# SIEG C1 MICRO-LATHE MOTOR CONTROL PCB - The FC150BJ / 230V. Dr. H. Holden, Sept. 2021.


**BACKGROUND:**

The C1 micro-lathe is a highly versatile and well made compact mini-lathe which has countless uses in Mechanical Engineering, construction projects and machinery repairs.

I have used my C1 for a number of design projects to machine small objects. Also by adding an RPM meter to it and a rotation counter, I have also used it used it to wind transformers and calibrate vintage mechanical speedometers and RPM meters. It is such a useful tool that I could not be without it. I congratulate the design Engineers at Sieg who designed and made this great little machine.

**Safety Note:**

Since much of the circuitry in the motor controller pcb is operated at Line (Mains) voltage potential, it should only be worked on by experienced & qualified Electronic Service Personnel. This is because there is an **Electrocution Hazard** and only the qualified are aware how to mitigate these risks and avoid death, or injury, or destruction of the apparatus being serviced.

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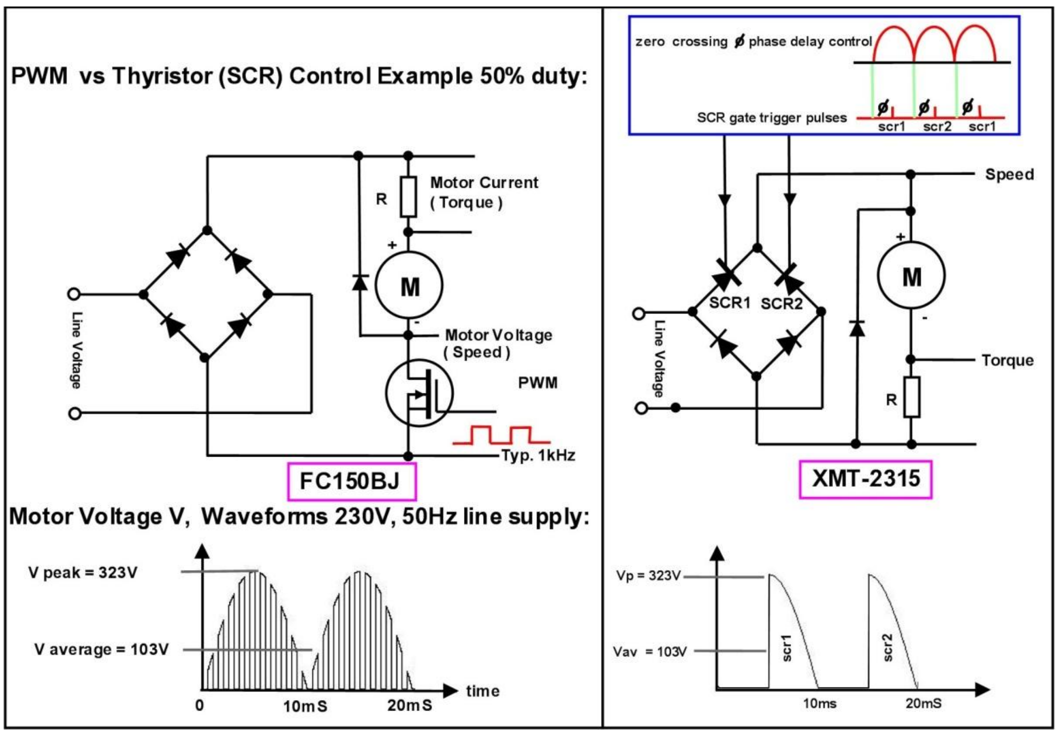
**Discussion PWM versus SCR based DC motor control.**

There are a number of ways to speed control DC brush motors from an AC source. The C1 Lathes original DC motor controller, the FC150BJ was a pwm (pulse width modulation) controller.

Sieg subsequently replaced the FC150BJ/230V with an SCR based controller part XMT-2315. This article is primarily about the FC150BJ controller, however it is worth looking at the difference between it and the SCR based controllers:




The waveforms shown above are representative of the situation if the motor was replaced with a purely resistive load. The actual waveforms, across the motor terminals are altered by the motor's electrical properties.

The motor, as an electrical load, has both Resistance and Inductance and when rotating generates a back emf (electromotive force, or voltage). This alters the form of the voltage seen on the motor's terminals, compared to a resistive load.

The speed of a DC motor is fairly linearly proportional to the average voltage applied to the motor's terminals. The motor's back emf is also correlated with speed too. With the luxury of a Tachometer monitoring the motor's shaft speed, this signal could be fed back to make a speed control circuit.

However, in the absence of a tachometric reading, the voltage across the motor's terminals can be fed back via a *Speed Negative Feedback Loop* to compare its value with a manual speed control potentiometer, for a speed regulation system.

Also, to assist motor control, the motor's current is measured as a voltage drop across a current sensing resistor, placed in series with the motor. This is used to provide positive feedback for a *Torque Positive Feedback Loop.* This loop is used to help maintain motor speed under increasing mechanical loads, which result in increased motor current.

The *average voltages* of the applied pulsatile voltages to the motor are important. This is because the measurement values of both the motor voltage and the voltage developed across the current sensing resistor are performed by the OP Amps configured as integrators. These have output values that assume the average of the fluctuating input voltages.

With abrupt voltage changes applied across the motor's terminals, motor itself integrates these changes to result in more average changes in the magnetic field of the motor's armature. This is due to a combination of inductance of the armature, but also the hysteresis of the magnetic core of the armature which effectively results in additional smoothing.

To a great extent, the applied rapid switching events applied to the motor are "smoothed out" by the motor itself. The physical motor rotation, under some circumstances, can be as smooth as if the motor was connected to a DC source. Irregularities of speed, with SCR or PWM based control, tend to show up at very low motor speeds.

The more rapid switching events of the pwm system, at around 1kHz, are better smoothed out than what amounts to the base frequency, which is twice the line power frequency.

In the case of the SCR control, the SCR comes out of conduction (after they have been triggered) only when the anode to cathode current of the SCR is near zero. If the load was purely resistive, this would be around the timing of zero crossing of the line sine wave voltage. With a DC motor that is powered by full wave rectified line voltage, the motor as a load is inductive and is also generating back emf, so the timing of the SCR coming out of conduction is altered and can also be affected by high frequency voltage transients across the motor's terminals.

One of the complaints about speed control of a DC motor with SCR's is that the interruptions of current can be more abrupt than with a pwm circuit. And the peak motor currents are higher. The high peak currents of SCR control have been said by some to shorten the life of the motor brushes and make low speed control a little more difficult, sometimes producing jerky and erratic behaviour at the low speed end with SCR control. In addition, with inductive loads, due to the voltage transients involved, reliable SCR triggering and the SCR out of conduction timing can be more problematic.

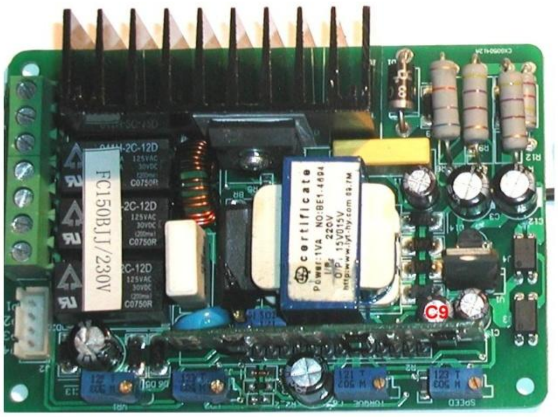
In the case of pwm, the output device/s, typically Mosfets, are directed ON and OFF (into conduction and out of conduction) by their gate drive signal and the Mosfet's drain current is not a significant factor in the timing. This makes the switching timing of the mosfet independent of the properties of the load, unlike the SCR case.

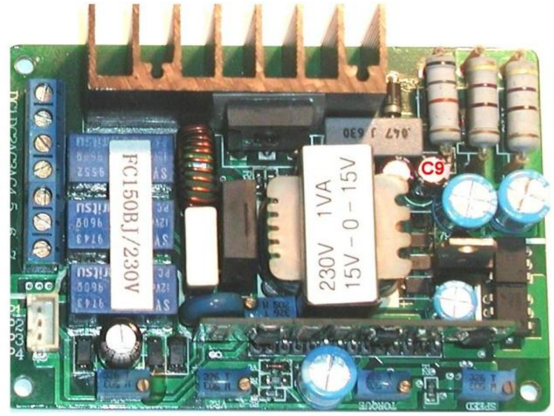
Another difference between the FC150BJ controller and the XMT-2315, is that the FC150BJ controller acquires its low voltage supplies from a small 1W rated transformer on the pcb, this is very efficient. In the case of the XMT-2315 the low voltage supplies are sourced via a series power resistor which dissipates about 3 Watts of heat and is less efficient especially in the case of the 230V pcb's. However, not using the transformer and moving to SCR's does make the XMT-2315 controller board more economical to produce than the FC150BJ.

While it is fair to say that both SCR and pwm methods "work" for DC motor control, if they are both well executed, the pwm method is my preferred method, given a choice.

**Variants of the FC150BJ PWM motor control pcb:**

There were early and later versions of the FC150BJ/230V.




**Late Board:**

# 2 layer pcb
# Pc817 (EL817) Opto-coulers
# 750R 200 mW Relay coils
# IRFP450 Mosfet
# C9 moved near daugher board.
# FR307 rectifier D1
# Lower Deg C/watt heatsink, 10 fins
# P4 is connected to P1 on both pcb's

**Early Board:**

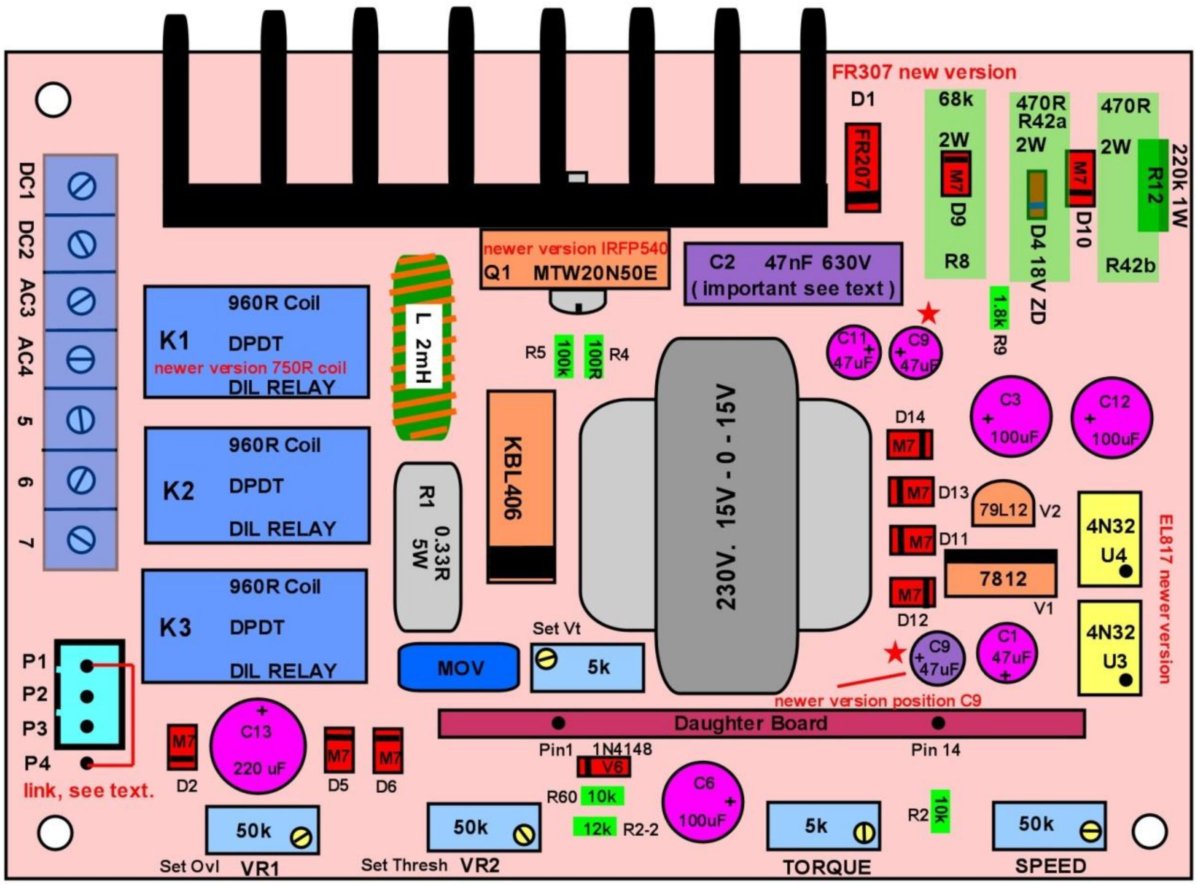
# 4 layer pcb
# 4N35 Opto-couplers
# 960R 150 mW Relay coils
# MTW20N50E Mosfet
# C9 placed near to R8
# FR207 rectifier D1
# 8 fin heat sink.
# Note: This board has been upgraded to Nichicon 125 DegC 10,000 hr life 50V capacitors (pale blue insulation) and a new 47nF 630 capacitor, superior to the original type, see text.

Generally I would rate the reliability of the FC150BJ board as very good.

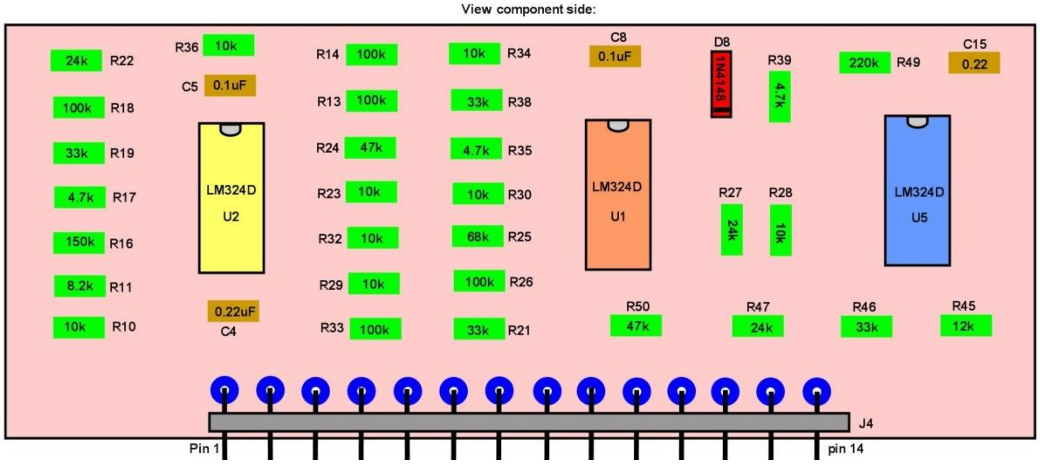
In nearly all electronic equipment, the electrolytic capacitors have a limited life and dry out. When this happens the circuitry initially starts to play up and fails. Other issues that have been reported are failures of the IRFP450 Mosfet. Failures, when they occur are not the fault of the design or construction of the board in many cases. It could be regarded that, for any line powered switching controllers for motors, as the years go by, some repairs will be required no matter how well made the circuit board was in the first place.

