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How to Design Electronics for Hydraulics to Survive Y2000 Mobile Equipment

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HOW TO DESIGN ELECTRONICS FOR HYDRAULICS TO SURVIVE Y2000 MOBILE EQUIPMENT

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Abstract

"Most experienced hydraulics engineers are well versed in fluid contamination and compatibility issues, as well as sizing and selecting valves, pumps, and actuators. However, their lack of understanding of electronics and how it interacts with the hydraulics often makes it difficult for them to select the electronics for an electro-hydraulic system."

"Project engineers are usually better off working with a broad line electronics supplier with mobile equipment experience, rather than attempting to design the electronics or write their own detailed specifications for the application."

"Although hydraulics engineers do not have to design the electronic controls, they should know some widely used ways electrical engineers protect them." (MACHINE DESIGN June 5, 1997 article based on December 1996 NFPA/CIMA meeting presentation)

The three paragraphs above are no longer "*of interest*" they are critical. The number of mobile machines applying electro-hydraulic control is increasing exponentially and the problem applications are increasing faster. It is critical that engineers that apply electro-hydraulics clearly understand what characteristics are needed in the electronics to survive on mobile equipment. (Survival skills needed for mobile equipment can be applied to the difficult industrial machinery applications.)

This paper will not only cover what the problems are, but also suggest some solutions. This information is the result of numerous different applications handled by the author and companies the author has worked with over the last 30 years. However, the emphasis will be on the changes in the last three years. A time of rapid change in the capabilities of electronics and the challenges to survival that new machines have presented to electronics. The solutions discussed are solutions that every electronic supplier of electro-hydraulics should provide to mobile equipment manufacturer customers.

Introduction

There has been considerable change in the mobile machines that use electro-hydraulics over the last five years. The number of items controlled by the electro-hydraulics, the number of items being controlled by electronics, and the number of items that control both have increased by orders of magnitude. Five years ago, it was unusual for a mobile machine to have more than five axes of control that was powered by electro-hydraulics. The number of other items controlled electrically (other than lights) was generally less than 10. Today, the number of electro-hydraulically controlled items can number higher than twenty-five and the number of electrically controlled items can exceed one hundred.

The increase in the number of controlled points as well as the controlling (input) points has made the problem of survival of the electronic controls a major design item and potential problem for the project manager, mechanical designer as well as the controls designer. All must take into consideration the needs of the machine environment, the machine itself, and the electronic controls requirements for survival. In addition, it is necessary to consider not only the effect of the environment on the controls but also the effect of the controls on the environment.

The move to international regulations compliance is a major element in the decisions to be made concerning the specifications for electronic controls to control electro-hydraulics as well as other electrical functions on the mobile machine. Today the many international (and often conflicting) specifications must be considered during the initial machine design concepts. Designing for use in only one country or continent is not acceptable anymore.

While the hydraulic engineers, mechanical engineers, or the project manager do not have to design the electronic controls, they should know the general methods to make the electronics survive and the methods to prevent the electronics from having a detrimental effect on the environment. They need to know this in order to insure that the electronics supplier is capable of and is supplying electronics that meets the needs of the machine in every way.

Problem Areas in Electronic Modules

Power Input

The area of the electronics that can cause machine failure the fastest is the power supplied to the electronics. The attack on the electronic package is continuous and comes from all directions. Jump starts, load dumps, back EMF, injected transients, injected EMI/RFI, ESD, voltage drops, phantom grounds, floating grounds are terms in use on a regular basis to describe the types of assaults coming in on the power input line. Each requires a different approach to "tame the monster".

Jump Starts- The fact of life is that mobile equipment suffers from two starting problems that will lead to abuse of the electronics. The equipment may sit for long periods of time; during which, the battery self discharges or connected loads discharge the battery. Mobile equipment is expected to start in a cold environment, often without the benefit of lighter motor oil or starting aids. Both problems lead to jump starting. When connecting one machine to another does not result in the engine turning over fast enough to start the engine, operators and mechanics turn to more aggressive jump starting. While starting a 12 VDC nominal system with a 24 VDC powered piece of equipment is severe, starting a 24 VDC nominal system using an engine driven DC welder is worse-start voltages can reach up to 80 VDC.

