency	0	Hz	0	0.00 ... 400.00
A070	Acceleration hold time	0	s	0	0.0 ... 60.0
A071	PID enable	00:(PID Disable)		00:(PID Disable)	
A072	PID proportional gain	1		1	0.00 ... 25.00
A073	PID integral time constant	1	s	1	0.0 ... 3600.0
A074	PID derivative time constant	0	s	0	0.00 ... 100.00
A075	PV scale conversion	1		1	0.01 ... 99.99
A076	PV source	01:([O] terminal (vol...		00:([O] terminal (c...	
A077	Reverse PID action	00:(PID input = SP-...		00:(PID input = SP-...	
A078	PID output limit	0	%	0	0.0 ... 100.0
A079	PID feed forward selection	00:(Disabled)		00:(Disabled)	
A081	AVR function select	02:(AVR enabled ex...		02:(AVR enabled ex...	
A281	AVR function select,2nd motor	02:(AVR enabled ex...		02:(AVR enabled ex...	
A082	AVR voltage select	02:(220)	V	00:(200)	
A282	AVR voltage select,2nd motor	00:(200)	V	00:(200)	
A083	AVR filter time constant	1	s	0.3	0.000 ... 10.000
A084	AVR deceleration gain	100	%	100	50 ... 200
A085	Energy-saving operation mode	00:(Normal operation)		00:(Normal operation)	
A086	Energy-saving mode tuning	0	%	50	0.0 ... 100.0
A092	Acceleration time (2)	3	s	10	0.00 ... 3600.00
A292	Acceleration time (2),2nd motor	10	s	10	0.00 ... 3600.00
A093	Deceleration time (2)	3	s	10	0.00 ... 3600.00
A293	Deceleration time (2),2nd motor	10	s	10	0.00 ... 3600.00
A094	Select method to switch to Acc2/De...	00:(2CH input from ...		00:(2CH input from ...	
A294	Select method to switch to Acc2/De...	00:(2CH input from ...		00:(2CH input from ...	
A095	Acc1 to Acc2 frequency transition p...	0	Hz	0	0.00 ... 400.00
A295	Acc1 to Acc2 frequency transition p...	0	Hz	0	0.00 ... 400.00
A096	Dec1 to Dec2 frequency transition p...	0	Hz	0	0.00 ... 400.00
A296	Dec1 to Dec2 frequency transition p...	0	Hz	0	0.00 ... 400.00
A097	Acceleration curve selection	00:(linear)		01:(S-curve)	
A098	Deceleration curve selection	00:(linear)		01:(S-curve)	
A101	[O] input active range start frequency	0	Hz	0	0.00 ... 400.00
A102	[O] input active range end frequency	0	Hz	0	0.00 ... 400.00
A103	[O] input active range start current	20	%	20	0 ... 100
A104	[O] input active range end current	100	%	100	20 ... 100
A105	[O] input start frequency select	00:(Use offset (A10...		00:(Use offset (A10...	
A131	Acceleration curve constant	2		2	1 ... 10
A132	Deceleration curve constant	2		2	1 ... 10
A141	A input select for calculate function	02:(Terminal [O] inp...		02:(Terminal [O] inp...	
A142	B input select for calculate function	02:(Terminal [O] inp...		03:(Terminal [O] in...	
A143	Calculation symbol	00:(ADD (A input + ...		00:(ADD (A input + ...	
A145	ADD frequency	0	Hz	0	0.00 ... 400.00
A146	ADD direction select	00:(Plus (adds A145...		00:(Plus (adds A145...	
A150	Curvature of EL-S-curve at the star...	10	%	10	0 ... 50
A151	Curvature of EL-S-curve at the end ...	10	%	10	0 ... 50
A152	Curvature of EL-S-curve at the star...	10	%	10	0 ... 50
A153	Curvature of EL-S-curve at the end ...	10	%	10	0 ... 50
A154	Deceleration hold frequency	0	Hz	0	0.00 ... 400.00
A155	Deceleration hold time	0	s	0	0.0 ... 60.0
A156	PID sleep function action threshold	0	Hz	0	0.00 ... 400.00
A157	PID sleep function action delay time	0	s	0	0.0 ... 25.5
A161	[VR] input active range start frequen...	0	Hz	0	0.00 ... 400.00
A162	[VR] input active range end frequency	0	Hz	0	0.00 ... 400.00
A163	[VR] input active range start	0	%	0	0 ... 100
A164	[VR] input active range end	100	%	100	0 ... 100
Data ID	Data Name	Current value	Unit	Default value	Range
A165	[VR] input start frequency select	01:(Use 0Hz)		01:(Use 0Hz)	
b001	Restart mode on power failure / und...	00:(Alarm output af...		00:(Alarm output af...	