Repairs are always assisted by good quality manufacturer's schematics and circuit descriptions and measured voltages on important circuit nodes under a few test conditions. In other words a "Service Manual". It has become less customary these days for manufacturers to produce service manuals to support their equipment.

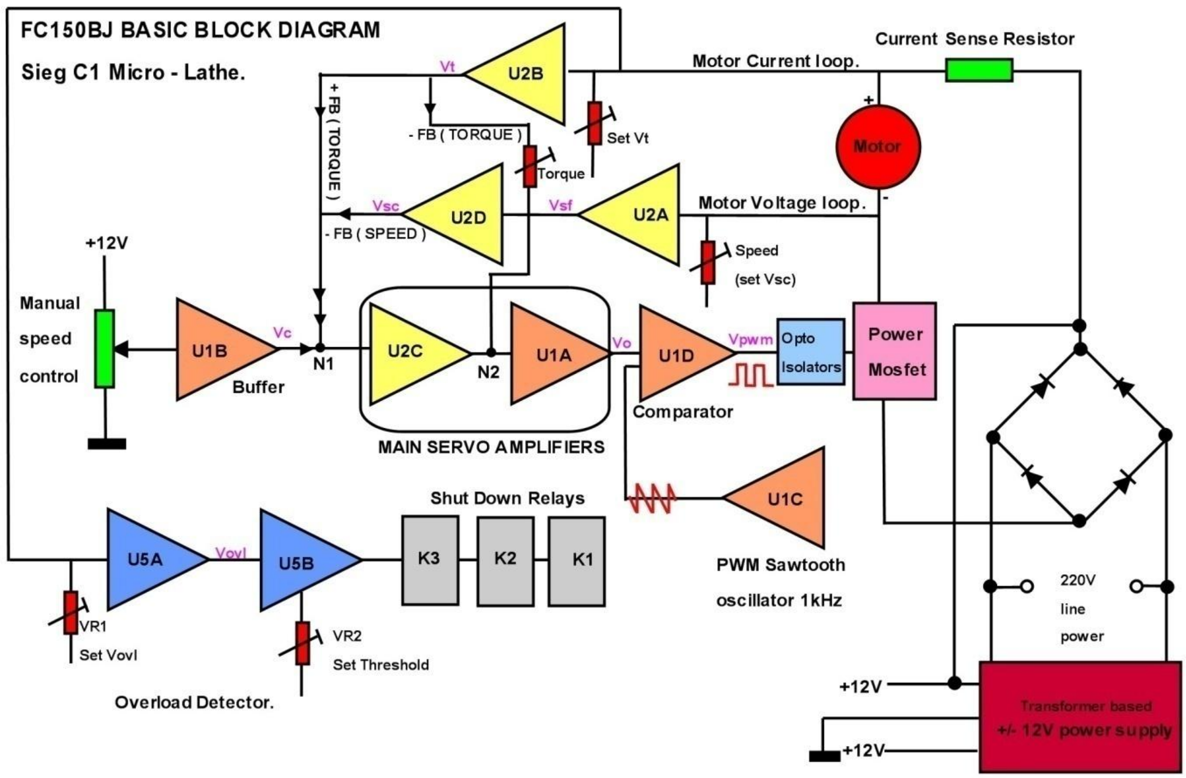
**Component layout of the FC150BJ main & daughter board:**




View component side:



**Basic block diagram of the FC150BJ:**




Although the basic block diagram above has little utility in detailed pcb level circuit repairs, it does provide an initial overview of the system design and how the important parts are linked together.

The diagram shows that the DC brush motor is powered from an unfiltered full wave rectified line voltage (100Hz pulsed DC half sine waveform) which is then pwm (pulse width modulated or chopped up) by a power output Mosfet. The OP amps are supplied by the transformer based low voltage power supply.

The pwm generator is a simple sawtooth oscillator. A comparator compares the output voltage Vo, of the main servo amplifiers U2C and U1A, with the sawtooth wave to generate the variable duty cycle pwm voltage. The main control amplifiers U2C and U1A are the heart of the operations and are enclosed in a Speed and Torque feedback loop created OP Amps U2A,U2B,U2D.

Three main inputs contribute to U2C at node N1:

One input is from the user’s manual speed control on the lathe’s control panel via a buffer U1B, and another input from the Speed (motor voltage) negative feedback loop and the third input from a Torque (motor current) positive feedback loop.

The torque compensation is interesting in that it introduces both positive and negative feedback, but as will be shown in this article, the overall result is positive feedback, to provide the motor with a little more drive voltage (and power) when it is mechanically loaded down and drawing more current.

Also the motor current is sensed with a threshold, to cut the motor off, if say it is abruptly mechanically stalled and the current rises very high. The motor current is monitored by OP amps U5A and U5B. When overload is detected relay K3 is deployed for a period of time. This shuts off relays K1 and K2, killing the power to the motor and the power to the pcb, which can only be recovered when the fault is cleared, the manual control switched to off and the unit switched on again. Details on these functions are added near the end of this article.

One interesting thing here: The switch on the manual speed control potentiometer is a little unusual, in that its contacts are closed with the knob rotated fully counter clockwise and the switch deployed. This is unlike most generic potentiometers with on board switches. When Sieg moved to the SCR based controller, the XMT2315, they change to a conventional potentiometer where the switch is open with the potentiometer rotated fully counter clockwise.

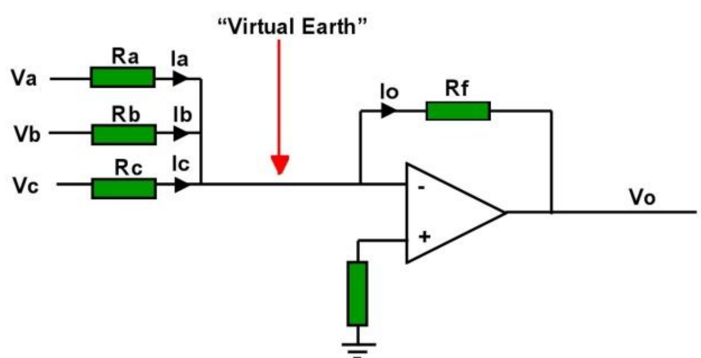
**Five Principles: OP Amp theory to understand the FC150BJ design:**

Since the FC150BJ controller is primarily based on Operational Amplifiers and mostly these are configured as *mixing and inverting amplifiers*, it is necessary to review at least five principles involving OP Amp behaviour. If the circuit is to be properly understood, there is no escaping this work. No assumptions and shortcuts will save anybody any time here. Without this understanding, attempted repairs on a defective board will be ill-considered and haphazard at best. In addition, when feedback loops are involved, a fault inside the loop affects the voltage levels everywhere inside the loop. A commonly used technique in solving problems inside a defective feedback loop, is to break the loop, and injected a fixed voltage into the circuit. There has to be enough information to know what level to inject, where and why.

It will be noted that in the design of the FC150BJ board that signals (or DC control voltages) relating to automatic Speed and Torque control and Manual Speed control are "mixed" together at the negative inputs of the OP amps at the main mixing nodes N1 and N2.

**a) Virtual Earth signal mixing.**

Typically OP amps are configured with a resistor from the output to the inverting (or negative) input. This lowers the Op amp's voltage gain, which in the open loop condition might be millions. The result is that the negative OP amp input then behaves as a "Virtual Earth" when the positive input of the OP amp is tied to zero volts or a fixed potential. This is because the OP amp's output moves so as to eliminate the difference voltage, or voltage disparity between its + and – input terminals. This is shown in the diagram below.




This is also common method in the Audio industry to create "Signal Mixers" where many signals can be mixed together, without one signal being altered by the magnitude of the other signal, as would happen, if the signals were just mixed together with resistors.

A way to examine this arrangement is to view the circuit currents. Since the positive OP amp input is tied to zero volts, the OP amp output moves to make the negative input zero volts (allowing for a very tiny offset voltage peculiar to the particular OP amp).

Therefore with the currents, I:

$$Ia + Ib + Ic = -Io$$

The minus sign because the current Io is leaving the virtual earth point as the input currents are arriving there in this example.

Since Va/Ra = Ia, Vb/Rb = Ib and Vc/Ic = Ic and Vo/Rf = Io then:

$$Va/Ra + Vb/Rb + Vc/Rc = -Vo/Rf$$

Re-arranging the above yields:

$$Vo = -Rf(Va/Ra + Vb/Rb + Vc/Rc)$$

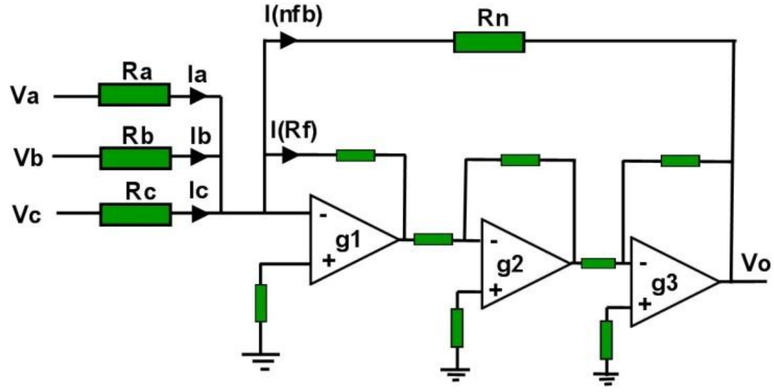
Therefore ***voltage gain*** for any “input channel” or “Port”, say for voltage Va is simply:

$$Vo/Va = - Rf/Ra$$

The voltage gain therefore, depends primarily on the properties of the external resistors and their ratios, not the OP amp’s properties, because the closed loop gain is much lower than the Open loop gain.

**b) Closed loop versus open loop gain for a chain of amplifiers:**

Sometimes, the negative feedback pathway may be placed around a whole series of amplifiers in a string. It does not matter the total number as long as the feedback is still negative:



In the above case, the total gain of the amplifier (in the open loop condition without resistor Rn present) is the product of the individual gains or -(g1g2g3). If this voltage gain is significantly higher than the closed loop gain (when the negative feedback resistor Rn is connected), then most of the current which brings the negative input of the input OP amp to zero volts, is the current I(nfb). The current I(Rf) is dwarfed.

In the case where the open loop gain is much higher than the closed loop gain, the current I(Rf) can be ignored. Therefore the gain of the above arrangement can be ***approximated*****:**

(Ia + Ib + Ic) is very nearly equal to -I(nfb).

The approximate voltage gain therefore, for input Va:

Gain = Vo/Va = - Rn/Ra.

As will be explained, in the case of the FC150BJ lathe controller, the Speed feedback loop significantly lowers the overall gain of the chain of other amplifiers in the loop.

**c) Calculation of voltage gain for a signal injected inside a closed loop amplifier chain:**

One of the interesting things about amplifiers or circuitry bound by negative feedback is that if any change is impressed internally, on the circuit inside the loop, for example injecting or removing a current from it, ***the loop will always move in a direction to oppose that change.***

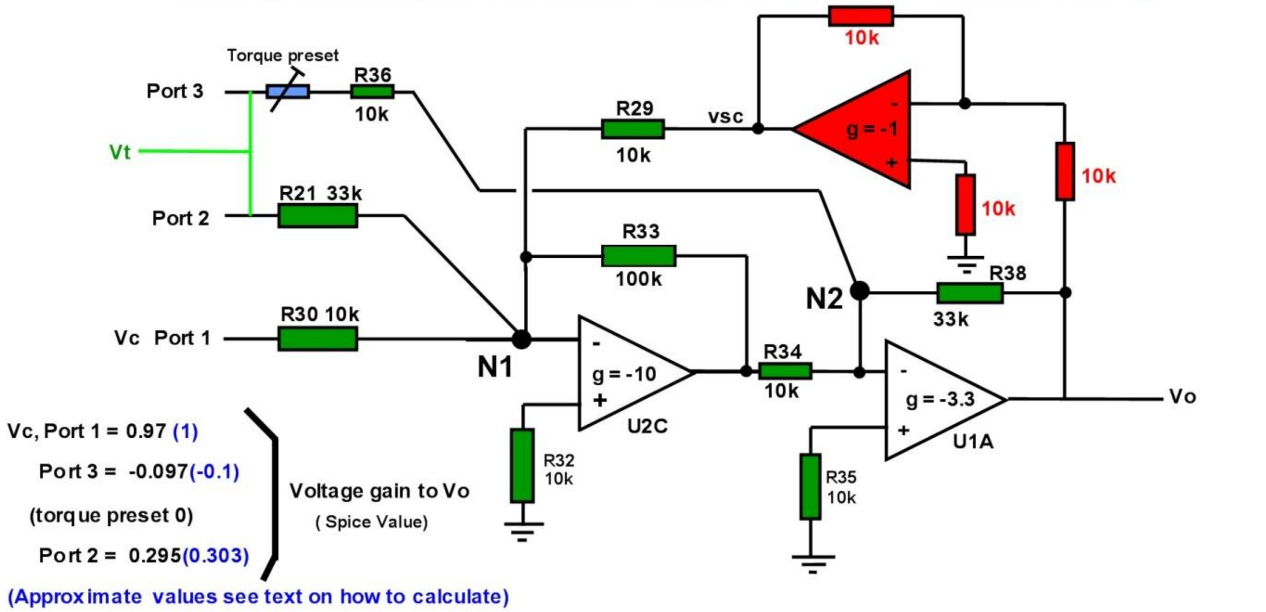
A good question could therefore be: In a chain of amplifiers bound by a tight negative feedback loop, what is the effect of injecting a voltage or a current elsewhere inside the loop into a virtual earth point, in terms of the way it affects the loop's output voltage?