All mobile electronics should be designed to take a minimum of 60 VDC jump start for 1 minute at 25ºC on systems intended for 12 VDC nominal operation and 80 VDC jump start for 2 minutes at 25ºC on systems intended for 24 VDC nominal operation. If the equipment designer does not insure that these conditions are accounted for in the electronics design, he should be sure to insert warnings relative to jump starting in the instruction manual and apply warning decals to the appropriate location on the machine.

In addition to the Jump Start rating, all electronic controllers should operate over the range of +9 to +32 VDC. continuous voltage without time limits over the specified ambient temperature range. The typical temperature range is -40ºC to +85ºC for mobile machinery (except for displays).

Load Dumps- Load dumps occur when a high current load is disconnected from the vehicle power supply circuit. To put this in the terms of the mechanical world, suddenly blocking hydraulic flow results in water hammer. Other causes are loose connections and unstable regulators in the charging circuit.

Load dumps have been addressed by placing a MOV (Metal Oxide Varistors) or diode on the incoming power line and connecting the other end to ground. This approach may be too slow to protect sensitive electronic components in the controller (especially the MOV approach) or may not withstand the high instantaneous currents.

Today there are specific purpose suppression diodes that are faster and have the ability to withstand transients in the hundreds of Amperes.

When coupled with a pre-regulator design incorporating a BJT (Bipolar Junction Transistor) with a maximum rating higher than the highest expected transient, the use of a specific purpose suppression diode will result in a very robust protection of the power supply section of onboard electronics.

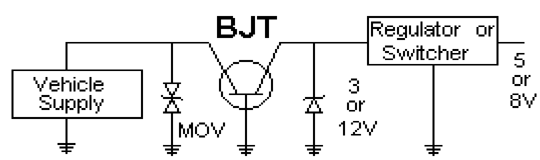

Figure 1. BJT Pre-regulator

Maximum transient protection for today's electronic controllers should be between 250 VDC to 1,500 VDC. The protection should be specified high enough to provide complete protection but not higher as the higher the voltage protection, the higher the cost and the larger the components.

Back EMF (ElectroMotive Force)- is caused by interrupting the ground connection on a powered coil. The interruption can be intentional as in the case of the breaker points on an ignition coil where the ignition coil is designed to create a back EMF of 30 to 50 kV in the secondary to fire the sparkplugs. The interruption may be unintentional as found when the ground wire to a coil is broken or when someone places a pressure switch in the common ground return wire to shut off a solenoid valve in the event of overload in the circuit.

A 12 VDC coil can produce an instantaneous voltage of hundreds of volts at over 7 Amperes. The larger the coil current during operation the higher the back EMF current. The more windings and iron in a solenoid the higher the back EMF voltage. The worst case is a high current solenoid that is large with a high winding count and a massive iron core.

Back EMF can often be suppressed to acceptable levels through the use of a fast recovery diode (flyback diode). These diodes should have a response time of 10 nanoseconds or faster. The current rating should be large enough to handle the peak current. (Note: the peak current rating is not the same as the sustained current rating.) Suppression diodes should be located at the offending coil. Often slower (and lower cost) diodes can be applied when the suppression is done at the coil.

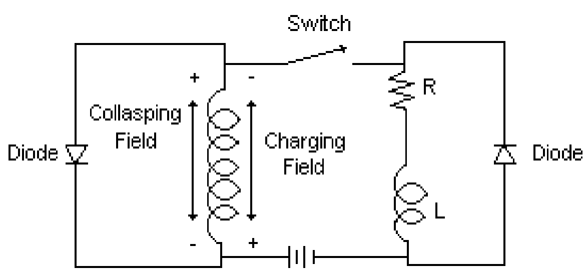

Figure 2. Back EMF

Injected Transients- Injected transients are of interest for two reasons. The first is survival when transients are injected onto the battery supply line leading to the electronic controller. This most often occurs when the supply line is co-located with a line that has a heavy load switching on and off. The co-location can be the result of both wires being included in the same cable bundle or the wires being placed alongside of each other for a significant distance. The second reason for interest is the requirement for testing of tolerance to Injected Transients to meet SAE, CE, and other standards.