b002	Allowable under-voltage power failur...	1	s	1	0.3 ... 25.0
b003	Retry wait time before motor restart	1	s	1	0.3 ... 100.0
b004	Instantaneous power failure / under-...	00:(Disable)		00:(Disable)	
b005	Number of restarts on power failure ...	00:(Restart 16 times)		00:(Restart 16 times)	
b007	Restart frequency threshold	0	Hz	0	0.00 ... 400.00

b008	Restart mode on over voltage / over...	00:(Alarm output af...		00:(Alarm output af...	
b010	Number of retry on over voltage / ov...	3	tim...	3	1 ... 3
b011	Retry wait time on over voltage / ov...	1	s	1	0.3 ... 100.0
b012	Level of electronic thermal	100	%	100	20.0 ... 100.0
b212	Level of electronic thermal, 2nd motor	100	%	100	20.0 ... 100.0
b013	Electronic thermal characteristic	01:(Constant torque)		01:(Constant torque)	
b213	Electronic thermal characteristic, 2n...	01:(Constant torque)		01:(Constant torque)	
b015	Free setting, electronic thermal frequ...	0	Hz	0	0
b016	Free setting, electronic thermal curr...	0	%	0	0.0 ... 100.0
b017	Free setting, electronic thermal frequ...	0	Hz	0	0
b018	Free setting, electronic thermal curr...	0	%	0	0.0 ... 100.0
b019	Free setting, electronic thermal frequ...	0	Hz	0	0 ... 400
b020	Free setting, electronic thermal curr...	0	%	0	0.0 ... 100.0
b021	Overload restriction operation mode	01:(Enabled for acc...		01:(Enabled for acc...	
b221	Overload restriction operation mode, ...	01:(Enabled for acc...		01:(Enabled for acc...	
b022	Overload restriction level	170	%	150	20.0 ... 200.0
b222	Overload restriction level, 2nd motor	150	%	150	20.0 ... 200.0
b023	Deceleration rate at overload restrict...	1	s	1	0.1 ... 3000.0
b223	Deceleration rate at overload restrict...	1	s	1	0.1 ... 3000.0
b024	Overload restriction operation mode 2	00:(Disabled)		01:(Enabled for acc...	
b025	Overload restriction level 2	150	%	150	20.0 ... 200.0
b026	Deceleration rate 2 at overload restri...	1	s	1	0.1 ... 3000.0
b027	OC suppression selection	01:(Enabled - Witho...		01:(Enabled - Witho...	
b028	Current level of active freq.matching	100	%	100	20.0 ... 200.0
b029	Deceleration rate of active freq. mat...	1	s	0.5	0.1 ... 3000.0
b030	Start freq. of active freq. matching	00:(freq at previous...		00:(freq at previous...	
b031	Software lock mode selection	10:(High level acces...		01:(all parameters e...	
b033	Motor cable length parameter	5		10	5 ... 20
b034	Run/power ON warning time	0	hr	0	0 ... 655350
b035	Rotation direction restriction	00:(No restriction)		00:(No restriction)	
b036	Reduced voltage start selection	2		2	0 ... 255
b037	Function code display restriction	00:(Full display)		04:(Basic display)	
b038	Initial display selection	001:(d001)		001:(d001)	
b039	Automatic user parameter registration	00:(Disable)		00:(Disable)	
b040	Torque limit selection	00:(Quadrant-speci...		00:(Quadrant-speci...	
b041	Torque limit 1 (fwd/power)	200	%	200	0 ... 200, 255
b042	Torque limit 2 (rev/regen.)	200	%	200	0 ... 200, 255
b043	Torque limit 3 (rev/power)	200	%	200	0 ... 200, 255
b044	Torque limit 4 (fwd/regen.)	200	%	200	0 ... 200, 255
b045	Torque LAD STOP selection	00:(Disable)		00:(Disable)	
b046	Reverse run protection	01:(Reverse rotatio...		01:(Reverse rotatio...	
b049	Dual Rating Selection	00:(CT mode)		00:(CT mode)	
b050	Controlled deceleration on power loss	01:(Decelerates to ...		00:(Trips)	
b051	DC bus voltage trigger level of ctrl. d...	220	V	220	0.0 ... 1000.0
b052	Over-voltage threshold of ctrl. decel.	360	V	360	0.0 ... 1000.0
b053	Deceleration time of ctrl. decel.	1	s	1	0.01 ... 3600.00
b054	Initial freq. drop of ctrl. decel.	0	Hz	0	0.00 ... 10.00
b060	Maximum-limit level of window comp...	100	%	100	0 ... 100
b061	Minimum-limit level of window compa...	0	%	0	0 ... 100
b062	Hysteresis width of window comparat...	0	%	0	0 ... 50
b063	Maximum-limit level of window comp...	100	%	100	0 ... 100
b064	Minimum-limit level of window compa...	0	%	0	0 ... 100
b065	Hysteresis width of window comparat...	0	%	0	0 ... 50
b070	Operation level at O disconnection	255	%	255	0 ... 100, 255
b071	Operation level at OI disconnection	255	%	255	0 ... 100, 255
b075	Ambient temperature	40	C	40	-10 ... 50
b078	Watt-hour clearance	00:(OFF)		00:(OFF)	
b079	Watt-hour display gain	1		1	1 ... 1000
b082	Start frequency	0.5	Hz	0.5	0.01 ... 9.99
Data ID	Data Name	Current value	Unit	Default value	Range
b083	Carrier frequency	12	kHz	2	2.0 ... 15.0
b084	Initialization mode (parameters or tri...	00:(Initialization dis...		00:(Initialization dis...	