The answer is that the voltage gain for a signal port injected inside a closed loop, consisting of a chain of amplifiers, depends very much on the gain of the amplifier (OP amp in this case) driving the virtual earth point (in this case node N2) *just prior to where the port's signal is injected.*

The diagram below is related to the FC150BJ, shows two OP amps U2C and U1A wired as inverting mixing amplifiers and enclosed in a tight negative feedback loop provided by the imaginary OP amp drawn in red with a voltage gain of -1. Control signals are "virtual earth mixed" at node N1 and node N2. R29 performs the role as the primary feedback resistor, not R33 or R38.

**Main Servo Amplifier block analysis. Sieg C1 Micro-Lathe Controller FC150BJ/230v**

Imaginary Feedback Amplifier representing remaining PWM & Motor circuit & speed feedback loop




| | | |
|---|---|---|
| Position of Torque preset resistance : | 1800 Ohms | Zero Ohms |
| Combined port 2 and port 3 effect = Vt, on Vo per volt input : (Voltage Increase) | 213mV | 198mV |

The imaginary red OP amp is represented in the real FC150BJ pcb by the components which are in the Speed feedback Loop pathway which are:

1) The pwm control circuitry, oscillator, comparator, Opto-couplers.

2) The power output Mosfet

3) The Motor and other OP amps U2A and U2D, monitoring the motor’s speed.

Without closing the loop, the “open loop” (assume R29 is absent) the voltage gain of U2C and U1A is +33, the product of the individual gains of U2C and U1A.

With the loop closed, R29 present, then for input port 1 (the voltage from the manual speed control potentiometer Vc), the gain is calculated approximately as +1, from the value of R29/R30 = 10k/10k. In practice it is just a little less due to the currents in R33 and R38 and measures at +0.97 in a Spice simulator that takes the smaller currents in R33 and R38 into account.

The gain for port 2 is approximately estimated at R29/R21, or 10k/33k = 0.303 and in practice measures a little lower at 0.295, due to the smaller currents in R33 and R38.

For the input port 3 supplying current to node N2, this is where things get much more interesting:

Assuming for example that the preset potentiometer labelled Torque is set at zero Ohms, and the total input resistance, is that of R36=10k, call this value Rt. Then the gain is determined primarily by the gain of U2C and the value of R34 and Rt. R34 assumes the role of the feedback resistor, balancing out the currents at node N2.

This is because any change impressed inside the loop, by an outside agency is partially compensated by the loop behaviour as the loop is always attempting to zero the voltage difference at U2C's input. In other words,

A very small offset voltage at U2C's inputs results in a much larger voltage change at U2C's output, U2C itself has a voltage gain of -10.

The approximate gain for port 3 to Vo, can be calculated as close to a value of:

$$-(R34/Rt)(1/10) = -0.1.$$

(The factor of 1/10 being present due to the gain of U2C being -10)

The minus sign because Vo moves negative when port 3 voltage moves positive. In practice, in the simulator, the actual result measures a little lower at -0.097, again due to the small currents in R33 and R38.

In summary, the voltage gain via Port 2 is + 0.295 and that via port 3 is – 0.097, and since these circuit points are connected together in the actual controller (green link on the diagram above), the total voltage gain for input Vt is +0.198 when the Torque preset is set at zero Ohms.

As shown, the higher the resistance value of the Torque preset resistance, the lower the negative component of the feedback and therefore the higher the positive feedback. For example with the torque preset set to 1800 Ohms the negative feedback diminishes and there is a little more positive feedback with a net gain of +0.213.

In both the FCB150BJ boards I have tested, the factory setting of the 5k torque potentiometer was below 1000 Ohms. Probably it is set close to zero Ohms, initially, turned fully clockwise and turned anti-clockwise during setting, increasing the overall positive feedback, until the overall torque increase suits the machine. (see section below on how to adjust it in practice).

The port 2 and port 3 signal, or "Vt", comes from the output of IC U2B (see more schematics below) and is derived from the *averaged* motor current. Vt is such that its signal swings more positive with increasing motor current (which increases with mechanical loading).This positive feedback provides extra energy to the motor under mechanical load and frictional forces. If this compensation is too high, the motor could speed up or develop speed oscillations.

The gain for the Vt signal port being close to +0.2 has other implications. The way the system was designed there was a requirement for an initial offset voltage on Vt in the order of -6V to -8V, depending on the value of Vsc set by the Speed preset.

This is because there is a +1V offset voltage from the manual potentiometer, in that the motor has to be stopped before full CCW rotation of the manual control or it would not be possible to reduce the motor speed to zero near full CCW control rotation of the manual control.

Also, the range of voltage fed back into the mixing node N1 from the speed control loop, from its output Vsc, has an offset voltage of close to zero volts with no motor rotation, depending on how the Speed preset is set. To balance these inputs to N1, it requires an offset voltage introduced to the U2C and U1A amplifier block. This has to come from Vt.

**Interactions of Speed (Vsc), Torque (Vt), manual control (Vc) settings:**

In the case, with no motor rotation and the manual speed control set to produce just on 1V = voltage for Vc, there are combinations of Vsc and Vt preset settings that both work to give a condition where the pwm and motor are just starting.

On one of my FC150BJ boards (original factory settings) the Vt preset was set to give a Vt of -7V and Vsc was set by the Speed preset at +0.4v. On the other FC150BJ board Vsc was set close to zero volts and Vt was set to -6V. Both of these combinations of settings are compatible with normal operation. A combination of Vsc = 0, Vt = -6V would mean that the lathe motor just starts with a Vc of 1.2V

IN terms of initial settings with zero motor rotation, the equation, where it is desired that the motor just starts at some Vc from the manual speed control, is close to:

$$Vc = -0.2Vt - Vsc.$$

Remembering that; Vt itself is a negative value, Vsc a value from zero to positive and the factor of 0.2 is to some extent affected by the Torque preset resistance.

Therefore, as noted in the settings section, after Vt is set to -7V, then the Speed preset set to just start the motor, with the manual control at 1V, then after the Torque preset is adjusted, it is worth re-setting the speed preset.

It is not a good idea to have the motor starting point at a Vc of much more than 1.2V from the lathe control manual potentiometer. This is because of the limitation of the buffer OP amp U1B's output stage that the control feeds, can only climb to +10.7V to +11V even when the output from the control is +12V, because of OP amp U1B's output stage not being able to swing full rail to rail. The BJT based ouptput stage in the OP amp drops some voltage.

The speed control feedback circuit operates with a Vsc over a total voltage range of close to 9.4V, so to get full speed from the motor, the voltage range produced by the manual control must be:

10.7 – Vc , it must be greater or equal to 9.4

Limiting the maximum Vc for pcb calibration purposes to 1.3V.

So if the Speed preset and Vt presets are set with the manual control at too high a voltage, when the motor just starts, it will not be possible to get the lathe motor to full speed. Probably the ideal position for Vc prior to calibrating the Speed preset is 1 volt. And Vt set initially to -7V.

**d) Principle of all offsets = Zero.**

The FC150BJ amplifier system under consideration and its negative feedback system, is one where its open loop gain is significantly higher than its closed loop gain, (in the FC150BJ controller the ratio is 33:1, which is high enough for the principle to reasonably apply). And such when all of the amplifiers in the system (including the feedback loops) are *operating inside their dynamic range*, then the output of the amplifier U1A will always move in a direction to make the voltage at the input to the amplifier, in this case amplifier U2C, such that the plus and minus inputs ofU2C have a zero voltage difference.

“Operating inside the dynamic range” also means that when the pwm comparator is operating inside its control range window (approximately +4 to -6V). This is between less than a 100% duty cycle and more than a zero duty cycle. Therefore that a change in the pwm duty cycle (and the average motor voltage) is therefore reflected in a change in the speed feedback voltage Vsc returning to amplifier U2C via the speed feedback loop. Outside this range the dynamic feedback is abolished.

Since the + input of U2C is connected to common (0v), via R32, the pwm control system moves in a direction to keep the input voltage at node N1 (the minus input of U2C) close to zero volts.

**e) Implications of limited dynamic range at the OP Amp's output.**

The principle relates again to the voltage gain of open loop versus closed loop conditions. Without any negative feedback around an OP amp, its open loop voltage gain could be in the millions. With feedback it could be a very low value. The basic idea is that if the gain of the OP amp is very high, open loop, with the negative feedback resistor or negative feedback pathway removed. Then the gain you end up with, with the feedback present, becomes a function of the relative values of the resistors or other components around the OP amp, independent of the OP amp itself. This is the great utility (and genius) of the OP amp which helps designers make use of them. It also makes it possible for many types of OP amps, especially in low frequency circuits, to be substituted for each other in the same circuit, with minimal effects on circuit function.

In the case of the main control OP amps U2C and U1A, in the open loop condition, if they were not receiving any feedback from the Speed control feedback loop, their total voltage gain product has been limited to a value of 33. This essentially means that if the Speed feedback signal Vsc "went missing" it would only require an input voltage at U2C's + input of about +/- 360mV to swing the output of U1A between +/- 12V. The control range of U1A's output is normally > +4V (max speed) to around < -6V (min speed or stopped).

One way the negative feedback can go missing is if any of the OP amp outputs in the feedback loop runs out of dynamic range at the OP amp output. In this case, the output voltage clips to a value close to the +12 or -12V volt power supply rails. When this happens, the feedback signal vanishes from the dynamic perspective, as the OP amp's output stays frozen.

Exactly the same effect occurs when the pwm comparator is pushed above or below the control range corresponding to 100% duty cycle at one extreme and zero duty cycle at the other. After those extremes the output of the pwm comparator simply stays near -12 or +12 volts and the mosfet is either fully enhanced, of off.

For example, if the output of the amplifier in the speed feedback loop U2D, pin 14, signal Vsc, is driven into clipping, this allows the manual speed control producing Vc, to relatively suddenly, push the pwm control voltage Vo well over +4V and taking the motor to full speed.

In essence, if the output of any amplifier in a system, providing the negative feedback pathway, clips to its supply rail, or cannot respond with an output variation for a variation in input signal, it results in the gain of the amplifier controlled by the feedback loop to revert to its open loop value.

**Circuit analysis PWM Section:**

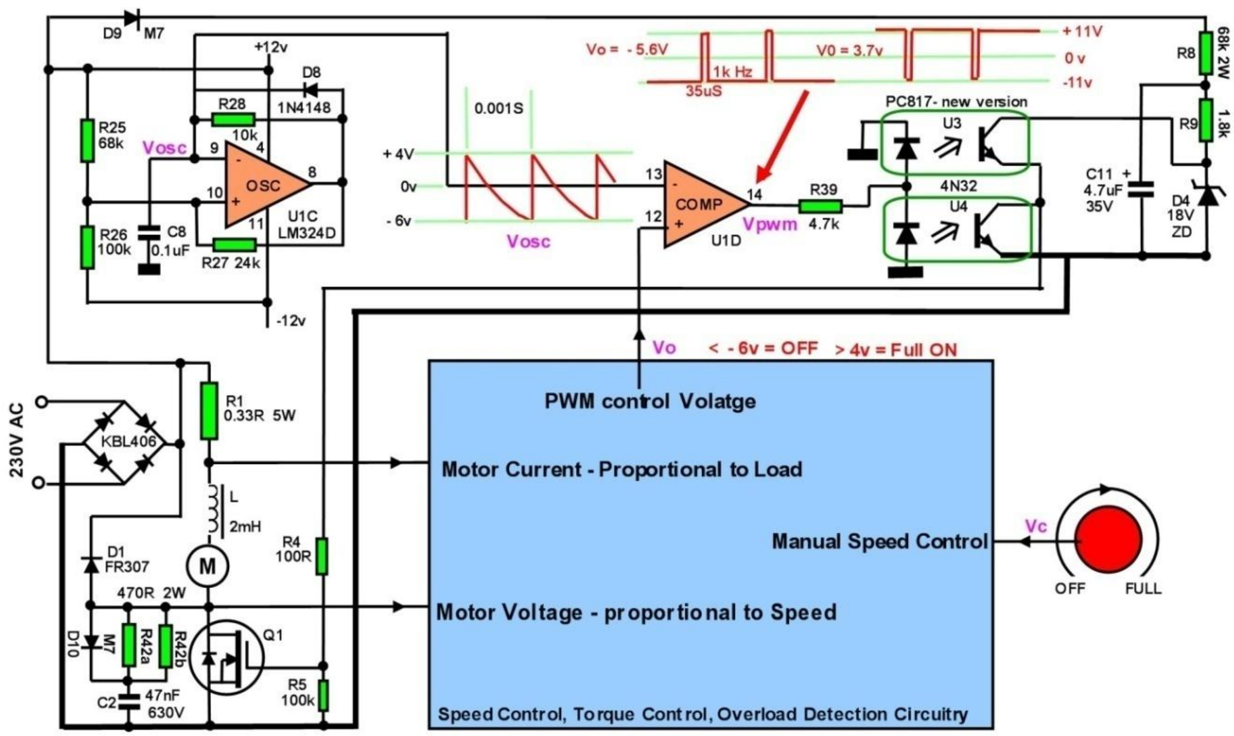
(For clarity the motor reversing switch and some relay contacts are not shown yet).

U1C and U1D are physically on the daughter board. The oscillator waveform is not a triangle wave, common to many OP amp oscillators because the designers added a diode D8, to alter the properties of the feedback pathway around the OP amp oscillator and it results in rapid charging of the timing capacitor to produce a *sawtooth* voltage.

U1C behaves as an oscillator because of the hysteresis it is given by the positive feedback resistor R27. This allows the op amp output to have two stable input and output states, with the charge and voltage on the timing capacitor C8 alternating between the two input threshold voltages.

OP amp U1D is used as a comparator. The DC control voltage range fed to the + input of U1D controls the duty cycle of the output voltage, Vpwm, which appears at pin 14. Any Vo voltage much greater than +3.7V results in the output of U1D adopting a +11V voltage without pwm pulses and any voltage much more negative than -5.6V results in the output falling to -11V.

The maximum full control range occurs across approximately -6v to +4V for the control voltage signal Vo. For example a Vo voltage of approximately -1V results in a Vpwm voltage that is close to a 1kHz square wave with a 50% duty cycle.




Q1 = MTW20N50E or IRFP450 new version

Power mosfets have significant gate capacitance in the order of 1500 to 3000pF for the types used here. When the Vpwm output goes high, this turns on opto-coupler U3, which applies 18V to the gate of the IRFP450 mosfet to enhance it. When the Vpwm signal swings negative, opto-coupler U4 discharges the mosfet's gate capacitance to ensure the mosfet turns off quickly.