The simplest method of handling injected transients is for the designer to separate the offending wires. The electronics manufacturer needs to place sufficient suppression into the input supply circuitry to conduct the transients to ground. This is done through the use of diodes, capacitors, and ferrite suppression beads. The exact design depends on the nature of the injected transients.

Injected EMI/RFI (ElectroMagnetic Interference/ Radio Frequency Interference)- Injected EMI/RFI is the electromagnetic and radio frequency interference picked up by the supply cable. The pickup may be the result of an emitter being placed close to the supply cable or the supply cable being the correct length to act as an antenna for the primary frequency or a harmonic of the transmitter frequency. The transmitter is not always an intended radiator.(radio communication transmitter). The transmitter could be another microprocessor based control, data communication line, arcing connection or other generator of high frequency noise.

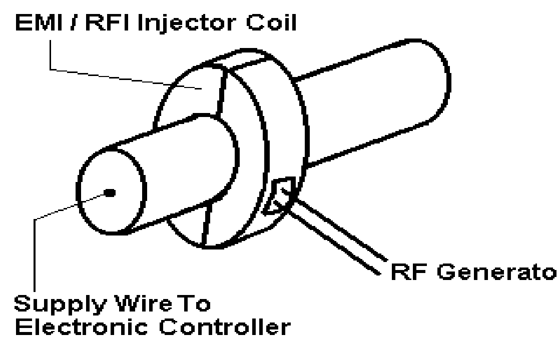

Figure 3. Injected EMI/RFI

The suppression of injected EMI/RFI is similar to the suppression of injected transients. However, the components generally are smaller with higher frequency response. This may result in circuits with two capacitors connected from the supply input to ground. One for the lower frequency injected transients, and a smaller capacitor for the injected EMI/RFI. The typical method of controlling injected EMI/RFI is to either block it from entering the controller through the use of a low pass filter in series with the input supply or to use a high pass filter to filter the EMI/RFI to ground.

ESD- Electro Static Discharge is the result of someone or something touching the input supply after having become charged. The charge is rapidly dissipated through whatever component has the lowest voltage resistance. The charge is created by the rubbing together of two objects such as nylon clothing against a nylon seat. When the charged body (the person wearing the clothing) touches the power input pin, the charged body tries to bring the controller to the same potential instantly. The result is a high instantaneous current that can damage electronic components. The voltage causing the instantaneous current can reach several thousand volts. The insidious part of the problem is that the damage may not show up immediately; but, may result in a premature failure later

The general method of controlling ESD is to use capacitors across the power supply line to ground. The capacitors take the rapid high voltage charge and then discharge it slowly after the potential has been reduced

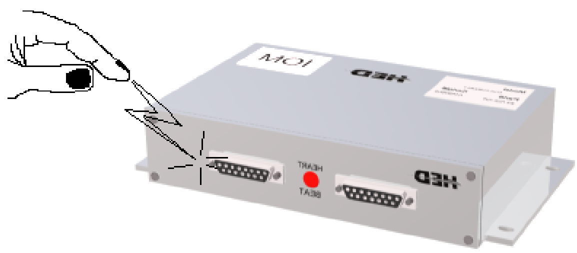

Figure 4. ESD damage

Voltage Drops- Voltage Drops generally do not damage the electronic controller but, often cause the electronic controller to temporarily shutdown or in extreme cases lock up. Voltage drops are usually caused by the sudden addition of loads and the inability of the generating/battery system to respond. The response problem may result from the fact that the sudden load is closer to the controller than the generating/battery system.
The drops are reduced through the use of electrolytic capacitors and coils to supply power during the voltage reduction and the use of watch dog timers to insure that the microprocessor does not lock up.

Phantom Grounds- Phantom Grounds are often confused with Floating Grounds. Phantom Grounds rarely cause trouble for the power supply section of an electronic controller. A Phantom Ground is an alternate path to ground that is not anticipated in the equipment design

Floating Grounds- Floating grounds are ground conductors that are not at true ground for the mobile equipment.. They are often caused by poor ground connections at the point of connection to the battery or frame. Occasionally the problem is the result of the machine frame not being a good electrical conductor because of assembly methods.
Floating Grounds can only be corrected by the machine builder using good design procedures.