b085	Country for initialization	00:(Japan)		00:(Japan)	
b086	Frequency scaling conversion factor	29		1	0.01 ... 99.99
b087	STOP key enable	00:(Enabled)		00:(Enabled)	
b088	Restart mode after FRS	00:(Restart from 0H...		00:(Restart from 0H...	
b089	Automatic carrier frequency reduction	01:(Enabled, depend...		01:(Enabled, depend...	
b090	Dynamic braking usage ratio	10	%	0	0.0 ... 20.4
b091	Stop mode selection	00:(DEC (decelerat...		00:(DEC (decelerat...	
b092	Cooling fan control	01:(Fan is ON durin...		01:(Fan is ON durin...	
b093	Clear elapsed time of cooling fan	00:(Count)		00:(Count)	
b094	Initialization target data	00:(All parameters)		00:(All parameters)	
b095	Dynamic braking control (BRD) selec...	01:(Enable during ru...		01:(Enable during ru...	

b096	BRD activation level	360	V	360	330 ... 390
b097	BRD resistor value	50	Ohm	35	35.0 ... 600.0
b100	Free-setting V/F freq. (1)	0	Hz	0	0
b101	Free-setting V/F volt. (1)	0	V	0	0.0 ... 800.0
b102	Free-setting V/F freq. (2)	0	Hz	0	0
b103	Free-setting V/F volt. (2)	0	V	0	0.0 ... 800.0
b104	Free-setting V/F freq. (3)	0	Hz	0	0
b105	Free-setting V/F volt. (3)	0	V	0	0.0 ... 800.0
b106	Free-setting V/F freq. (4)	0	Hz	0	0
b107	Free-setting V/F volt. (4)	0	V	0	0.0 ... 800.0
b108	Free-setting V/F freq. (5)	0	Hz	0	0
b109	Free-setting V/F volt. (5)	0	V	0	0.0 ... 800.0
b110	Free-setting V/F freq. (6)	0	Hz	0	0
b111	Free-setting V/F volt. (6)	0	V	0	0.0 ... 800.0
b112	Free-setting V/F freq. (7)	0	Hz	0	0 ... 400
b113	Free-setting V/F volt. (7)	0	V	0	0.0 ... 800.0
b120	Brake control enable	00:(Disable)		00:(Disable)	
b121	Brake Wait Time for Release	0	s	0	0.00 ... 5.00
b122	Brake Wait Time for Acceleration	0	s	0	0.00 ... 5.00
b123	Brake Wait Time for Stopping	0	s	0	0.00 ... 5.00
b124	Brake Wait Time for Confirmation	0	s	0	0.00 ... 5.00
b125	Brake release freq.	0	Hz	0	0.00 ... 400.00
b126	Brake release current	100	%	100	0.0 ... 200.0
b127	Braking frequency	0	Hz	0	0.00 ... 400.00
b130	Deceleration overvoltage suppressio...	01:(Enabled)		00:(Disabled)	
b131	Decel. overvolt. suppress level	390	V	380	330 ... 395
b132	Decel. overvolt. suppress const.	1	s	1	0.10 ... 30.00
b133	Decel. overvolt. suppress proportiona...	1	tim...	0.2	0.00 ... 5.00
b134	Decel. overvolt. suppress integral time	1	s	1	0.0 ... 150.0
b145	GS input mode select	00:(No trip (Hardwa...		00:(No trip (Hardwa...	
b146	Delay time of release operation	0	s	0	0.00 ... 2.00
b147	Special monitor display cancellation	00:(Cancellation of ...		00:(Cancellation of ...	
b148	Special monitor display re-display time	30		30	1 ... 30
b150	Display ex.operator connected	d001		d001	
b160	1st parameter of Dual Monitor	d001		d001	
b161	2nd parameter of Dual Monitor	d002		d002	
b163	Freq. set in monitoring	00:(Freq. set disabl...		00:(Freq. set disabl...	
b164	Automatic return to the initial display	00:(Disable)		00:(Disable)	
b165	Ex. operator com. loss action	02:(Ignore)		02:(Ignore)	
b166	Data read/write selection	00:(R/W enable)		00:(R/W enable)	
b171	Inverter mode selection	00:(Disabling)		00:(Disabling)	
b180	Initialization trigger	00:(Initialization dis...		00:(Initialization dis...	
b910	Electronic thermal subtraction functi...	00:(OFF)		00:(OFF)	
b911	Thermal subtraction time	600	s	600	0.10 ... 100000.00
b912	Thermal subtraction time constant	120	s	120	0.10 ... 100000.00
b913	Thermal accumulation gain	100	%	100	0.0 ... 200.0
C001	Input [1] function	00:(FW:FORWARD ...		00:(FW:FORWARD ...	