The output of the bridge rectifier, rectifies the incoming line voltage has its positive terminal connected to the +12 low voltage power supply rail. This was done to make it easier for the OP amp circuitry, powered by the +/- 12V low voltage supplies, to monitor the motor current developed across the motor current sensing resistors R1.

The voltage seen on the drain terminal of the mosfet, connecting to the motor's negative terminal, with respect to the common of the low voltage power supply, swings between +12V and peaks to around -309 to -337V with respect to common, depending on the exact *rms* line voltage in the range of 220 to 240V.

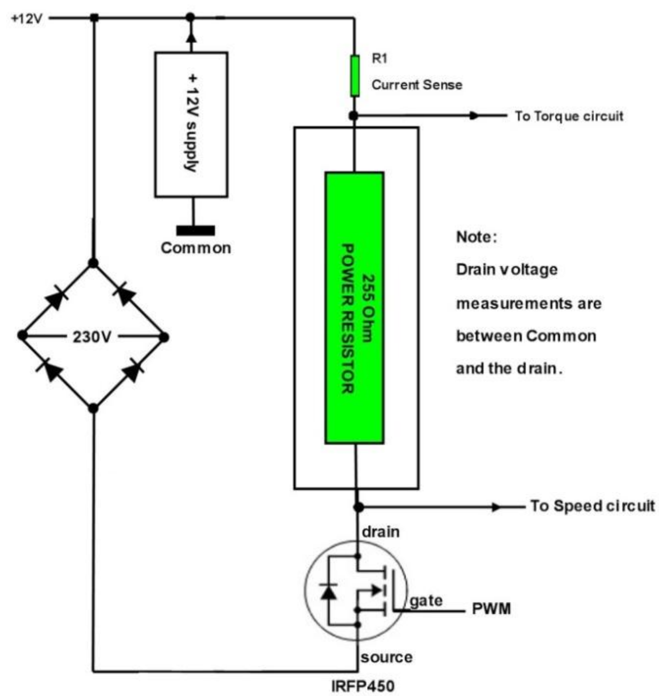
The components, R42a and R42b, the 47n capacitor are configured so that the capacitor charges initially to the average value of the motor voltage, so that voltage transients with a high dV/dt are snubbed to a degree by the diode D10 and charging current of capacitor C2.

Due to the fact the motor is a reactive load and stores some magnetic field energy, both the rapid on-off pwm voltage control and the activity of the motor's commutator, can both result in high voltage transients. In addition the motor generates a back emf proportional to its speed. The average motor terminal voltage is closely correlated with the motors actual speed.

Any high voltage transients that are produced across the motor's terminals are a threat to the mosfet. The diode D1, helps prevent the drain voltage of the mosfet exceeding the potential of the + output of the bridge rectifier (and +12V supply rail) and the mosfet's own internal drain-source diode prevents the mosfet's drain voltage from going significantly lower than its source terminal.

Simple simulation of the mosfet's pwm control:

With view to examining the voltage on the mosfet's drain, for initial recordings on a Spice simulator, the motor was replaced with a resistive Dummy Motor Load of 255 Ohms.

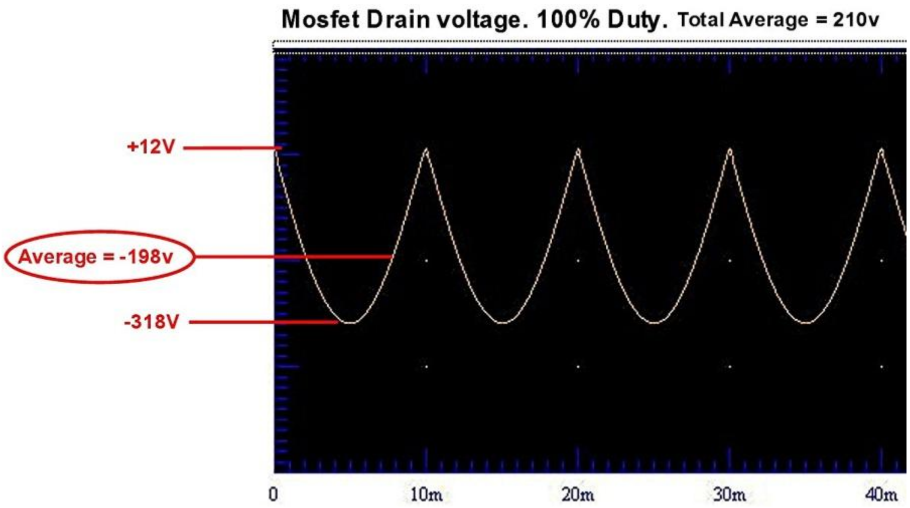



The circuit simulations with this simple model will be shown first, prior to a more elaborate motor model. The reason to use the simulation with the simple resistor dummy load first, is to observe what the pwm-mosfet system is attempting to achieve with the applied motor voltage and to examine the ***average*** voltages involved.

The reason why the average voltage is of interest, is that it is a “DC system”, despite the pulsed voltages and the OP amps in both the motor Speed control circuitry and in the Torque control circuitry, work on average values, not peak or rms values.

As noted on the diagram, the voltages on the mosfet drain is measured or displayed with respect to **common**, which in this case is the negative connection of the +12V power supply. Also, in this design the + output of the line power bridge rectifier is directly connected to the +12V supply terminal.

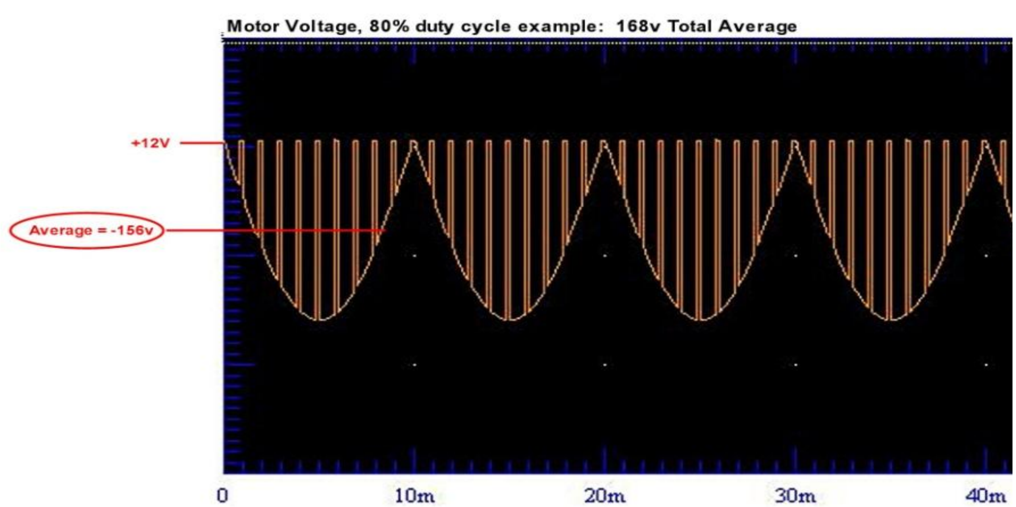
When the mosfet is fully enhanced, with no pwm activity, the following simulation shows the mosfet’s Drain voltage. The *applied voltage*, across the dummy load, is the total between the mosfet’s drain and the +12V terminal.



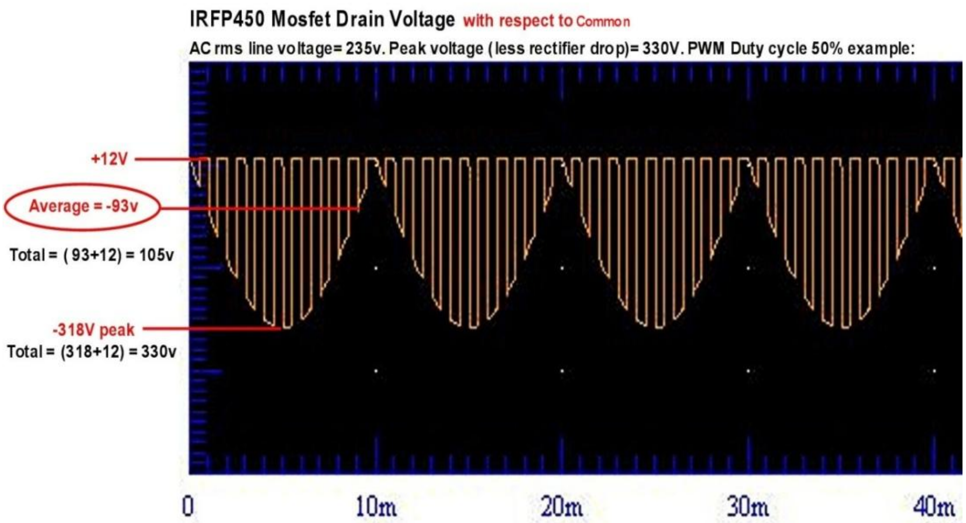

The magnitude of the total ***average*** applied voltage to the dummy load is close to 210v with the Power Line voltage in the vicinity of 230V rms. The value of interest though is the average value in the red ellipse, in this case -198V, because this is what is processed by the Speed control feedback loop.

It is worth noting here, that examination of this waveform with an oscilloscope on the actual controller pcb shows it to be flattened off a little on peaks. The reason is that the line supply in many dwellings is loaded by multiple appliances with SMPS supplies and they draw current on peaks, causing harmonic distortion of what should be a perfect sine wave.

When pwm activity is present, this lowers the average applied voltage. The recording below shows the situation with a pwm duty cycle of 80%. To clarify this remark, it means that if the pwm oscillator was a 1kHz frequency, it would have a period of 1mS, so if within that cycle time the mosfet was switched *on* for 0.8mS of it and *off* for 0.2mS of it, then that would be an “80% duty cycle”.

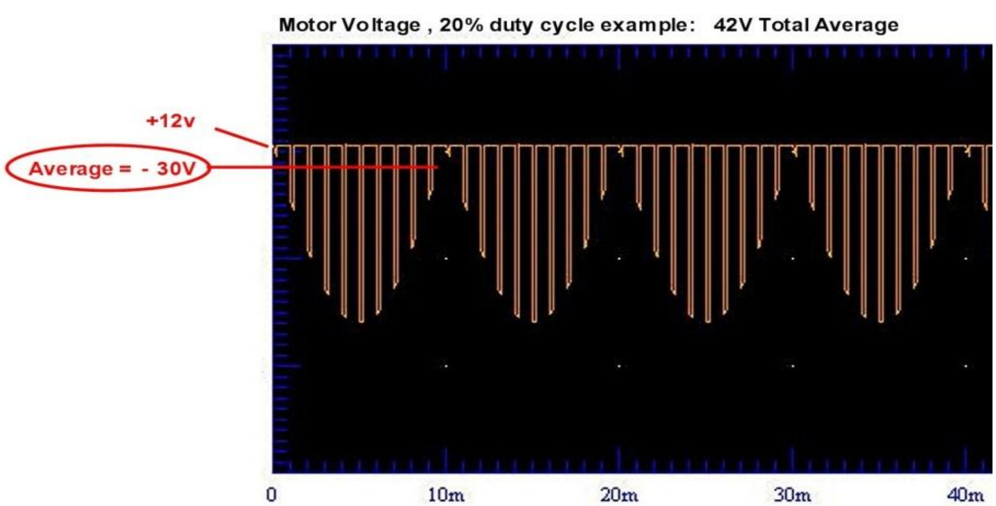


**The 50% duty cycle case:**




As can be seen in the 50% duty cycle case, the average applied voltage to the dummy load has a magnitude of 105V and the voltage, fed to the Speed control feedback amplifiers is -93V.

**The 20% duty cycle case:**



**Zero % duty cycle case:**

I this case, the motor would be off with no motor current and the mosfet is not enhanced. The potential of +12V, or very close to that, appears on the mosfet's drain terminal because the non-rotating motor has a relatively low DC resistance in the region of 25 to 30 Ohms.

Conclusion:

From the above we have determined that the average voltage, fed to the Speed feedback amplifiers, is +12V (motor off) to -198V (motor full speed) over the full range of pwm control. Since we are initially considering the voltages just outside the full range over which the pwm control is active, for now we do not have to concern ourselves with the details of the pwm and the motor's response to it inside the control range.

**DC Motor modelling.**

It is worth addressing some motor questions now.

If it is true that the DC motor's actual shaft speed is proportional to the average voltage applied to the motor, then why bother having a Speed negative feedback loop at all? Why not just an open loop controller that applies an average voltage to the motor from zero to its maximum rated voltage and controlled by the manual speed potentiometer? (Some simple controllers do work this way).

And what would be the advantage, in the case where a negative Speed feedback loop was derived from the average applied motor voltage and fed back to the motor speed control amplifier, given that the average voltage is applied by an agency external to the motor and already has a known range of values?

In other words, how is the motor's actual terminal voltage helpful in motor speed control when, perhaps ideally, one might have a tachometer on the motor's shaft?

The answer to these questions lies in the properties of the real DC motor.

The DC brush motor itself is a more electrically complex object than just the 255 Ohm dummy load that was substituted for it in the simulations above.

The three important properties that the real motor has are its armature resistance **Ra**, the armature inductance **La** and the **back emf** produced by the armature when the shaft of the motor is rotating.

It is the ***back emf value***, which appears across the motor terminals in use, which is both:

1) Proportional to the motor’s actual speed.

2) Contributes to the motor’s terminal Voltage when the mosfet is not conducting.

In other words, the back emf contributes to the average voltage which appears across the motor’s terminals. It is proportional to the motors speed thereby creating the possibility to better speed regulate the motor in a closed loop, rather than open loop control system.

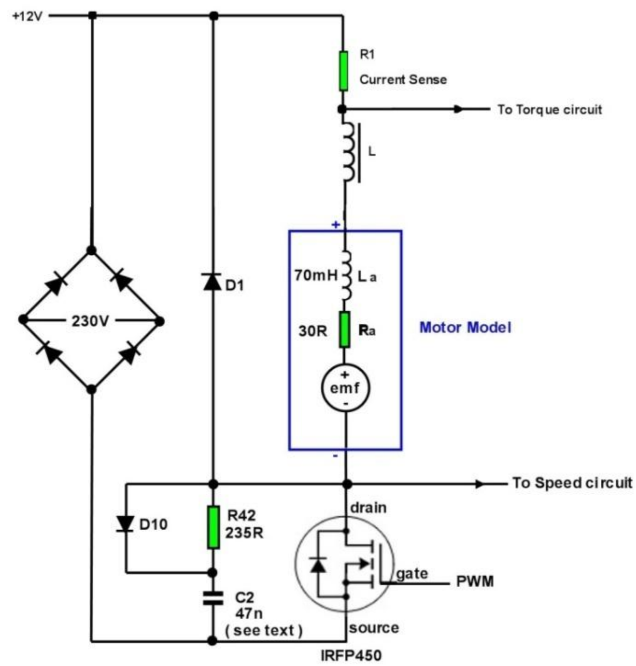
With the speed loop closed, external factors such as load on the motor shaft, slowing is rpm, result in a lower average motor terminal voltage because the back emf component of the average voltage on the motor’s terminals is reduced. With less total negative feedback, therefore the loop compensates *to a degree* and the pwm duty cycle increases. The speed negative feedback loop cannot totally compensate speed reduction under load, which is what a Torque feedback loop, adding some positive feedback is still required.

