IBO training day – low voltage electrics in organ building

In organ building, there are normally two areas that electronic control systems are used for. The first is to deal with all the key and stop inputs. The data is then processed and transferred to where any magnets which control parts of the instrument are. In some large installations, there may be two or more locations where parts of the organ are situated. The cable connecting all the various parts of the organ is normally a four-pair cable. These have a total of 8 conductors. There is normally a requirement to have a screen (sometimes called a drain) included within the cable.

The other duty of electrical control systems, is to handle all the movements of the drawstops or stop-tab units in the console. This part of the system is normally referred to as a "capture" system. The organist can set up any stop combinations on any pistons.

System basics

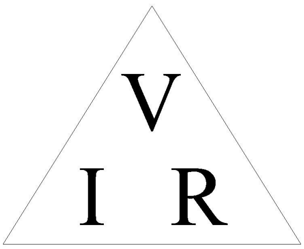
Virtually all systems follow these formats...

All inputs normally switch to positive, so the common feed is positive.
All outputs (to magnets) are normally negative, so their common return is positive.

There are some exceptions, but this keeps things simple – all feeds and returns normally wire to positive.

The generally accepted voltage for organ electrics is 15 volts. This is what any power units would be supplied as. Some heavy duty (Heuss and Laukhuff) magnets are supplied in 24 volt variances.

Load calculation



This is a representation of Ohms Law. It is shown this way to make it easier to arrange in order to find one of the missing variables.

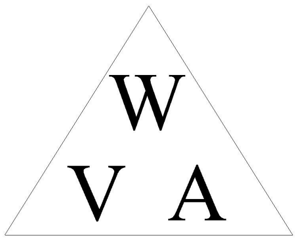
V = I x R To calculate volts
I = V/R To calculate current (in amps)
R = V/I

If you have a magnet of 30 ohms (which many console drawstop units are), and want to know the current it will draw, you can do it thus: I = 15/30. The unit uses 0.5 amps. If you multiply this by the number of stop units, you have the maximum possible current draw for the console.

If there are 30 drawstop units, there is the possibility of a load which draws 15 amps.

Power supplies are normally supplied in standard units. These may be 300 Watts, 600 Watts etc. As the trend is to state the power rating rather than give a current rating, we have another equation to look at here.

Watts Law



This works the same way as the example above.

W = V x A
V = W/A
A = W/V

So with our 30 stop console, the power consumed is 15 X 15. This works out to 225 Watts. This should be well within the capability of a 300 Watt unit. It's normal to build in a safety factor, this is your maximum projected load, plus somewhere in the region of 15-20%

These calculations are relatively easy for a console, because you know the maximum number of coils you could be driving – it's unusual for all the stops to energised at the same time though.

A large electric action organ can be more awkward to estimate though. You need to sit down with a pen and paper for a while! If it has a large number of slide solenoids, there could be a few hundred amps drawn monetarily.

Cable rating

Consideration should be given to the cable size (cross section area), certainly when returning the current for many magnets. The table below shows approximate current handling capabilities of different size cables.

Size	Current
$1mm^2$	18
$1.5mm^2$	22
$2.5mm^2$	31
$4mm^2$	41
$6mm^2$	53
$10mm^2$	75
$16mm^2$	100

Cable is available in larger sizes, but hardly ever used in organ building.

This is only a guideline, and nothing serious will happen if slightly more current is drawn than quoted. One thing to bear in mind though, is for a long cable run, the voltage will *sag* quite appreciably on a large load. It was quite common years ago, to have a transformer/rectifier unit in the organ, then supply the console from that as well as the organ. If the console had any low voltage lights or volt meters, you could see the results of large demands at the console.

It's good practise to try and locate a power supply near any large load area such as slide solenoids.

Fault finding

As is sometimes said, the bigger the problem, the easier the solution! Radical faults like the whole organ not working are most likely to be something like a power supply unit failing. Fuses are also one of the first things on the check-list.

Ciphers are a great enemy of organists (and by extension, organ builders). Assuming all avenues of physical causes have been travelled, let's take a further look. If, for example there is a cipher on the Great, try the Swell to Great coupler. If the Swell can be made to cipher on the same note, then input card for the Great can be suspected. The input cards on the Solid State Multisystem are in multiples of 16. Musicom, Taylor and Dedham Organ Systems normally have 64 way input cards. Only after establishing the fault isn't at the console end of the system, look at the output card in the organ controlling the magnet of the troublesome note.