C002	Input [2] function	01:(RV:Reverse Run...		01:(RV:Reverse Run...	
C003	Input [3] function	06:(JG:Jogging)		02:(CF1:Multi-spee...	
C004	Input [4] function	13:(USP:Unattende...		03:(CF2:Multi-spee...	
C005	Input [5] function	12:(EXT:External Tr...		09:(2CH:2-stage Ac...	
C006	Input [6] function	09:(2CH:2-stage Ac...		18:(RS:Reset Invert...	
C007	Input [7] function	18:(RS:Reset Invert...		13:(USP:Unattende...	
Data ID	Data Name	Current value	Unit	Default value	Range
C011	Input [1] active state	00:normally open [N...		00:normally open [N...	
C012	Input [2] active state	00:normally open [N...		00:normally open [N...	
C013	Input [3] active state	00:normally open [N...		00:normally open [N...	
C014	Input [4] active state	00:normally open [N...		00:normally open [N...	
C015	Input [5] active state	01:normally closed [...		00:normally open [N...	
C016	Input [6] active state	00:normally open [N...		00:normally open [N...	
C017	Input [7] active state	00:normally open [N...		00:normally open [N...	
C021	Output [11] function	01:(FA1:Frequency ...		01:(FA1:Frequency ...	
C022	Output [12] function	00:(RUN:Run Signal)		00:(RUN:Run Signal)	
C026	Alarm relay function	05:(AL:Alarm Signal)		05:(AL:Alarm Signal)	
C027	[EO] terminal selection(Pulse/PWM ...	07:(LAD frequency ...		07:(LAD frequency ...	
C028	[AM] terminal selection(Analog volta...	07:(LAD frequency)		07:(LAD frequency)	
C030	Digital current monitor reference value	100	%	100	20.0 ... 200.0
C031	Output [11] active state	00:normally open [N...		00:normally open [N...	
C032	Output [12] active state	00:normally open [N...		00:normally open [N...	
C036	Alarm relay active state	01:normally closed [...		01:normally closed [...	
C038	Output mode of low current detection	01:(During constant...		01:(During constant...	
C039	Low current detection level	100	%	100	0.0 ... 200.0
C040	Output mode of overload warning	01:(During constant...		01:(During constant...	

C041	Overload warning level	115	%	115	0.0 ... 200.0
C241	Overload warning level, 2nd motor	115	%	115	0.0 ... 200.0
C042	Frequency arrival setting for acceler...	0	Hz	0	0.00 ... 400.00
C043	Frequency arrival setting for deceler...	0	Hz	0	0.00 ... 400.00
C044	PID deviation level	3	%	3	0.0 ... 100.0
C045	Frequency arrival setting 2 for accel...	0	Hz	0	0.00 ... 400.00
C046	Frequency arrival setting 2 for decel...	0	Hz	0	0.00 ... 400.00
C047	Pulse train input/output scale conve...	1		1	0.01 ... 99.99
C052	PID FBV output high limit	100	%	100	0.0 ... 100.0
C053	PID FBV output low limit	0	%	0	0.0 ... 100.0
C054	Over-torque/under-torque selection	00:(Over-torque)		00:(Over-torque)	
C055	Over/under-torque level(Forward po...	100	%	100	0 ... 200
C056	Over/under-torque level(Reverse re...	100	%	100	0 ... 200
C057	Over/under-torque level(Reverse po...	100	%	100	0 ... 200
C058	Over/under-torque level(Forward reg...	100	%	100	0 ... 200
C059	Signal output mode of Over/under-t...	01:(During constant...		01:(During constant...	
C061	Electronic thermal warning level	90	%	90	0 ... 100
C063	Zero speed detection level	0	Hz	0	0.00 ... 100.00
C064	Heat sink overheat warning	100	C	100	0 ... 110
C071	Communication speed	05:(9600bps)		05:(9600bps)	
C072	Modbus address	1		1	1 ... 247
C074	Communication parity	00:(No parity)		00:(No parity)	
C075	Communication stop bit	01:(1bit)		01:(1bit)	
C076	Communication error select	02:(Disable)		02:(Disable)	
C077	Communication error time-out	0	s	0	0.00 ... 99.99
C078	Communication wait time	0	ms	0	0 ... 1000
C081	O input span calibration	100	%	100	0.0 ... 200.0
C082	OI input span calibration	100	%	100	0.0 ... 200.0
C085	Thermistor input (PTC) span calibrati...	100	%	100	0.0 ... 200.0
C091	Debug mode enable	00:(Disable)		00:(Disable)	
C096	Communication selection	00:(Modbus-RTU)		00:(Modbus-RTU)	
C098	EzCOM start adr. of master	1		1	1 ... 8
C099	EzCOM end adr. of master	1		1	1 ... 8
C100	EzCOM starting trigger	00:(Input terminal(4...		00:(Input terminal(4...	