The back emf component of the motor’s average terminal voltage is particularly helpful at low to medium rpm values where the pwm duty cycle is less than 50%. It is in this zone that the speed feedback loop is particularly effective compared to an open loop system.

A closer simulation, of what the motor voltage would be expected to look like, across the motor terminals, with the real motor being driven by the FC150BJ controller, the other components surrounding the mosfet are required and better motor model also required.

These components include a 47nF capacitor C2, two parallel 470 Ohm resistors and two additional diodes.

The circuit for the model below takes everything into account, except for the transients produced by the brushes and commutation processes at the armature. As will be shown, the motor’s back emf only manifests itself on the motor’s terminals under certain circumstances.



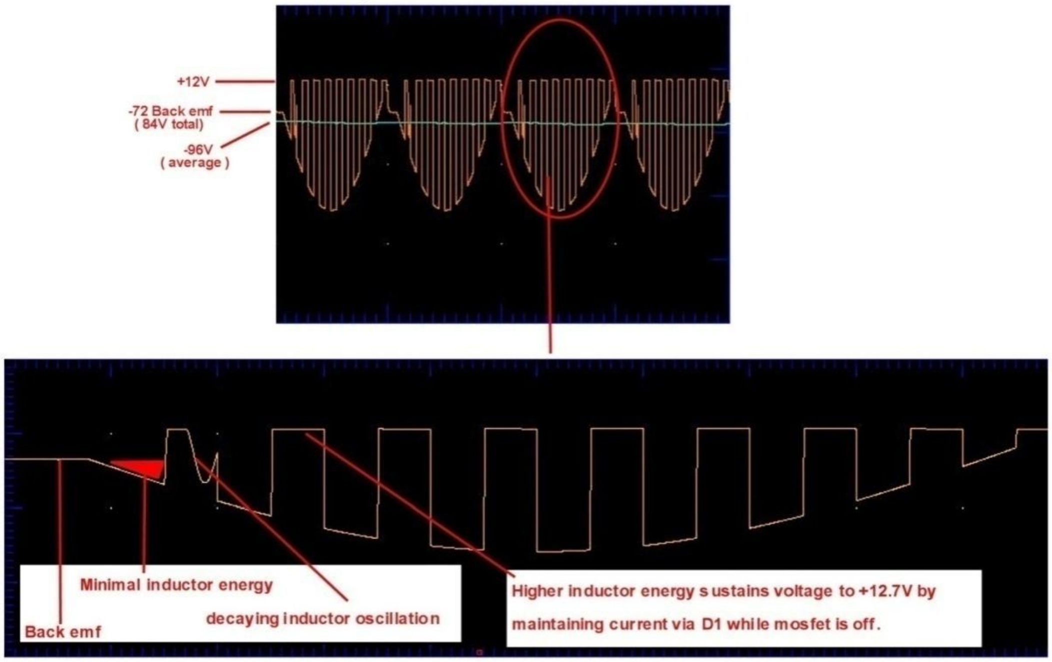

Generally one might expect that when the mosfet turns off, the voltage that would soon appear across the rotating motor's terminals would be the back emf value, the motor acting as a DC generator.

With duty cycles much greater than 50% and medium motor currents, energy is stored in the inductance, La, of the armature. When the current is interrupted abruptly (mosfet turns off) the polarity of the voltage across the inductance La reverses as the armature field collapses and this voltage can be higher than the motor's back emf value and opposite in polarity to it. Therefore the voltage at the mosfet's drain terminal (negative motor connection) is pushed over the +12 level forcing diode D1 into conduction and clamping the voltage to about +12.7V for a period of time.

However, with a low duty cycle, less energy is stored in the armature's inductance La, so when the mosfet turns off, the stored La inductor energy dissipates in a series of oscillations, allowing the back emf value to appear, before the mosfet switches on again.

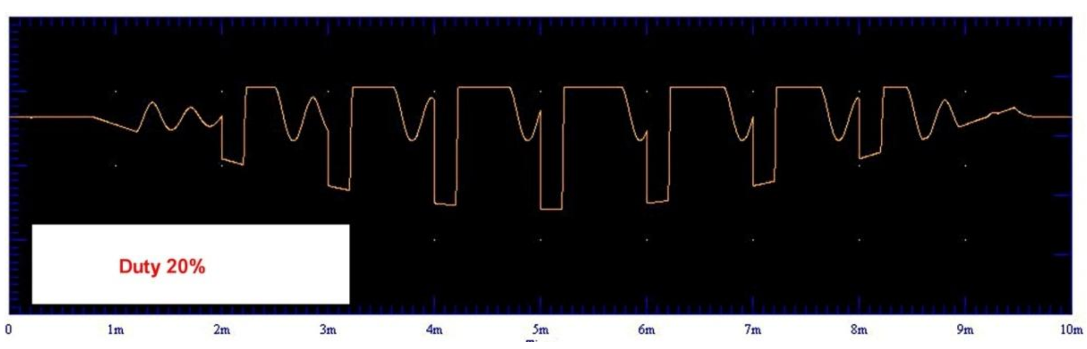
A simulation is shown below. Let us assume the motor is running at a 50% duty cycle under little load, just the friction of the bearings, drive belt etc. We will assume due to losses that there is roughly 15 to 20 Watts dissipated as heat and assign that total loss to the resistance Ra. Assigning a duty cycle of 50%, a back emf of 84V, a motor resistance of 30 Ohms. An armature inductance of 70mh (these two values were measured from the actual lathe motor), the simulator yields a picture of how these factors interact:

50% Duty. Back emf 84v. Power loss = 15W




The average voltage across the motor is similar to the resistor model but the motor's back emf appears in the waveform as do oscillations from the armature's inductance La. There is some contribution from the external inductor L, but its inductance is small compared to the armature.

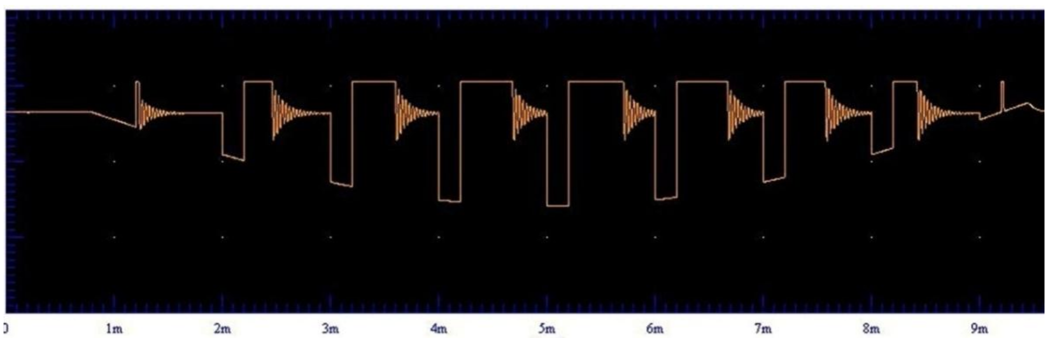
At the start of the next ½ sine cycle of the full wave rectified waveform, the initial pwm pulse stores very little energy in the armature's inductance, so the motor terminal voltage starts to collapse in an oscillatory manner toward the back emf value until the next pwm pulse turns on the mosfet. When the stored energy is higher, the collapsing inductor's field (armature field), is controlled by diode D1 and the voltage is clamped to around 12.7V. This means that effects seen on the voltage waveform, on the motor's terminals, of the armature's inductance are more obviously seen at lower duty cycles where there is less energy storage in the armature's magnetic field. A recording below shows the situation at 20% duty cycle, all other parameters unchanged:



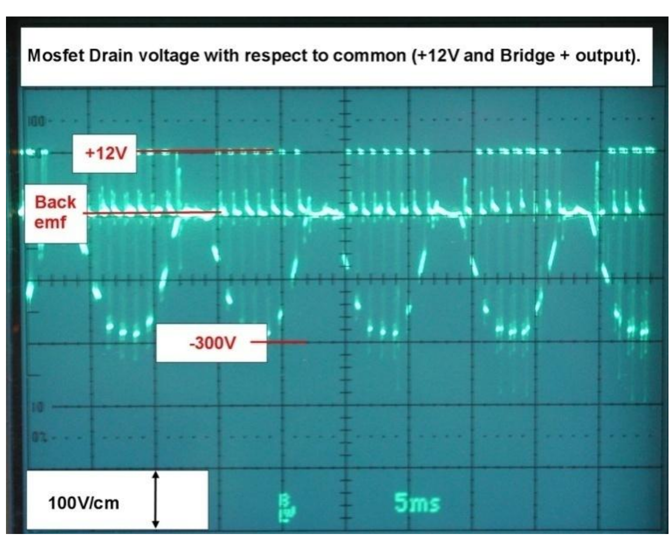
The armature's own self resonant frequency, with its inductance of 70mH and small self capacitance is much higher than about the 2700 Hz resonance seen on the above simulation. The reason is that the 47n capacitor, C2, significantly down tunes the frequency. This is one of the applications of the snubber capacitor C2.

C2 is also present to limit high frequency commutation noise from the brushes. As noted it is important that C2 is in perfect order. There are some remarks about this near the end of the article, with a recommended replacement part number for C2 . Ideally C2 is ***NOT*** an X2 line suppression type, despite this type of capacitor being used by the manufacturer and in many designs.

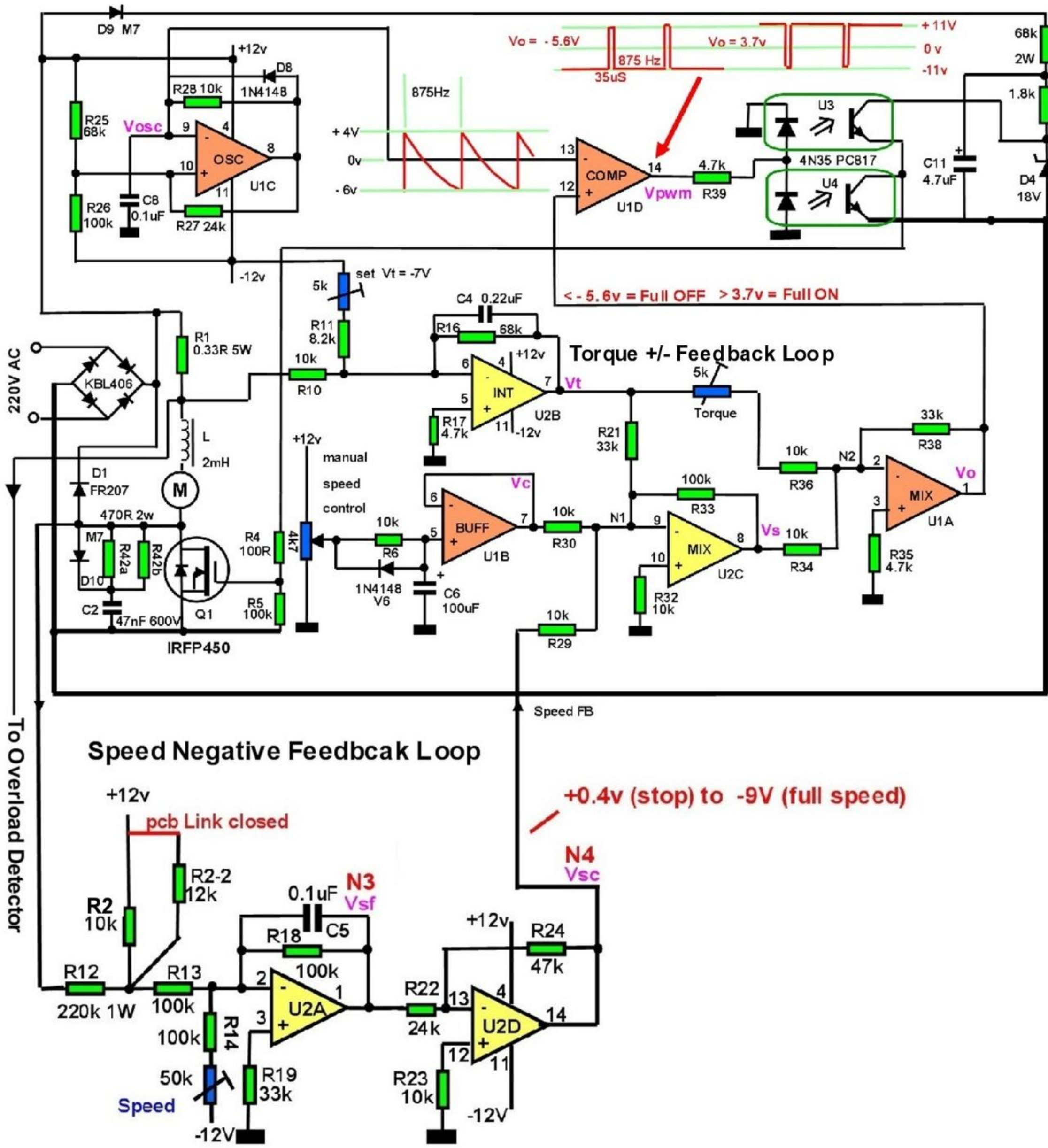
Of note, if the 47nF capacitor is not present and the armature assigned a self capacitance of 250pF the following result is seen with the armature resonant frequency being around 34kHz:




An oscilloscope recording of the actual motor voltage in use at about 1/3 speed is shown below. It is difficult to attain a stable locked scope trace, primarily because the 1kHz pwm frequency is not phased locked to the line power supply, so the scope triggering is erratic. The point of the recording though is to show that the motor's back emf is contributing the motor's average terminal voltage:



**Circuit analysis of Speed and Torque feedback amplifiers.**




It is easy to determine the voltage divider ratio of R12, R2, R2-2 and R13 (which couples into a virtual earth). The Thevenin resistance of the latter three resistors (in parallel) is 5.172k. Therefore 5.172/(220+5.172) = 0.023. The range of motor voltage of 210V total, is divided down at the output of U2A to 0.023 x 210 = 4.82V. U2A has a gain of 1 and averages the values. U2D has a gain of 47/24 1.96, so the voltage Vsc varies over a dynamic range of 1.96 x 4.82 = 9.45V. In practice over the full range of speed control 9.4V was measured.