Signal Inputs

The Signal Inputs of an electronic controller can be problems in two ways. One is failure of the input through damage and the second is improper operation of the electronic controller through acceptance of improper signals.
The component damaging causes are some of the same ones that cause problems with the Power input. They are: ESD, Injected Transients, and the new problem of over ranging of the input signal. The improper operation causes are Injected Transients, Injected EMI/RFI, and Floating Grounds.

ESD- The causes of ESD are the same as in the Power Input. The cure is the same-capacitors from the input line to ground. The only difference is that the protection has to be better as the signal inputs are generally more sensitive to the high currents caused by Electro Static Discharge.

Injected Transients- While Injected Transients can reach voltage and/or current levels sufficient to cause permanent damage to the signal input, the most common result of Injected Transients is creation of false signals.
Injected transients are best controlled prior to entering the signal input pin. The use of twisted pairs and shielding, as necessary, is recommended. If the signal of interest is not a rapid response signal, electronic filtering of the input can help. Additional relief can be obtained through the use of averaging in the software and various signal qualification schemes.

Over Ranging of the Input Signal- 0 to 5 VDC analog inputs should be protected for withstanding direct shorts to battery. Digital inputs should be able to withstand direct shorts to +battery and –battery. Negative spike protection to 1,000 VDC should be provided on all inputs.

EMI/RFI-EMI/RFI on the incoming signal leads can cause both false signals and the EMI/RFI can be carried to other parts of the electronic controller where the stray frequencies may find a resonant circuit and cause many types of problems.
The best way to handle stray EMI/RFI on the input leads is to first prevent the reception of the stray EMI/RFI through the use of twisted pairs, shielding, and low impedance signal sources where possible. Once the EMI/RFI enters the electronic controller, input signal filtering is necessary.

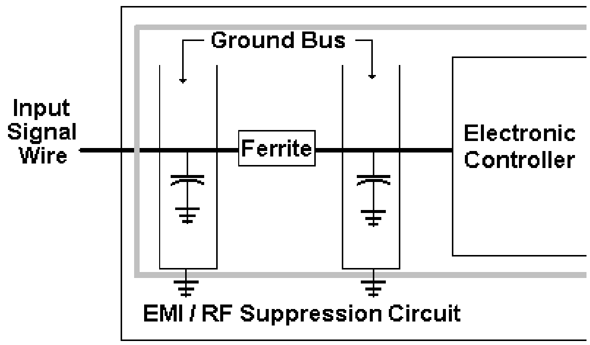

Figure 5. EMI/RFI Filtering

Floating Grounds.- Floating grounds that result in the sensor ground being at a different potential in relationship to the electronic controller ground will cause inaccurate readings in analog circuits and failure of a digital circuit to recognize a change of state. (Turning off or turning on.)
Floating Grounds must be corrected by the machine designer.

Signal Outputs

Signal Outputs includes the outputs that supply analog signal level outputs to other instrumentation and electronic controllers, digital signals to other instrumentation and electronic controllers, and data communications links. Signal outputs are susceptible to damage from ESD, Injected Transients, Over ranging of the input signal, and excessive loads. Since data signal outputs and inputs are generally common, they will be covered together here. Signal outputs of a digital nature can also generate RFI.

The protection methods for ESD, Injected Transients, and Over Ranging of the Input Signal are the same as for Signal Inputs. The only difference is the compromise needed to prevent distorting the received or transmitted data signals.
With data transmissions, it is necessary to prevent the radiation of RFI from the data transmission wires. While twisted pairs and shielding can be used to reduce the amount of RFI radiated, it is better to reduce the amount sent out the data connections. Because data is generally transmitted as a square wave, the amount of time between an “off” signal versus an “on” signal is purposefully kept to a minimum. (The higher the data rate, the quicker the signal has to change states.) Today’s solid state electronics can change state at amazing speeds. This virtue can also be a problem. The quick rise time between “off” and “on” results in RF generation that will exit the electronic controller on the data transmission lines. The way to reduce the RFI is to reduce the rate of change from the “off” state to the “on” state. This is done through the use of slew resistors on the data transmitter chip. This is a “pennies” solution to a sometimes difficult problem and it eliminates the need for expensive shielding of the data cables.