C101	Up/Down memory mode selection	00:(Clear last frequ...		00:(Clear last frequ...	
C102	Reset selection	00:(Cancel trip stat...		00:(Cancel trip stat...	
C103	Restart mode after reset	00:(Start with 0 Hz)		00:(Start with 0 Hz)	
C104	UP/DWN clear mode	00:(0Hz)		00:(0Hz)	
C105	EO gain adjustment	100	%	100	50 ... 200
C106	AM gain adjustment	100	%	100	50 ... 200
C109	AM bias adjustment	0	%	0	0 ... 100
C111	Overload warning level 2	115	%	115	0.0 ... 200.0
C130	Output [11] on delay	0	s	0	0.0 ... 100.0
C131	Output [11] off delay	0	s	0	0.0 ... 100.0
C132	Output [12] on delay	0	s	0	0.0 ... 100.0
C133	Output [12] off delay	0	s	0	0.0 ... 100.0
C140	Relay output on delay	0	s	0	0.0 ... 100.0
Data ID	Data Name	Current value	Unit	Default value	Range
C141	Relay output off delay	0	s	0	0.0 ... 100.0
C142	Logic output 1 operand A	00:(RUN:Run Signal)		00:(RUN:Run Signal)	
C143	Logic output 1 operand B	00:(RUN:Run Signal)		00:(RUN:Run Signal)	
C144	Logic output 1 operator	00:([LOG] = A AND...		00:([LOG] = A AND...	
C145	Logic output 2 operand A	00:(RUN:Run Signal)		00:(RUN:Run Signal)	
C146	Logic output 2 operand B	00:(RUN:Run Signal)		00:(RUN:Run Signal)	
C147	Logic output 2 operator	00:([LOG] = A AND...		00:([LOG] = A AND...	
C148	Logic output 3 operand A	00:(RUN:Run Signal)		00:(RUN:Run Signal)	
C149	Logic output 3 operand B	00:(RUN:Run Signal)		00:(RUN:Run Signal)	
C150	Logic output 3 operator	00:([LOG] = A AND...		00:([LOG] = A AND...	
C160	Input [1] response time	1		1	0 ... 200
C161	Input [2] response time	1		1	0 ... 200
C162	Input [3] response time	1		1	0 ... 200
C163	Input [4] response time	1		1	0 ... 200
C164	Input [5] response time	1		1	0 ... 200
C165	Input [6] response time	1		1	0 ... 200
C166	Input [7] response time	1		1	0 ... 200
C169	Multistage speed/position determinat...	0		0	0 ... 200
C900	IRDY action selection	01:(After Step3(Ver...		01:(After Step3(Ver...	
C901	Judge cycle select of overload warning	00:(40ms cycle)		00:(40ms cycle)	
C902	Time const. for overload warning judge	0	ms	0	0 ... 9999
C903	Hysteresis for overload warning judge	10	%	10	0.00 ... 50.00
H001	Auto-tuning selection	00:(Disabled)		00:(Disabled)	
H002	Motor constant selection	02:(Auto tuned data)		00:(Hitachi standard...	
H202	Motor constant selection, 2nd motor	00:(Hitachi standard...		00:(Hitachi standard...	

H003	Motor capacity	07:(2.2)	kW	07:(2.2)	
H203	Motor capacity,2nd motor	07:(2.2)	kW	07:(2.2)	
H004	Motor poles setting	01:(4P)		01:(4P)	
H204	Motor poles setting,2nd motor	01:(4P)		01:(4P)	
H005	Motor speed response constant	100	%	100	1 ... 1000
H205	Motor speed response constant, 2nd ...	100	%	100	1 ... 1000
H006	Motor stabilization constant	100		100	0 ... 255
H206	Motor stabilization constant, 2nd mot...	100		100	0 ... 255
H020	Motor constant R1 (Hitachi motor)	0.874	Ohm	0.874	0.001 ... 65.535
H220	Motor constant R1, 2nd motor (Hitac...	0.874	Ohm	0.874	0.001 ... 65.535
H021	Motor constant R2 (Hitachi motor)	0.558	Ohm	0.558	0.001 ... 65.535
H221	Motor constant R2, 2nd motor (Hitac...	0.558	Ohm	0.558	0.001 ... 65.535
H022	Motor constant L (Hitachi motor)	8.52	mH	8.52	0.01 ... 655.35
H222	Motor constant L, 2nd motor (Hitachi...	8.52	mH	8.52	0.01 ... 655.35
H023	Motor constant I0 (Hitachi motor)	5.39	A	5.39	0.01 ... 655.35
H223	Motor constant I0, 2nd motor (Hitach...	5.39	A	5.39	0.01 ... 655.35
H024	Motor constant J (Hitachi motor)	0.027	kg...	0.027	0.001 ... 9999.000
H224	Motor constant J, 2nd motor (Hitachi...	0.027	kg...	0.027	0.001 ... 9999.000
H030	Motor constant R1 (Auto tuned data)	0.719	Ohm	0.874	0.001 ... 65.535