Odd notes off can be treated the same way initially as ciphers. If a note is off on the Swell (again for arguments sake), check if it works through the Swell to Great coupler. If it does, suspect the Swell input card. If the problem can't be traced to the console end, establish the position of the output card. On a Solid State Multisystem, the outputs are grouped in multiples of 16. Musicom output driver cards are in multiples of 32. Taylor systems have plug-in cards, which normally handle 64 outputs. Some system manufacturers supply spare input and output cards with their systems – that way, the fault can be cured with a single visit. Worth sending the troublesome card back to the supplier to get a replacement for the future.

On some systems (notably Taylor and Dedham Organ Systems) you have a chance to replace the output device. To be honest though, you probably wouldn't have the devices as part of an organ builders tool-kit. Sometimes there are some unused output devices, specially at the top of the cards compass. One of these could be *poached* to replace the suspected device. Any devices that have been replaced **must** also have its suppression diode replaced too. Some burnt out components may need further investigation, as something has normally happened to bring about their demise. Missing parts of tracks around the output stages of a driver card could indicate a short – worth investigating before a replacement is put in.

Some replacement cards may need to be coded before they are inserted. Two manufacturers that use this system are Taylor and Dedham Organ Systems. This is necessary as each card has a unique coding, so the system can communicate with it

There is some good information on the Solid State Organ Systems site on diode switching troubleshooting – this is at http://www.ssosystems.com/downloads/Diode%20Coupler %20Installation%20Guide.PDF

During our open day here, hopefully we'll have resurrected an old diode switching system so various problems it has can be diagnosed. If it doesn't have any problems, I'm sure we can put some in!

Below are some tables for pre-defined currents and powers for different conditions.

Table of Amps (Voltage ÷ Resistance)

Volts \ ohms	4.5	30	32	50	60	70	90	100	120
12	2.67	0.40	0.38	0.24	0.20	0.17	0.13	0.12	0.10
13	2.89	0.43	0.41	0.26	0.22	0.19	0.14	0.13	0.11
14	3.11	0.47	0.44	0.28	0.23	0.20	0.16	0.14	0.12
15	3.33	0.50	0.47	0.30	0.25	0.21	0.17	0.15	0.13
16	3.56	0.53	0.50	0.32	0.27	0.23	0.18	0.16	0.13
18	4.00	0.60	0.56	0.36	0.30	0.26	0.20	0.18	0.15
24	5.33	0.80	0.75	0.48	0.40	0.34	0.27	0.24	0.20

Table of Amps (Amps per magnet × Number of magnets)

Number \ Amps (up to)	0.15	0.2	0.3	0.4	0.5	2	3	4	5
12	1.8	2.4	3.6	4.8	6	24	36	48	60
25	3.75	5	7.5	10	12.5	50	75	100	125
32	4.8	6.4	9.6	12.8	16	64	96	128	160
44	6.6	8.8	13.2	17.6	22	88	132	176	220
61	9.15	12.2	18.3	24.4	30.5	122	183	244	305
73	10.95	14.6	21.9	29.2	36.5	146	219	292	365
85	12.75	17	25.5	34	42.5	170	255	340	425
97	14.55	19.4	29.1	38.8	48.5	194	291	388	485

Table of Watts (Amps × Voltage)

Volts \ Amps	5	10	15	20	25	30	40	50	75
12	60	120	180	240	300	360	480	600	900
13	65	130	195	260	325	390	520	650	975
14	70	140	210	280	350	420	560	700	1050
15	75	150	225	300	375	450	600	750	1125
16	80	160	240	320	400	480	640	800	1200
18	90	180	270	360	450	540	720	900	1350
24	120	240	360	480	600	720	960	1200	1800

Table of wire thickness for < $^{1}/_{2}$V drop (sq mm)