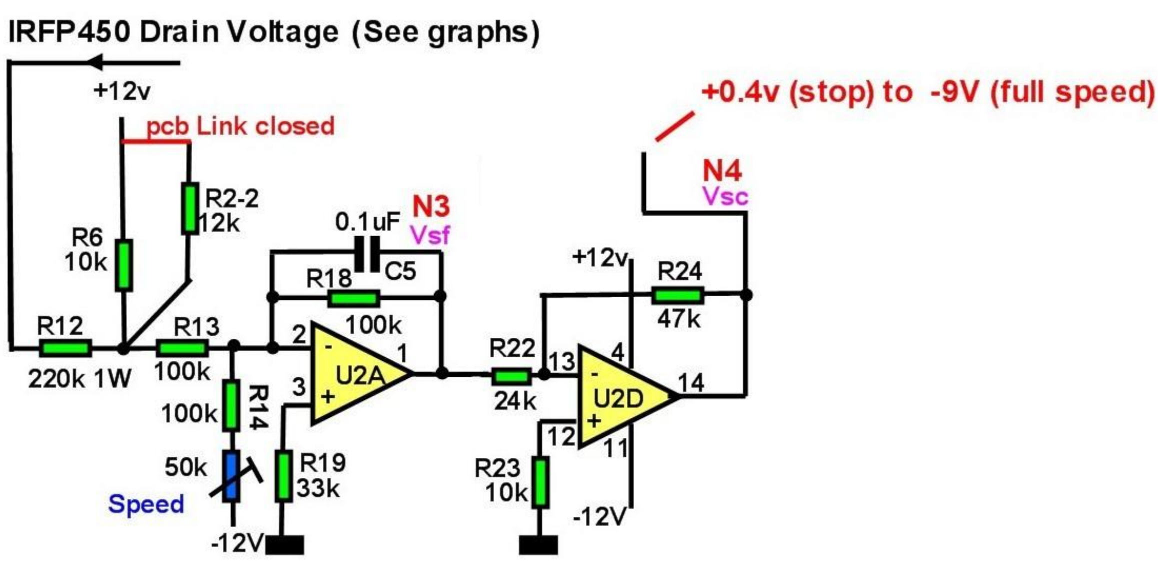
***The Speed feedback loop*** is shown in more detail below, along with a table with the voltages that appear on the circuit nodes N3 and N4.

The first IC in the Speed amplifier feedback network is U2A, see below. This is configured for a voltage gain of 1 with a feedback capacitor from its output to its - input, causing the stage to average the pulsitile applied voltage.

The Speed control preset sets the starting value of voltage Vsf which in turn sets the starting point of voltage Vsc. With no motor rotation and the voltage applied to the R12 being +12v and with the Speed preset set for a Vsf value of -0.2v, this sets the Vsc voltage at close to +0.4V because

Vsc = - Vsf(47/24)

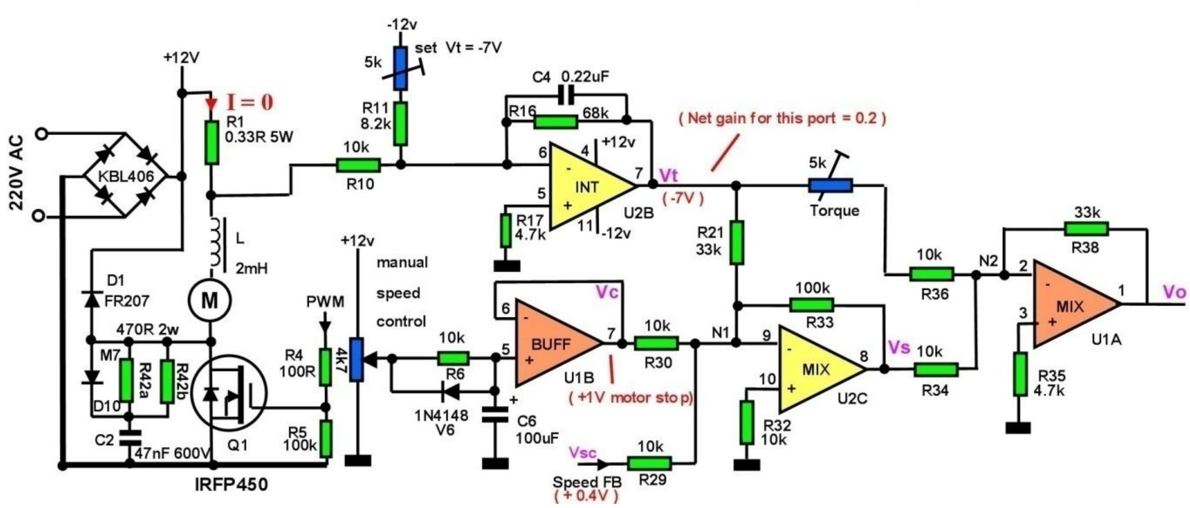
When the average voltage at the mosfet's drain varies by +12V to -198 volts, or 210V average, the change of the output voltage of U2A, signal labelled Vsc, varies over a measured range of +0.4v (motor off) to -9v (Motor full on) a range of close to 9.4V. The +0.4V starting voltage is set by the 50k Speed preset. It will be explained below, the starting voltage of Vsc could be in the range of 0 to +0.4V. (It interacts with the setting Vt, see later). It was found to be factory set at close to +0.4V in my C1 original lathe board. If the Speed preset sets an initial value of Vsc = 0V, then the range of voltage at Vsc would in that case be 0 to -9.4V.



| Averaged Mosfet Drain Voltage | N3 Volts | N4 Volts Speed preset = 7.29 k | PWM PERCENTAGE |
|---|---|---|---|
| +12v | -0.20 | 0.4 | 0% |
| -30v | 0.72 | -1.41 | 20% |
| -93v | 2.11 | - 4.13 | 50% |
| -156v | 3.55 | - 6.95 | 80% |
| -198v | 4.68 | - 9V | 100 % |

As the manual speed control is increased, starting at 1V when the pwm just begins to power the motor and increasing to around 10.4 volts from the manual control, the voltage offset at U2C's negative input pin node N1,is nearly exactly countered by the feedback from Vsc at node N4 because the output of the servo amplifier U1A moves to alter the pwm to correct the differences between the manual control voltage and the speed feedback voltage. While the speed loop is running inside its dynamic range, the pwm duty cycle is always adjusted to create a zero offset at the input of Op amp U2C.

***The torque feedback loop*** *involves* the current sensing resistor R1 and the integrating amplifier U2B. As previously noted the overall effect of the torque feedback loop is positive feedback. The torque potentiometer and R36 introduces negative feedback to node N2 at the input of U1A, which counters a proportion of the positive feedback introduced via R21 into the input of U2C, the overall effect still being positive feedback.



With zero motor current, the voltage dropped across R1 is practically zero. The Set Vt preset potentiometer is used to set the output of U2B to an offset of -7V.

As previously explained the Vt signal has a voltage gain of approximately 0.2 (with the torque preset value near zero Ohms), in terms of the way it influences the main amplifiers of U2C and U1A, at least in the case when the Speed feedback loop is closed.

However, as pointed out previously if the the PWM switching stops (in either state, mosfet full on or full off) the Speed negative feedback loop is disabled from the dynamic perspective. When this happens, the voltage gain of the amplifiers U2C and U1A revert to their open loop condition, with a total gain of 33.

Therefore, if we consider the situation where the manual speed control is still just operational, with the manual speed potentiometer signal set just a fraction above 1V , and the pwm active then applying the previously discussed zero offset principle to the three input ports (Vt, Vc and Vsc) of the amplifier system comprising U2C and U1A, The voltages must all balance out to a zero offset.

To balance out the voltages at U2C's input, the +1V from the manual control (as the motor stop position) and the +0.4V from the Speed feedback amplifier's initial set point, making +1.4V total. It therefore requires -7V from Vt because -7V x 0.2 = -1.4V. As previously noted, Vsc could be set to +0.2V, this would require Vt to be set to around -6V to have a zero offset when the manual control was producing 1V.

In practice, the Vt preset can be set in the region of -6 to -7V because the exact value of Vsc occurs automatically when the manual speed control is set to +1V and the Speed preset is adjusted so the motor has just stopped (see section on preset adjustments).

It does not matter that the resting voltage of U2B is in the region of -7V because any voltage developed across R1 is such that the output of U2B, or Vt, only moves in a positive direction. So the output of U2B has a very wide dynamic range from -7V to +11V at least and is unlikely to be clipping limited. When the motor is mechanically loaded, the motor's back emf drops and therefore the current drain increases. This increases the voltage drop across the current sensing resistor R1.

This voltage Vt is amplified with a gain of 68/10 or 6.8 by U2B and appears at the output of the U2B pin 7 as signal Vt.

The current signal is a positive going voltage, on Vt, rising above -7V (to a less negative value) as the motor is loaded. U2B is heavily integrating with the 0.2uF feedback capacitance.

The voltage developed across R1 is also sent to another pair of OP amps, U5A and U5B to detect overload (see below).

At full speed and full rated motor power output, 100% duty cycle, according to the sticker on the motor, is rated at 0.9A and 230V DC. Therefore at maximum load and motor power, the voltage across R1 is 0.9A x 0.33 Ohms = 0.3V. Even though this is pulsed DC, the signal is averaged by U2B. Therefore, Vt increases in value, from its -7V resting value at no motor current, over the range of about 0.3 x 68k/10k = +2 average volts, from no motor load, to full load where the motor is consuming close to 200W of power. Leaving Vt at close to -5v at full motor load.

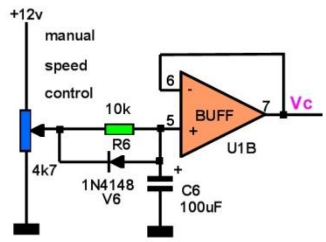
As noted previously, the Vt signal feeds into the main amplifiers of U2C and U1A with an overall gain of close to + 0.2. So the current feedback signal range of influence is fairly small altering U1A’s out by only about 0.4V over its full range. This would have to be the case, as it is overall **positive feedback**, and too much of it would result in the motor speeding up with loads and possible surges in speed.

If there is inadequate positive feedback, the chuck will slow down with frictional loading. See the preset setting section on how to set the Torque preset. Increasing the Torque presets resistance value results in less negative feedback and more overall positive feedback and more Torque compensation. In some other Sieg Lathe control boards for other models, such as the FC250 and SC350, Sieg used a smaller value resistor in series with the Torque preset, 6.8k in one case and 5k in another. This allows a wider +/- mechanical range on the preset.

Once the user’s manual speed control has been turned down, anti-clockwise, to a position at the region of just one volt or below, and the pwm switching activity just stops, it only takes a fractional movement of the control further anti-clockwise to swing Vo hard negative. This is because the speed feedback is abolished and the gain of U2C and U1A reverts to 33. To get Vo to swing fully hard to the negative rail only takes the voltage to decrement from around 1V to around 0.8V from the potentiometer.

**The manual speed control buffer.**

Sieg introduced the R-C and diode network into the control buffer input on most of their later boards. The resistor and capacitor delay the rise in voltage, due to the time it takes, for the capacitor C6, to charge via R6 and the potentiometer's source resistance. If the manual control is suddenly rotated counter clockwise, the capacitor discharges more rapidly via the 1N4148 diode and potentiometer's source resistance, but C6's discharge still delays the rate of Vc's voltage drop, compared to having no capacitor.




From start at least, with the motor not rotating, if high voltage is applied to the motor there is a very large current surge because it takes a while for the motor shaft to start rotating and generating back emf and for the current to drop. The motor's DC resistance for example is only about 20 to 30 Ohms. So if the Lathe operator rapidly spun the manual control from off to full, the current surge could be interpreted by the current overload circuit as a mechanical jam and trigger a fault condition, or possibly blow the fuse too.

In addition, if the voltage generated by the manual control can change too rapidly, when turning the control anti clockwise from a high range speed, the motor appears to transiently cut out without this delay network. This is because the back emf generated by the motor does not fall fast enough to track the mechanical rotation of the control, so the pwm pulses are momentarily cut off because of the speed feedback circuitry's influence on the main servo amplifiers U2C and U1A, before the mechanical speed drops, to match the manual control setting.

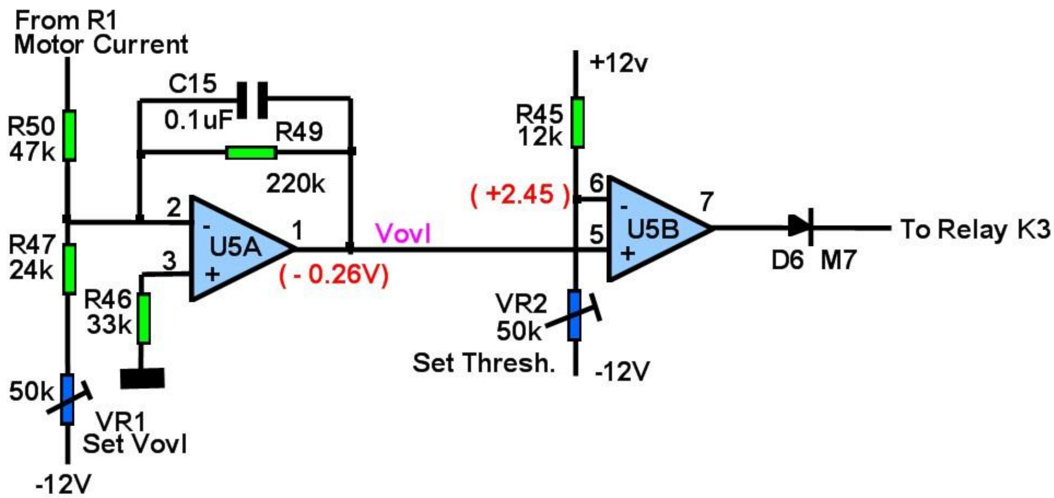
One thing of note: When the actual 4.7k manual speed potentiometer is rotated fully clockwise, its wiper reaches a voltage of 12V. However the output of the buffer OP amp U1B only reaches 10.7V to barely 11V, due to the limitations of the output stage of the OP amp and the fact that the OP amp is powered by the +/-12V power supplies.

