How a P&G fader is manufactured

The resistive element

The key technology in a P&G fader is the use of 'co-molded conductive plastic' resistive elements that tightly bond the resistive track with the supporting plastic substrate in a single molding operation. Unlike other processes that coat a resistive track onto the surface of an existing flat substrate, co-molding embeds the resistive track into the substrate during the molding process that forms the substrate.

The manufacturing process begins with an extremely smooth sheet of aluminum, much like the very smooth aluminum cores of a 'lacquer' master disk for cutting a phonograph record. The smoothness of the surface of the aluminum will eventually determine the smoothness of the resistive element's surface.

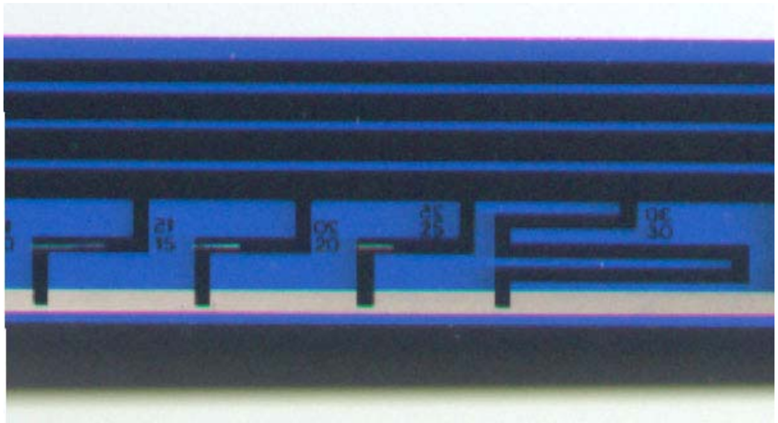
Silkscreen stencils with multiple identical images so that several faders can be processed simultaneously are used to print multiple layers of images onto the aluminum surface. The compositions of the various 'inks' are adjusted to provide the appropriate resistive and conductive traces of the fader element. The first layer printed will be on the outside of the finished substrate, and is the layer contacted by the sliding fingers of the wiper assembly. Other layers provide conductive paths similar to traces on a printed circuit board and resistive shunts necessary to create non-linear resistance tapers for audio taper and VCA taper products.

Once the silkscreening is completed, the aluminum sheet with the multiple images is loaded into a plastic molding machine that has multiple cavities aligned with the multiple screened images. The mold is heated and melted plastic is injected into the mold cavities. The hot plastic flows around and bonds to the exposed backside surface of the silkscreen patterns, forming a unitized structure with the fader pattern molded into the surface of the substrate. The mold is cooled to solidify the plastic, and then the molded elements are peeled from the aluminum sheet.

The resulting smooth surface of the track is a mirror image of the aluminum sheet, yielding excellent contact with the sliding wire brushes for noise-free operation. The rigid support of the resistive track provides low wear and long life.

The silkscreen printing process does include several variable factors such as the accuracy of the coating thickness and the variation of ink conductivity that cause variations in the final resistances on the substrate pattern. These variations are reduced to the specified limits in a final calibration process. The resistive elements are deliberately manufactured on the low side of the resistance tolerance so that they can be trimmed by cutting away part of the trace to raise the resistance to the desired value.

The substrate is placed in a test fixture that can measure the resistance at various fixed points along the track. For linear tracks, the side of the resistive element is cut away to yield the desired resistance at each of the test points. For non-linear tapers that have multiple shunt taps, each shunt is trimmed to yield the appropriate curve.



Once this calibration process is completed, the voltage variation from one end to the other will be correct, but the resistance looking into the terminals may be other than the desired nominal value for the device. The final calibration step is to trim one extra resistor bridge across the terminals that sets the overall resistance to the desired value.

Penny & Giles uses both automated laser trimming and manual trimming, depending upon the product line. Both methods provide finished products that meet the published specifications.

The mechanical components

The resistive element is only half the story for a fader. The other half includes the sliding wiper contacts, the slider assembly with its bearings, the rods upon which the slider glides, and the enclosure that supports everything.

The sliding wiper assemblies are composed of several parallel spring wires each about ½" long. One end of the wire is formed into a 'V', with the tip of the V contacting the resistive track, and the other end of the wire is soldered to a mounting plate to create a cantilever. The multiple wires provide redundant contacts to minimize electrical noise when the slider is moving.

(The cantilever mounting produces slightly less drag when the wire tips are sliding toward the mounting plate, which is typically in the direction of increasing attenuation.)

The body of the slider is supported on the rods by press-in bushings or bearing surfaces molded into the slider. The design typically includes two tight-fitting bushings on one rod to properly position the slider and a looser bearing surface on the second rod that just holds the slider parallel to the substrate. Various bushing materials are used, including Teflon (white), Delrin (brown), and Tercite (blue).

The rods anchor into the end caps with press mounts or screws. Some designs include a 'shed' to divert any spilled liquids or dirt away from the rods and bushings.