Length (m), up to	1	2	3	4	5	10	15	20	30
Amps									
0.5	0.22	0.22	0.22	0.22	0.22	0.22	0.5	0.5	0.75
1	0.22	0.22	0.22	0.22	0.22	0.5	0.75	0.75	1.5
2	0.22	0.22	0.5	0.5	0.5	0.75	1.5	1.5	2.5
3	0.22	0.5	0.5	0.5	0.75	1.5	2.5	2.5	4
4	0.22	0.5	0.5	0.75	0.75	1.5	2.5	4	6
5	0.22	0.5	0.75	0.75	1	2.5	4	4	6
10	0.5	0.75	1.5	1.5	2.5	4	6	10	16
15	0.75	1.5	2.5	2.5	4	6	10	16	25
20	0.75	1.5	2.5	4	4	10	16	16	25
25	1	2.5	4	4	6	10	16	25	50
30	1.5	2.5	4	6	6	16	25	25	50
40	1.5	4	6	6	10	16	25	50	50
50	2.5	4	6	10	10	25	50	50	75
75	4	6	10	16	16	50	50	75	100

Suppression

Coils of wire, e.g. magnets, have a property called inductance which resists a change in the flow of current. When you switch on a magnet the current takes a short while to build up and when you switch it off it takes a short while to die down. If you use a mechanical (or electromechanical) switch to turn the magnet on and off then when you switch off you break the circuit completely. However the current in the magnet tries to carry on flowing. The current reaches the open switch and has nowhere to go. The electrons build-up until there is enough voltage to jump across the gap between the switch contacts. This will be seen and heard as a spark. The voltage can build up to hundreds or even thousands of volts. In electronic controls the transistor has replaced the electromechanical switch. However, transistors have a limited voltage capacity, often 30-60V. A voltage of 100V or more will destroy most transistors.

To stop the build-up of the voltage a circuit must be provided to allow the current in the magnet to die away. The most common method is to place a diode across the two terminals of the magnet to allow the current to flow round in a circle. It flows out of one end of the magnet, through the diode, and back into the magnet. Eventually (pretty quickly) this dies away. The diode should always be fitted so that it has the stripe towards the positive.

Electronic controls come with built in spark-suppression diodes for their own protection and in most cases you won't need to fit diodes. There are a few cases where it is necessary or recommended to fit diodes to magnets.

Where there is a break contact between the magnet and the electronics:

· Electro-mechanical relays

· Electro-mechanical tremulants where a break contact and magnet are used to produce oscillation

· Directly wired expression engines

· Some off-note/top note chests incorporate single/multi-contact relays

Suppression should be fitted to all magnets that aren’t connected to electronic controls. e.g. if an electronic capture system is being fitted to an organ with an electro-mechanical switching system then all the magnets (except the drawstops) will need to be suppressed even though they aren't connected directly to the electronics. This is because the sparks will produce interference on both the power (conducted emissions) and through the air (radiated emissions) which will interfere with the operation of the electronics. Bear in mind that some contact systems rely on the spark to keep the contacts clean.

Where a solenoid is controlled by a circuit that has a power control (e.g. slider solenoids, pull and hold coupler solenoids) it is recommended to fit diodes directly to the solenoid even though the circuit board includes suppression diodes. Power control is usually implemented by pulse-width modulation - a technique that rapidly switches the solenoid on and off. This switching will usually happen thousands of times a second. Each switch off releases more energy from the solenoid which needs to be suppressed. If the cables from the solenoid to the slider card are not short and/or thick enough then the energy will not be dissipated quickly and can cause failure of the driver. This can often be caused by the driver card/rack and the solenoid having separate feeds from the power supply. The suppression path then includes both feeds from the power supply reducing the effectiveness of the built-in suppression.

Zener suppression

Suppression diodes allow the current to keep flowing in the magnet until it dissipates. This slows the release of the magnet and can affect the repetition rate of the action. It turns out that the current keeps flowing in the magnet until it doesn't have enough energy to overcome the voltage drop of the diode. Diodes have a voltage drop of around $^1/_2$V. By increasing this voltage we can make the current stop sooner and increase the release speed and repetition rate of the magnet. This can be done using Zener diodes which are available with a variety of voltages. However they cannot be fitted across the magnet. For this reason Zener suppression usually has to be built into the control system. Some systems now come with Zener suppression as standard but find out before you buy.