H230	Motor constant R1, 2nd motor (Auto ...	0.874	Ohm	0.874	0.001 ... 65.535
H031	Motor constant R2 (Auto tuned data)	0.448	Ohm	0.558	0.001 ... 65.535
H231	Motor constant R2, 2nd motor (Auto ...	0.558	Ohm	0.558	0.001 ... 65.535
H032	Motor constant L (Auto tuned data)	6.25	mH	8.52	0.01 ... 655.35
H232	Motor constant L, 2nd motor (Auto t...	8.52	mH	8.52	0.01 ... 655.35
H033	Motor constant I0 (Auto tuned data)	6.5	A	5.39	0.01 ... 655.35
H233	Motor constant I0, 2nd motor (Auto t...	5.39	A	5.39	0.01 ... 655.35
H034	Motor constant J (Auto tuned data)	0.014	kg...	0.027	0.001 ... 9999.000
H234	Motor constant J, 2nd motor (Auto t...	0.027	kg...	0.027	0.001 ... 9999.000
H050	Slip compensation P gain for V/f con...	0.2	tim...	0.2	0.00 ... 10.00
H051	Slip compensation I gain for V/f cont...	2	s	2	0 ... 1000
P001	Reaction when option card error occ...	00:(tripping)		00:(tripping)	
P003	[EA] terminal selection	00:(Speed referenc...		00:(Speed referenc...	
P004	Pulse train input mode for feedback	00:(Single-phase pu...		00:(Single-phase pu...	
P011	Encoder pulse-per-revolution (PPR) ...	512	pls	512	32 ... 1024
P012	Simple positioning selection	00:(simple positioni...		00:(simple positioni...	
P014	Creep pulse ratio	125	%	125	0.0 ... 400.0
P015	Creep speed	5	Hz	5	0.50 ... 10.00
P017	Positioning completion range	50	pls	50	0 ... 10000
P026	Over-speed error detection level	115	%	115	0.0 ... 150.0
P027	Speed deviation error detection level	10	Hz	10	0.00 ... 120.00
P031	Accel/decel time input selection	00:(digital operator)		00:(digital operator)	
Data ID	Data Name	Current value	Unit	Default value	Range
P033	Torque command input selection	00:(O terminal)		00:(O terminal)	
P034	Torque command setting	0	%	0	0 ... 200
P036	Torque bias mode	00:(disabling the mo...		00:(disabling the mo...	
P037	Torque bias value	0	%	0	-200 ... 200
P038	Torque bias polarity selection	00:(as indicated by ...		00:(as indicated by ...	
P039	Speed limit for torque-controlled ope...	0	Hz	0	0.00 ... 120.00
P040	Speed limit for torque-controlled ope...	0	Hz	0	0.00 ... 120.00
P041	Speed / torque control switching time	0	ms	0	0 ... 1000
P044	Communication watchdog timer	1	s	1	0.00 ... 99.99
P045	Inverter action on communication err...	00:(tripping)		00:(tripping)	
P046	DeviceNet polled I/O: Output instanc...	1		1	0 ... 20
P048	Inverter action on communication idl...	00:(tripping)		00:(tripping)	
P049	Motor poles setting for RPM	00:(0P)		00:(0P)	
P055	Pulse train frequency scale	25	kHz	25	1.0 ... 32.0
P056	Time constant of pulse train frequen...	0.1	s	0.1	0.01 ... 2.00
P057	Pulse train frequency bias	0	%	0	-100 ... 100
P058	Pulse train frequency limit	100	%	100	0 ... 100
P059	Lower cut off level of the input pulse	1	%	1	0.01 ... 20.00
P060	Multistage position0	0		0	-268435455 ... 268435455
P061	Multistage position1	0		0	-268435455 ... 268435455
P062	Multistage position2	0		0	-268435455 ... 268435455
P063	Multistage position3	0		0	-268435455 ... 268435455
P064	Multistage position4	0		0	-268435455 ... 268435455
P065	Multistage position5	0		0	-268435455 ... 268435455
P066	Multistage position6	0		0	-268435455 ... 268435455
P067	Multistage position7	0		0	-268435455 ... 268435455
P068	Homing mode selection	00:(Low speed mode)		00:(Low speed mode)	
P069	Homing direction	01:(RV)		01:(RV)	
P070	Low-speed homing frequency	5	Hz	5	0.50 ... 10.00
P071	High-speed homing frequency	5	Hz	5	0.00 ... 108.20
P072	Position range (forward)	268435455		268435455	0 ... 268435455

P073	Position range (reverse)	-268435455		-268435455	-268435455 ... 0
P075	Positioning mode	00:(With limitation)		00:(With limitation)	