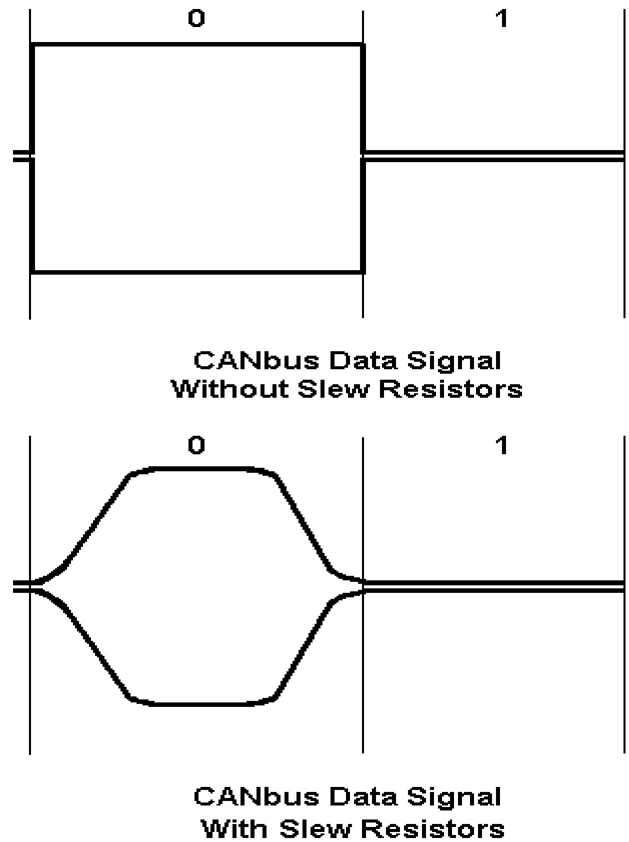

Figure 6. Data Signal with Slew Resistors.

Power Outputs

Controlled power outputs are by far the most damaged item on electronic controller applications. Fortunately electronic component design has progressed to the point that most damage causes can be addressed economically. The two largest causes of failed outputs are Back EMF and Current Overload. Outputs also sometimes need prevention of RFI emissions.

Back EMF- is caused by interrupting the ground connection on the powered coil attached to the output. The interruption may be unintentional as found when the ground wire to a coil is broken or intentional when someone places a pressure switch in the common ground return wire to shut off a solenoid valve in the event of overload in the circuit.

As stated before, a 12 VDC coil can produce an instantaneous voltage of hundreds of volts at over 7 Amperes. The larger the coil current during operation the higher the back EMF current. The more windings and iron in a solenoid the higher the back EMF voltage. The worst case is a high current solenoid that is large with a high winding count and with a massive iron core. BE PARTICULARLY CAREFUL OF THESE CONDITIONS.

Back EMF can often be suppressed to acceptable levels through the use of a fast recovery diode (flyback diode). These diodes should have a response time of 10 nanoseconds or faster. The current rating should be large enough to handle the peak current. (Note: the peak current rating is not the same as the sustained current rating.) Suppression diodes should be located at the offending coil. Often slower (and lower cost) diodes can be applied when the suppression is done at the coil.

Current Overload- Today the availability of thermally protected FET (Field Effect Transistor) switches has reduced the problem of direct shorts to ground at a reasonable price. However, the Thermal FETs are not fool proof. It is possible to operate the units in an area of current draw that will result in damage to the unit before the thermal protection can react.

Prevention of RFI Emissions- Any output that has rapid change of state (i.e., off to on) has the ability to emit RFI. To prevent the emission of RFI, it is necessary to either prevent the generation of RFI or to prevent the RFI from having suitable conditions to escape the system environment. Preventing generation is by far the most reliable method. The use of capacitors and resistors on either the output stage or the driver stage, along with resistors as needed, is recommended. (See Figure 6 above.) If RFI is generated, emissions can be reduced through the use of twisted pair cable, shielding of the cable, the use of a low impedance load, or a combination there of. Often the addition of a flyback diode to suppress back EMF is sufficient to also suppress most of the RFI output.