Auxiliary switches

Some applications require one or more switching functions on the fader to facilitate cueing of programs and/or starting of machines. One form of switch uses a gap in a pattern on the resistive element to sense when a fader reaches a desired position. This technique requires two traces on the substrate, one continuous pickoff track and another discontinuous position-indicating track, and a pair of contact fingers.

The second switching technique utilizes microswitches that are activated by the slider. Protrusions on the slider body contact the activating arm of the switch and toggle the switch.

Some switch functions, referred to as 'Overpress' switches, are activated by moving the fader knob beyond the normal range of travel against a spring-loaded stop. The spring loading can be provided by the switch's return spring or by a separate beryllium copper spring plate.

Special considerations for motorized faders

Fader automation systems require additional functions not usually required for manual operation, including touch sense, a position-sensing track and a motor drive.

The touch sense function utilizes a conductive coating on the knob that creates an electrical path from the operator's finger to the metal tab upon which the knob is mounted. The metalized path includes not only the top and sides of the fader, but also a conductive path to the tip of the metal slider assembly at the underside of the fader. If the knob is repeatedly removed, the plating in the knob's mounting slot may be worn away enough to break the electrical circuit.

On the slider assembly, the touch circuit is completed by a wire that is attached from the slider's metal tab to a set of wire brushes that ride on the track normally utilized to pick off the switching function described above. Various models attach the wire from the brush assembly to the metal slider frame with either solder or conductive epoxy. Servo problems that repeatedly slam the slider against the end stops of the fader can fracture the conductive epoxy bond, leading to intermittent touch signals.

The 'touch sense' circuit usually includes a free-running oscillator that is detuned by the extra capacitance of the operator's finger and body. A frequency-detector circuit senses the frequency shift and toggles a digital output to the automation system. Early motorized faders included the touch sense circuit within the body of the fader, but more recent designs place this function on a nearby circuit board.

An automation system requires a readout of the position (and velocity) of the fader so that a servo system can move the fader to any desired position quickly and accurately. This requires a dedicated linear resistive track within the fader for position information. For non-VCA systems, the audio signal is also passing through the fader, requiring one or two (for stereo) audio tracks, a position track and a touch track. Not all fader designs can accommodate all these tracks and the associated sets of slider contacts (up to 3 ½ pair for stereo with touch.)

The position track usually extends beyond the ends of the normal mechanical travel to assure that the servo system always sees a gradient so that it can determine the position and the velocity (speed and direction) of the fader. (If the position track had an extended region of zero volts or full-scale volts at the bottom or top of the stroke, the servo could not accurately park the fader at the ends. Since some fader servos operate to an accuracy of a thousandth of an inch, any 'flat' area is unacceptable.)

The drive system consists of a small motor, a drive cord or belt, an attachment device to hold the drive cord or belt to the slider and assorted pulleys.

Motors fall into two general categories – iron core and ironless. A conventional iron-core motor contains an armature consisting of a metal core surrounded by copper wire windings that attach to the commutator. The iron core adds considerable rotational inertia to the rotor, which reduces acceleration and deceleration. In addition, the iron core raises the inductance of the rotor, which makes rapid changes in current more difficult. The inductance also increases brush sparking, which reduces brush life. The advantage of the iron core motor is low cost.

The ironless motor has no metallic core. The copper windings are shaped into a self-supporting basketlike structure that spins within the magnetic gap of the motor, yielding low inertia and low inductance. To illustrate the performance capability of an ironless motor, the motor utilized in the Flying Faders automation system turns 4 ½ turns to move the fader from one end to the other. A fast jump from end to end requires only 80 milliseconds, during which the motor accelerates from a dead stop to 4000 RPM and then brakes to a stop at the other end of the fader.

Several different drive cord arrangements have been developed. The simplest version places the motor at one end of the fader and loops a cord or toothed belt around the motor drive spud and an idler pulley at the other end of the fader. The cord is attached to the side of the fader tongue.

The toothed-belt version includes an interesting twist, literally. The toothed belt is twisted 180 degrees as it runs from the drive pulley to the idler pulley. This places the smooth backside of the belt against the idler pulley to provide a smooth feel. The belt inversion continues to the anchor point on the fader slider. As a result, the two ends of the belt at the anchor point are of opposite orientation- the belt end pointed toward the motor has teeth in, and the end pointed toward the idler has teeth out.

Several fader versions utilize a cord or string as the transmission medium. These designs use multiple wraps of cord around a grooved motor pulley. The wraps around the pulley store enough string for one full stroke of the fader. On some designs the string is anchored at the center by passing the string through a transverse slot in the pulley. This prevents the string from migrating along the helix if the string ever slips.

The grooves in the drive pulley are fairly shallow to achieve the closest possible stacking of the turns of cord. As a result, there is a potential that the cord may pop out of the groove if there is any tension shock in the drive cord that stretches the string, for example when the slider slams against the end stop at high speed. Various resilient and fixed devices hold the string in the pulley groove to avoid any jumping.

If the motor is placed at the side or bottom of the fader, additional pulleys are required to properly route the string. These pulleys are typically constructed with a V-shaped plastic flange riding on a ball bearing support. Various screw and riveting techniques are employed to mount the pulleys to the fader shell and brackets.