P077	Encoder disconnection timeout	1	s	1	0.0 ... 10.0
P080	Positioning restart range	0	pls	0	0 ... 10000
P081	Store position at power off selection	00:(Not store)		00:(Not store)	
P082	Current position at power off	0		0	-268435455 ... 268435455
P083	Preset position data	0		0	-268435455 ... 268435455
P100	EzSQ user parameter U(00)	0		0	0 ... 65535
P101	EzSQ user parameter U(01)	0		0	0 ... 65535
P102	EzSQ user parameter U(02)	0		0	0 ... 65535
P103	EzSQ user parameter U(03)	0		0	0 ... 65535
P104	EzSQ user parameter U(04)	0		0	0 ... 65535
P105	EzSQ user parameter U(05)	0		0	0 ... 65535
P106	EzSQ user parameter U(06)	0		0	0 ... 65535
P107	EzSQ user parameter U(07)	0		0	0 ... 65535
P108	EzSQ user parameter U(08)	0		0	0 ... 65535
P109	EzSQ user parameter U(09)	0		0	0 ... 65535
P110	EzSQ user parameter U(10)	0		0	0 ... 65535
P111	EzSQ user parameter U(11)	0		0	0 ... 65535
P112	EzSQ user parameter U(12)	0		0	0 ... 65535
P113	EzSQ user parameter U(13)	0		0	0 ... 65535
P114	EzSQ user parameter U(14)	0		0	0 ... 65535
P115	EzSQ user parameter U(15)	0		0	0 ... 65535
P116	EzSQ user parameter U(16)	0		0	0 ... 65535
P117	EzSQ user parameter U(17)	0		0	0 ... 65535
P118	EzSQ user parameter U(18)	0		0	0 ... 65535
P119	EzSQ user parameter U(19)	0		0	0 ... 65535
P120	EzSQ user parameter U(20)	0		0	0 ... 65535
P121	EzSQ user parameter U(21)	0		0	0 ... 65535
P122	EzSQ user parameter U(22)	0		0	0 ... 65535
P123	EzSQ user parameter U(23)	0		0	0 ... 65535
P124	EzSQ user parameter U(24)	0		0	0 ... 65535
P125	EzSQ user parameter U(25)	0		0	0 ... 65535
P126	EzSQ user parameter U(26)	0		0	0 ... 65535
P127	EzSQ user parameter U(27)	0		0	0 ... 65535
Data ID	Data Name	Current value	Unit	Default value	Range
P128	EzSQ user parameter U(28)	0		0	0 ... 65535
P129	EzSQ user parameter U(29)	0		0	0 ... 65535
P130	EzSQ user parameter U(30)	0		0	0 ... 65535
P131	EzSQ user parameter U(31)	0		0	0 ... 65535
P140	EzCOM number of data	5		5	1 ... 5
P141	EzCOM destination 1 address	1		1	1 ... 247
P142	EzCOM destination 1 register	0		0	0 ... 65535
P143	EzCOM source 1 register	0		0	0 ... 65535
P144	EzCOM destination 2 address	2		2	1 ... 247
P145	EzCOM destination 2 register	0		0	0 ... 65535
P146	EzCOM source 2 register	0		0	0 ... 65535
P147	EzCOM destination 3 address	3		3	1 ... 247
P148	EzCOM destination 3 register	0		0	0 ... 65535
P149	EzCOM source 3 register	0		0	0 ... 65535
P150	EzCOM destination 4 address	4		4	1 ... 247
P151	EzCOM destination 4 register	0		0	0 ... 65535
P152	EzCOM source 4 register	0		0	0 ... 65535
P153	EzCOM destination 5 address	5		5	1 ... 247
P154	EzCOM destination 5 register	0		0	0 ... 65535
P155	EzCOM source 5 register	0		0	0 ... 65535
P160	Option I/F command register to writ...	0		0	0 ... 65535
P161	Option I/F command register to writ...	0		0	0 ... 65535
P162	Option I/F command register to writ...	0		0	0 ... 65535
P163	Option I/F command register to writ...	0		0	0 ... 65535
P164	Option I/F command register to writ...	0		0	0 ... 65535
P165	Option I/F command register to writ...	0		0	0 ... 65535
P166	Option I/F command register to writ...	0		0	0 ... 65535
P167	Option I/F command register to writ...	0		0	0 ... 65535
P168	Option I/F command register to writ...	0		0	0 ... 65535
P169	Option I/F command register to writ...	0		0	0 ... 65535
P170	Option I/F command register to read 1	0		0	0 ... 65535
P171	Option I/F command register to read 2	0		0	0 ... 65535
P172	Option I/F command register to read 3	0		0	0 ... 65535
P173	Option I/F command register to read 4	0		0	0 ... 65535
P174	Option I/F command register to read 5	0		0	0 ... 65535