Displays

Today, there are very few mobile equipment designs using LED (Light Emitting Diode) displays due to the difficulty of reading the red LED in sunlight. The most common display used is LCDs. (Liquid Crystal Display) However, LCD displays have significant problems that need to be addressed to insure survival in the field. Of the LCD displays, alpha-numeric displays have the widest temperature range- -30°C to +60°C. Graphic displays have a reduced temperature range of -20°C to +50°C. Both are subject to "sunburn". Sunburn is the destruction of the plastic polarizer (which is part of the display assembly) by the heat resulting from the concentration of bright sunlight on the face of the display. LCD displays may have their minimum operating temperature increased through the addition of heating elements to keep the display's temperature above the minimum operating temperature. Care should be take to never allow the display temperature to go below the minimum storage temperature specified by the display manufacturer. Recently there has been a move toward ¼ VGA (Video Graphics Adapter) displays. These displays have seen rapid adoption by the fuel dispenser market for displaying product sale information as well as advertisements for other products sold by service stations. This high volume use had dropped the price of the displays to a level that encourages their use by mobile machinery manufacturers. The limitation is that because the fuel dispenser market can hold the ambient temperature to a tighter range than normally seen by mobile machinery, there has not been a parallel development of the semiconductor chips to drive the display.

This lack of wide temperature range display driver chips is even more apparent with the newest display to see use in the mobile machinery market, the Electro Luminescent (EL) ¼ VGA unit. This display is available with a temperature range of up to -40°C to +85°C. The EL display has very high contrast and is readable in almost all sunlight conditions. The letters are generally the lighted portion of the display and are very readable from a distance of 3 to 6 feet at night.

Coming on the horizon are colored powdered crystal displays that have extremely wide temperature ranges with backlights and a promise of transreflectance (the ability of both transmitting light from the rear and reflectance of ambient light from the front).

Physical Environmental Conditions.

While each mobile machine has it's own physical requirements, there are minimums that should be used as a base design with revision as dictated by the application.

Temperature- Temperature specifications for mobile machinery typically are -40°C to +85°C operating and -55°C to +100°C storage. (Note the exceptions for displays listed above.) Some applications are now specifying -55°C to +125°C operating ambient. Be careful in specifying this extreme temperature range as there are limited devices available in the industry. Specifying such a wide range may result in much higher production costs and compromises on the design that may limit the capacity of the electronic controller.

Vibration- Vibration specifications vary widely and are generally based on the expected machine operation environment and shocks produced by the mobile machine. Typical minimum specifications are 3 Gs in three axes for five minutes each. Higher specifications going to as much as 10 times the 3 G specification occur. Typically the very high vibration specifications are specified in one plane only.

Shock- Shock specifications are generally at least 100 Gs with three repetitions in one or more planes. Specifying more than what is needed for survival on your specific application will result in excessive costs. However, if in doubt, go higher.

Conformal Coating- Thick conformal coating of the Silicone type is almost standard for mobile machinery. This material has better abrasion resistance, water tolerance, and vibration dampening than the old acrylic and urethane conformal coatings. Today the typical electronic controller design uses the silicone conformal coating in a typical NEMA 4 enclosure in which small diameter drain holes are located in the lowest point on the enclosure.

Sensors

The electronics supplier usually does not select the sensors. However, the electronics supplier is a valuable resource to help the mobile machinery builder to choose high reliability sensor systems. Often the electronics supplier will provide a filtered, protected power source to power the sensor,
For mobile equipment applications, millivolt output sensors are not recommended. The use of sensors with a 0 to 5 VDC signal output is recommended. For safety sensitive applications, the sensor zero point should result in an output higher than zero volts. The offset is used to determine when the sensor is bad or has a broken connection wire. For the same reason, the maximum normal operation output should be less than 5 VDC.

Some mobile machine manufacturers are using sensors with PWM (Pulse Width Modulation) outputs to the electronic controller. These signals are relatively immune to external electrical noise. The resolution of the signal sent to the electronic controller is somewhat limited.

The latest sensor scheme is the use of CAN (Controller Area Network). CAN provides exceptional noise immunity and is very cost effective because of the volume of units being made. CAN also allows the use of a pair of wires to connect an almost unlimited number of sensors to the electronics controller. Built in code checking further improves the reliability.

Summary

With attention to the requirements of the specific application on mobile machinery, it is possible to have high reliability, cost effective electronic control that will provide features and benefits that enhance the value of the machine to the user.