The range of voltages from the speed feedback loop is close to 9.4V and the range from the potentiometer (10.7V – 1V) or 9.7V, so, with the normal calibration settings of Vt of -6V to -7V and Vsc at +0.2 to +0.4V, the manual control maximum value exceeds that of the feedback maximum value, so the manual control, rotated fully clockwise can definitely drive the pwm system to 100% duty cycle and gain full motor speed.

**Overload Detection Circuitry.**

The question arises, where was the overload (factory) setting placed for the C1 lathe?

The voltages shown in red were the factory setting for my original lathe board, measured from the actual board. To see if these make sense:




And we know from the above analysis that the voltage across the current sense resistor increases from zero (no motor rotation or load) to about 0.3V at maximum motor power, assuming the resistor R1 is 0.33 Ohms as it is in the FC150BJ and the max motor current is 0.9A (from the C1 motor's sticker).

Therefore Vovl increases by 0.3 x 220k/47k = 1.4V average volts over the normal full load range for the 230V 0.9A rated motor.

If the motor is jammed, its terminal resistance drops to the vicinity of 25 Ohms and it stops generating back emf. The current then starts to rise rapidly to a very high value as does the voltage across R1.

It appears to be common practice that DC motor overload detectors are set to deploy if the motor current is 150% to 200% over the maximum motor rating.

If the Set Vovl preset VR1 is set for a voltage of -0.26V on pin one of U5A and if the threshold potentiometer VR2, on the comparator U5B, is set at 2.45v on pin6 of U5B, then to trigger the threshold comparator U5B, the voltage Vovl, has to rise 2.71V in total.

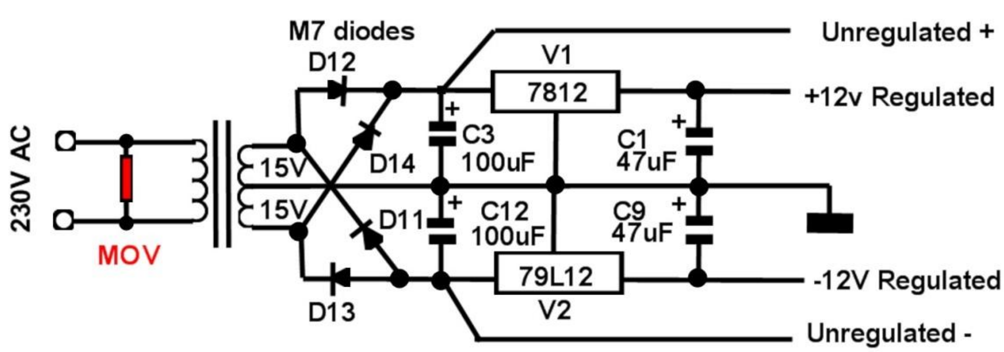
Since the motor full load value is 1.4V then this particular FC150BJ pcb was set up to deploy the overload circuit at 2.7/1.4 or about 190% overload, which is within range of what would be expected.

On setting VR1, the simple thing to do is to set Vovl to zero volts, to avoid having to add two numbers and set VR2 to the allowed overload percentage. For example if the threshold voltage was set at 2.1V, the overload trip point would be 2.1/1.4 or 150%.

Once the over-current threshold is reached relay K3 is deployed because the output of U5B swings close to +12V. This de-energises relays K2 and K1 cutting the power to the motor and switching off the AC line power to the control circuity. (The circuits around K3 and the relay and switch contact switching are explained below).

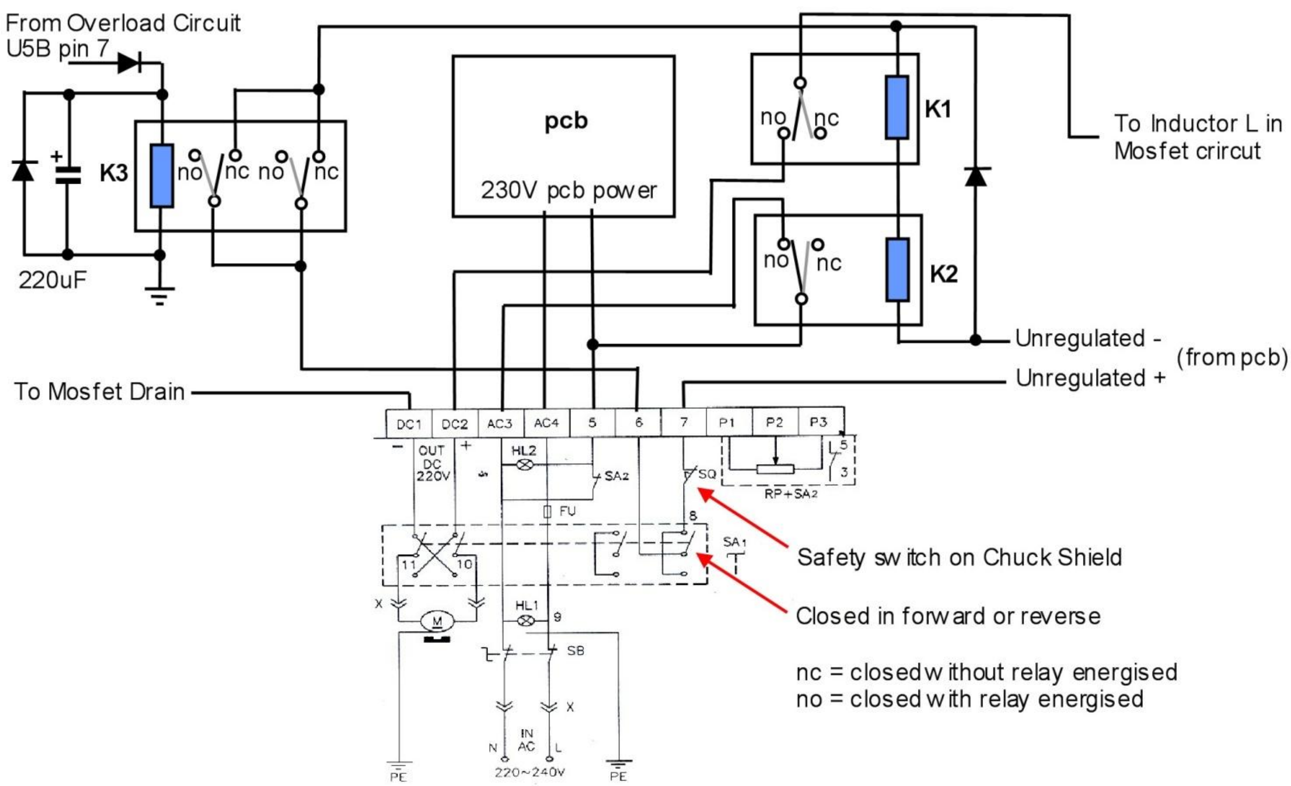
**Low voltage power supplies.**

These are conventional Analog supplies based on the small circuit board transformer and the linear regulator IC’s. This sort of low voltage supply is superior to transformer-less types, using power dropper resistors. The transformer method is more expensive due to the cost of the transformer and it makes the pcb a little heavier due to the transformer’s weight. However, in every other way, it is better and this is one of the many reasons I prefer the original FC150BJ control board. The unregulated voltages from the +/- supplies are also used to power the two relays K1 and K2.



**External connections to main board and shutdown relays:**

For the purposes of explanation, the diagram below was modified from the diagram supplied by Sieg, in their C1 lathe operator's manual.




Provided the Red safety switch on the Lathe's control panel is closed power is applied to the unit, the power light HL1 is illuminated. The Live of the line power is connected via the Fuse to the AC4 terminal of the FC150BJ pcb. If the manual speed control is fully CCW, with the switch SA2 deployed (closed), both the connections AC3 and 5 on the pcb are connected together. Also the Fault lamp HL2 is off, because it is shorted out. The line's neutral is supplied to the pcb on terminal AC3.

Initially at least as K2 is not energized, however, when the board is powered, both K1 and K2 are energised by the unregulated low voltage supplies, provided both the safety cover is closed over the chuck and the motor is selected to be in either forward or reverse mode.

(this is why with the manual control full CCW, when the motor direction switch is selected to forward and reverse, the relays K1 and K2 can be heard clicking as they close, or if the lathe power is disconnected in this circumstance K1 and K2 can be heard opening shortly afterwards)

Relay K3 is normally not energised. So its “nc” contacts are closed unless there is a motor overload condition where they open for a period of time until power falls away from the board. This is the purpose of the delay created by the 220uF capacitor C13 in parallel with K3’s relay coil to extend the time to allow the process to complete without any oscillations.

When the speed control is advanced clockwise it opens the potentiometer switch SA2. This has no effect, initially at least because at this point, K2’s contacts are in parallel with SA2, shorting SA2 out. At this point everything is powered, the pcb and the motor circuitry.

The motor’s terminals are connected to complete the circuit in the mosfet’s drain, by relay contacts K1 which are also closed because both relays K1 and K2 are both energised.

In the event of an overload, relay K3 deploys. When it does this de-powers both K1 and K2 as their coils are in series. When this happens, the lathe has been running at some speed, so switch SA2 on the potentiometer is open. With both switches SA2 and then the contacts in k2 and in K1 opening, four things happen:

1) The power is removed from the motor as K1 contacts open.

2) The pcb is de-powered because it loses its Neutral feed from the line power as both SA2 and the contacts in K2 open.

3) The fault neon lamp HL2 lights, because of the relatively low resistance that the pcb’s 220V power terminals represent (compared to the neon lamp) when the board is not powered.

4) Due to the power being removed from the pcb, after a time, relay K3 opens again because the charge on the 220uF capacitor, powering its coil, is depleted.

The nc contacts of K3 close again when this relay coil loses power. However, once relays K1 and K2 are de-energized, they stay that way because the power has been removed from the pcb because *both the contacts of K2 and SA2 are now open.* So, the design acts as a “latch” to de-power the lathe electronics and the lathe motor in the event of a motor current overload.

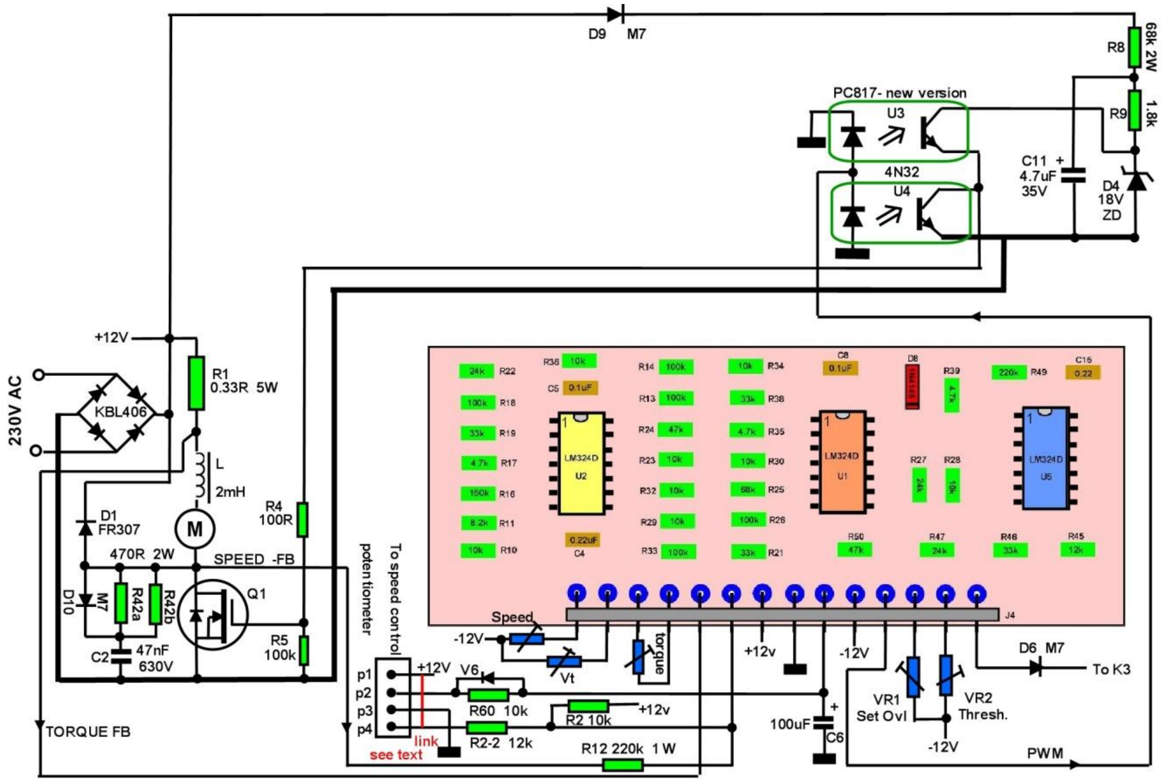
The only way to “reset” the “latched fault” condition is to rotate the manual speed control fully CCW, to deploy its switch. This resets the fault condition and extinguishes the fault neon indicator.

It is important in this design that both the power indicator and the fault indicator are of the neon (not LED) type, especially the fault indicator.

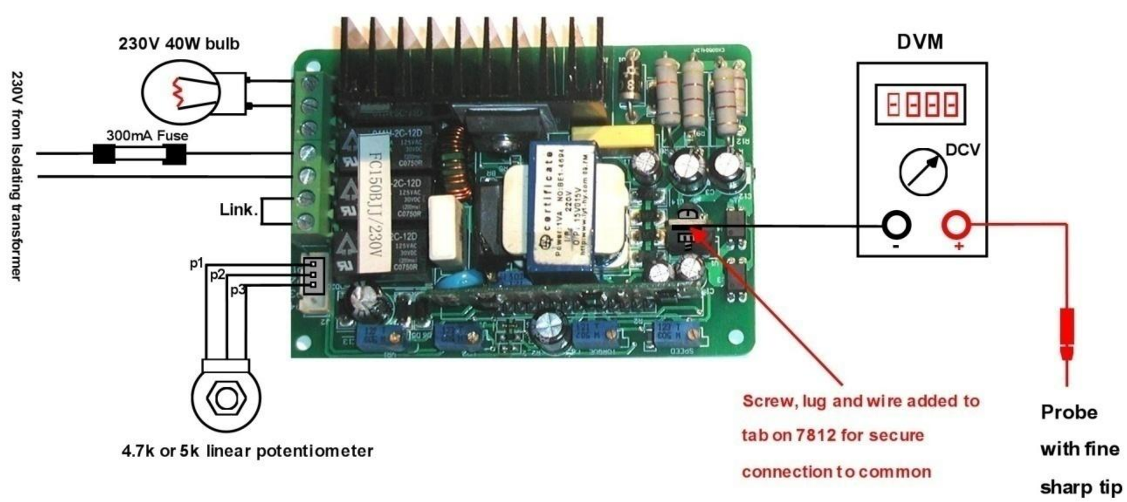
If these indicators are not available as spare, a suitable type is made by Arcolectric (see spare parts section). They come in 220V and 110V versions. The 110V version can be converted to a 220V type by placing an 82k resistor in series with one of its wires and covering that with heat-shrink sleeving.