P175	Option I/F command register to read 6	0		0	0 ... 65535
P176	Option I/F command register to read 7	0		0	0 ... 65535

P177	Option I/F command register to read 8	0		0	0 ... 65535
P178	Option I/F command register to read 9	0		0	0 ... 65535
P179	Option I/F command register to read...	0		0	0 ... 65535
P180	Profibus Node address	0		0	0 ... 125
P181	Profibus Clear Node address	00:(clear)		00:(clear)	
P182	Profibus Map selection	00:(PPO Type)		00:(PPO Type)	
P185	CANopen Node address	0		0	0 ... 127
P186	CAN open communication speed	06:(500kbps)		06:(500kbps)	
P190	CompoNet Node address	0		0	0 ... 63
P192	DeviceNet MAC ID	63		63	0 ... 63
P195	ML2 frame length	00:(32bytes)		00:(32bytes)	
P196	ML2 Node address	33		33	33 ... 62
P900	Half / All period select of 1ph Enc. In...	00:(Half period)		00:(Half period)	
P901	Time const. for enc. speed detection	20	ms	20	0 ... 9999
d080	Trip Counter	135	time	0	0 ... 99999
d081 0	Trip info. 1 (factor)	12:(External trip)		00:(No trip factor)	
d081 1	Trip info. 1 (inverter status)	01:(Stopping)		00:(Resetting)	
d081 2	Trip info. 1 (frequency)	0	Hz	0	0.00 ... 400.00
d081 3	Trip info. 1 (current)	0	A	0	0.00 ... 655.30
d081 4	Trip info. 1 (voltage)	321.7	V	0	0.0 ... 1000.0
d081 5	Trip info. 1 (running time)	5	hr	0	0 ... 1193028
d081 6	Trip info. 1 (power-on time)	45	hr	0	0 ... 1193028
d082 0	Trip info. 2 (factor)	12:(External trip)		00:(No trip factor)	
d082 1	Trip info. 2 (inverter status)	01:(Stopping)		00:(Resetting)	
d082 2	Trip info. 2 (frequency)	0	Hz	0	0.00 ... 400.00
d082 3	Trip info. 2 (current)	0	A	0	0.00 ... 655.30
d082 4	Trip info. 2 (voltage)	316.4	V	0	0.0 ... 1000.0
d082 5	Trip info. 2 (running time)	5	hr	0	0 ... 1193028
d082 6	Trip info. 2 (power-on time)	45	hr	0	0 ... 1193028
Data ID	Data Name	Current value	Unit	Default value	Range
d083 0	Trip info. 3 (factor)	12:(External trip)		00:(No trip factor)	
d083 1	Trip info. 3 (inverter status)	01:(Stopping)		00:(Resetting)	
d083 2	Trip info. 3 (frequency)	0	Hz	0	0.00 ... 400.00
d083 3	Trip info. 3 (current)	0	A	0	0.00 ... 655.30
d083 4	Trip info. 3 (voltage)	320.8	V	0	0.0 ... 1000.0
d083 5	Trip info. 3 (running time)	5	hr	0	0 ... 1193028
d083 6	Trip info. 3 (power-on time)	30	hr	0	0 ... 1193028
d084 0	Trip info. 4 (factor)	12:(External trip)		00:(No trip factor)	
d084 1	Trip info. 4 (inverter status)	01:(Stopping)		00:(Resetting)	
d084 2	Trip info. 4 (frequency)	0	Hz	0	0.00 ... 400.00
d084 3	Trip info. 4 (current)	0	A	0	0.00 ... 655.30
d084 4	Trip info. 4 (voltage)	320.7	V	0	0.0 ... 1000.0
d084 5	Trip info. 4 (running time)	5	hr	0	0 ... 1193028
d084 6	Trip info. 4 (power-on time)	30	hr	0	0 ... 1193028
d085 0	Trip info. 5 (factor)	12:(External trip)		00:(No trip factor)	
d085 1	Trip info. 5 (inverter status)	03:(Constant-speed...		00:(Resetting)	
d085 2	Trip info. 5 (frequency)	61.19	Hz	0	0.00 ... 400.00
d085 3	Trip info. 5 (current)	4.98	A	0	0.00 ... 655.30
d085 4	Trip info. 5 (voltage)	322.9	V	0	0.0 ... 1000.0
d085 5	Trip info. 5 (running time)	5	hr	0	0 ... 1193028
d085 6	Trip info. 5 (power-on time)	28	hr	0	0 ... 1193028
d086 0	Trip info. 6 (factor)	12:(External trip)		00:(No trip factor)	
d086 1	Trip info. 6 (inverter status)	03:(Constant-speed...		00:(Resetting)	
d086 2	Trip info. 6 (frequency)	18.57	Hz	0	0.00 ... 400.00
d086 3	Trip info. 6 (current)	4.86	A	0	0.00 ... 655.30
d086 4	Trip info. 6 (voltage)	324.8	V	0	0.0 ... 1000.0
d086 5	Trip info. 6 (running time)	5	hr	0	0 ... 1193028
d086 6	Trip info. 6 (power-on time)	28	hr	0	0 ... 1193028
d090	Warning monitor	00:Warning code		00:Warning code	