**Setting the five on board preset adjustments:**

On occasions it is helpful to have a diagram which is a hybrid between a schematic and a block diagram. For example, to quickly locate a particular IC and its pins:




There are 5 preset potentiometers on the pcb which may require to be reset. Most of them were sealed with a blob of glue at the factory. Most likely the factory setting will be ok, but occasionally it might be that somebody has tampered with the setting in an attempt to repair the board.



It is better to set up the board on a test bench for easy access with a 40W 230V lamp substituted for the motor (unless a spare motor was on hand). A simple 4.7k or 5k potentiometer is plugged onto the connector J2 to create the manual speed control. Use a proper plug. Improvised connections that fall off are too risky.

( Of note and further to the introductory remarks about electrical safety and only qualified people working on a Line Powered PCB; If connections are made to the powered PCB, to a standard Oscilloscope for waveform analysis, the pcb requires to be powered by an isolating transformer, or alternatively be a special isolated scope such as the Tek 222ps. Those qualified would know that the use of the isolating transformer, while the name of implies some additional safety, actually defeats the RCD (ELCB) protective function of this device on the dwelling's breaker/fuse box. If the scope is not used and only an isolated DVM is used for testing, it is probably better not to use the isolating transformer as the protective function of the RCD on the breaker box remains intact and it will trip if current from Active flows via a one handed contact via the person's arm and body, to some ground point).

As shown it pays to make a secure connection to common, I use a screw/nut and lug & wire attached to the tab of the 7812 regulator.

If wires are attached with clips, they can slip off their connections. It is bad news and they can short to the pcb, damaging and destroying components. So the connections can never be too secure. Also to help avoid accidents the board should never be powered without a fuse. A 300mA fuse is satisfactory for a 40W lamp test. The C1 lathe uses a 1A fuse.

The DVM's positive probe needs to be a sharp fine tipped type to avoid accidentally shorting any of the tests points on the pins of LM324D IC's together. And since these are fine pitch pin IC's, the testing is better done under very good light and magnification and a steady hand.

When the pwm becomes active, even using just a lamp and not the motor, a faint buzzing sound can be heard emanating from the control board. The source of this sound would be worthy of an entire scientific paper on the Piezo-electric properties of electronic components. If an actual motor is being used it is very easy to hear the pwm drive starting up from the motor itself.

Initially the Torque control pot should be rotated >10 turns fully clockwise (minimum resistance).The 4.7k manual speed control pot switched, but in a counter clockwise (minimum speed) position. If the lamp is glowing (or the motor is rotating) turn the speed control preset until pin 14 of U2D is at zero volts, if it doesn't stop the motor rotating proceed to step 1 and the correct Vt setting should stop the motor.

The procedure (except for the torque control adjustment) can be performed on the test bench with either a spare motor, or the 40W 230V lamp substituted for the motor.

1) Set preset Vt for -7V at pin 7 U2B

2) Set the SPEED preset for +0.4V at pin 14 U2D

3) Rotate the manual speed control for 1V output from U1B pin 7.

4) Re-adjust the Speed preset until the motor is just starting or on the verge of starting. Or in the case of the lamp where the pwm signal can be heard from the pcb.

5) Set VR1, (set Vovl) for zero volts on pin 1 of U5A.

6) Set VR2 so the threshold voltage on pin 6 of U5B is +2.5V

(This setting would correspond to an overload threshold of 2.5/1.4 or 178%)

7) For the Torque setting, it must be done in the Lathe. It either requires an RPM meter attached to the chuck or a stroboscopic method. Run the lathe motor at about 1/3 speed or around 600 rpm, with at least an 8 inch long thick plastic rod in the chuck. Then holding the rod with leather gloves to create a friction load, adjust the Torque preset anticlockwise so that the motor doesn't slow down under load and does not speed up with applied load either.

8) As noted previously, there is interaction between the Torque preset altering the effect (gain) of Vt on the main servo amplifier. Therefore once the Torque preset has been adjusted, it is worth checking the setting of the Speed control preset to ensure motor starting occurs at a Vc voltage of 1V.

If it is not possible to adjust the voltage levels correctly, then normal fault finding methodology is used to determine which IC/s or other components are defective. If the person doing this is not familiar with these techniques, then likely they should not be attempting to work on the board.

**Failure modes and practical repairs:**

One thing to bear in mind about DC brush motors, as the brushes wear down with use the high frequency transients across the motor's terminals tend to increase.

If the original capacitor C2, an X2 rated 47nF film capacitor, has lost some capacity and/or the motor brushes are very worn, the high voltage transients in the mosfet's drain-source circuit increase. The 47nF capacitor C2, is very important to help protect the mosfet and reduce high frequency oscillations on the motor's terminals.

Some designs of film capacitors can lose capacity as the film degrades over time. The typical type prone to this behaviour, are the X2 rated suppression capacitors. The X2's are designed for direct connection across the Line power source. Rather than shorting out as a failure mode, the film in the X2 designed capacitor tends to degrade and be eaten away when they are subject to high voltage or high current transients. After a time the X2 capacitor's capacitance or uF value drops away. However the X2's look attractive and they are often physically smaller than the standard film capacitor counterparts for the same uF value and similar voltage ratings. X2 capacitors are generally rated with AC voltage ratings, rather than standard film capacitors which generally have DC voltage ratings.

In this application, in the lathe motor controller, the 47nF capacitor C2 is not directly connected across the Line power feed and is not required to be an X2 type for electrical safety. There is a fuse in series with it and the bridge rectifier motor and other components leading to this capacitor. If C2 shorts out, as a failure mode, the result is exactly the same as a shorted mosfet or failed mosfet pwm circuit. The motor, when manually switched on, simply runs at full speed.

C2 is better being a very high voltage rated film capacitor of high efficiency type. An internal construction such that the film is welded to the plates for a very low ESR is helpful. And a capacitor suited to *pulse applications* where it is not degraded by relentless charge-discharge cycles of high peak currents.

Therefore, to help to avoid mosfet failure, from time to time it is worth renewing the motor brushes and testing the capacitor C2 on a capacitance meter and replacing it, if it is out of specification. The original 47nF X2 capacitor in my FC150BJ board had lost over 1/3 of its capacitance and was down to about 30nF on testing.

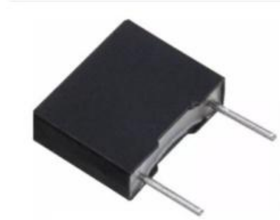
I would recommend the capacitor below as the replacement type for C2.The photo below shows the original X2 47nF capacitor, and the superior replacement sitting side by side:

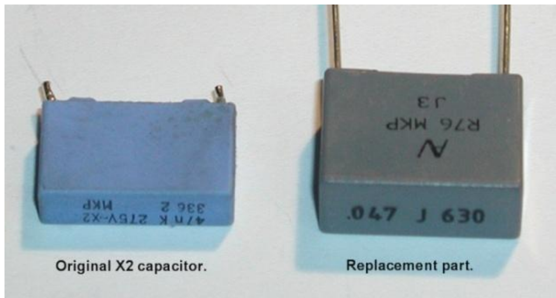
RS part Number 135-3482. MFR, Kemet, part: R76P124704030J
Double metalized Polypropylene type, welded plates, 47nF 630V
Automotive grade.

Applications

Typical applications include resonant circuit, high frequency high current, snubber and silicon-controlled rectifier (SCR and IGBT) and SiC (e.g. MOSFET) commutation circuits as well as applications with high voltage and high current.

Not suitable for across-the-line application






The replacement capacitor is wider on one dimension, 7.4mm versus 5mm, but there is room for it on the pcb.

Obviously, the diodes D1 and D10, have to be normal to protect the mosfet. And the mosfet’s gate drive voltage has to be normal to both fully enhance and rapidly turn off the mosfet. If the mosfet is not fully enhanced it can dissipate significant heat.

The common cause of the FC150BJ controller failing is dried out electrolytic capacitors. The electrolytic capacitor’s life is limited and decreased by high temperatures.

The superior capacitors to use as replacements are Nichicon brand 125 deg C types, rather than the more common 85 and 105 deg C 10,000hr types, because the higher temperature rated capacitors have a much longer life. A spare capacitor kit for the FC150BJ is worth putting together and having on hand.

I have seen many failed repairs when people have attempted to remove the surface mount LM324’s. The advice on some internet forums is to cut the IC pins before de-soldering them. However in many cases this technique damages the fine and delicate pcb tracks, lifting them from the pcb surface. I will explain how they should be removed without damaging the delicate pcb copper track-work.

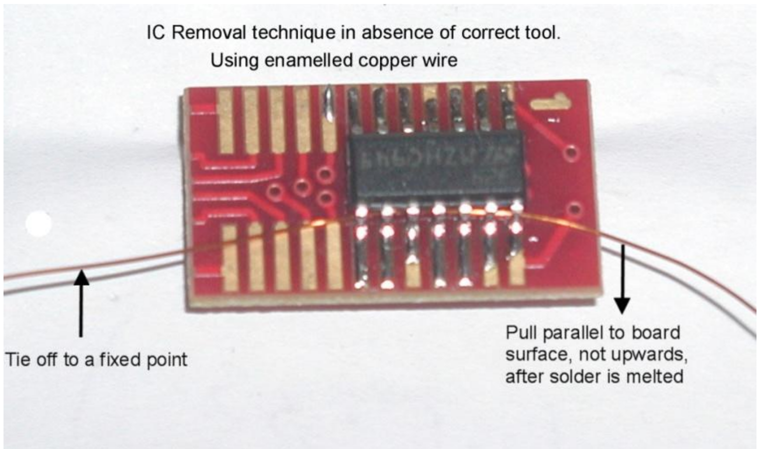
De-soldering surface mount IC’s:

The better method is to use the correct de-soldering tool. The pins on either side of the IC are flooded with fresh solder, the tool, fitted to the soldering iron is applied until it is certain that all the solder is in a melted condition on all pins, then a small rotation will release the IC. The pcb tracks are then cleaned up with solder wick and IPA.


If the correct tool for the specific IC size is not available or on hand, there is another method that is safe for the pcb tracks.

It is done using enamelled copper wire (preferably grade 2 enamel of the non-self fluxing variety) threaded under the IC pins where they exit the IC's body. Because of the enamel, the solder does not stick to the wire. The wire is used to separate the IC pin from the pcb only after the solder is melted with the soldering iron.

The forces are such, with this method, that the wire pushes the pcb track toward the pcb surface while the heat is present, so it does not lift the pcb track from the board. This technique has its advantages where the IC body has been glued to the pcb surface with strong glue, because once all of the pins are definitely free of the pcb tracks, more force can be applied to free the IC body from the board surface.



**Spare Parts for the C1 mini lathe and FC150BJ pcb:**

Many spares are still available from various machinery houses online including the motor forward and reverse switch and the power shutdown switch.

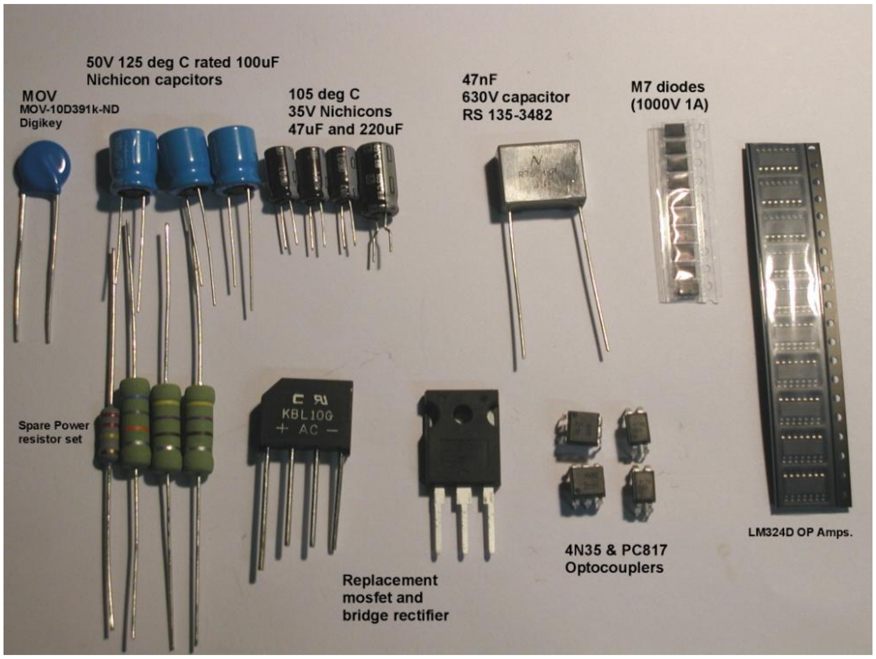
The plastic bodies of the original indicator Power and Fault Lamp were prone to cracking with age. In this case I would recommend replacing them with a non-original part, a type of very well made Neon indicator made by Arcolectric.


In addition it is worth having in your own stock spare parts such as motor brushes and drive belts.

Also it pays to have spare IRFP450 mosfets. These are readily available. An alternative part is the W14NK602 mosfet that has a higher voltage rating and an integral gate protection zener, so there is less chance of poor handling damaging the mosfet before you get it. The MTW20N50E is also suitable and used in the early FC150BJ boards.

Also some LM324D (SOIC package OP amps) are good to keep as spares. In addition, since the manual speed control potentiometer has an unusual switch (ON when full counter clockwise) it cannot easily be replaced by a generic switched potentiometer, so it is worth keeping some of these as spare parts, while they are still available.

The photo below, not a complete assortment, shows a selection of other spares to have on hand.




As noted in the section on the low voltage power supply, I could not acquire a 220V to 15V-0-15V transformer pre-made. So I simply rewound the secondary winding of a 12V version. The 12V versions are readily available from China on Ali-Express:

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