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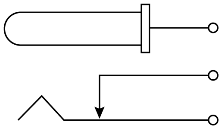
PROTEK POWER
NORTH AMERICA

Direct-Current Connectors:
An Overview of Options and Key Parameters



Introduction

The single most prevalent design modification request that we see at Protek Power is that for an alternate DC output connector. The DC connector, after all, is the one electromechanical interface between your design and its power source. There are innumerable connector options on the market spanning a wide range of applicability. This article aims to take a closer look at a few of the more common connector schemes used in the power supply industry, and the critical parameters that effect their use.

Key Parameters

Connector datasheets and specifications are full of detail, and it can be overwhelming to determine what really matters, and which connector is superior to the others for a given application. We will discuss all of the most important parameters (pertaining to the power supply industry) in this article:

- Mechanical
    - Physical Size & Configuration
    - Insertion Force
    - Retention Strength
    - Strain Relieving & Molding
    - Mating Cycles
- Electrical and Thermal
    - Contact Resistance
    - Current Rating
    - Voltage Rating
    - Temperature Rating
    - Conductor Count
- Features
    - Locking
    - Keying
    - Filtering
    - Ingress Protection
- Production Feasibility
    - Cost
    - Tooling

The resistivity of Gold is nearly 50% higher than that of silver or even copper. Gold is favored in the construction of electrical connector contacts primarily for its resilience against tarnishing, but also in part for its malleability.

(We will take a closer look at this in the next sections)

Did You Know?

Mechanical Parameters

One of the first considerations in the selection of an application appropriate connector system is the physical size and form of the connector and its mate. Engineering trade off's frequently need to be contemplated as, generally speaking, bigger and bulkier connectors perform better electrically and thermally than do low-profile connectors. Another important consideration when considering the size and form of a connector system, is the intended end user and the ease-of-use or familiarity with a particular connector system.

Other key mechanical parameters are a connectors insertion force and retention strength. How much energy should be required to either seat the connector, or to remove it from its mate? In most applications, it is not desirable for insertion of a power connector to be a difficult task, and yet it may be desirable to make it difficult to unseat the power connector without intent. Many strategies have been employed in the design of common connector systems toward the goal of controlling these parameters, some of which will be highlighted later in this article.

If a connector assembly is expected to withstand significant amounts of physical manipulation such that the cable is likely to be moved , bent, or twisted regularly, it is important to employ an appropriate strain relief system to prevent the contact assemblies (crimp or solder) from breaking or otherwise separating. A well implemented strain relief redirects an externally exerted force on the cable away from the contact assembly to a more mechanically rigid location such as plastic or metallic connector housing. Solder creates an excellent electrical connection, but a rather poor mechanical one. Often times a strain relief can be molded around the connector providing for a durable support system and a "finished" aesthetic. Molded strain relief systems often require the design of special tooling which requires equipment and engineering resources and therefor has an effect on total system cost. Many connectors have strain relief systems built in that can be set during assembly.

Finally, connectors do not last forever. One major parameter to consider when selecting a connector system is how frequently the connector is expected to be inserted and disconnected over the course of the products life. Connectors have a rated number of mating cycles, the number of times they can be connected and disconnected from the mate before the wear on the connector is significant enough to bring other mechanical or electrical parameters out of specification. Mating lifetimes vary widely from as few as a dozen cycles for some specialty connectors to tens of thousands of cycles for durable connectors that are intended for tens of connections a day, every day, for several years. It is important to ensure that the rated mating lifetime is aligned with the expected usage.

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A Closer Look at Contact Resistance

Most of the electrical and thermal parameters that will be discussed in this article are very closely associated with the connectors contact resistance. For this reason, it is beneficial to discuss this key parameter in detail first. Going back to the basics, recall that an electrical elements resistance is a measure of its tendency to impede the flow of electrical current under the influence of a given electrical potential, as defined by Ohms law:

$$R = \frac{V}{I} \qquad [1]$$

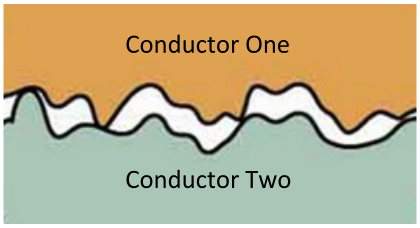
Resistors convert electrical energy to thermal energy and dissipate that energy into the environment as heat. The amount of energy dissipated as heat per unit time, is directly proportional to the square of the current through the resistor. The constant of proportionality is the resistance as defined by Joules law:

$$Q = I^2 R \Delta t \qquad [2]$$

Lastly, an elements resistance is a function of its material properties and its geometry as given by Pouillet's law:

$$R = \frac{\rho l}{A} \qquad [3]$$

Where ρ is the resistivity of the element as determined by its material composition, l is the length of the element parallel to the flow of electrical current, and A is the cross sectional area of the element, orthogonal to the flow of current. In examining equations 1 through 3, notice that both the voltage-current relationship of an element, and the tendency of that element to generate heat are impacted by the elements material composition, and its geometry.



All real circuit elements have some finite resistance, even those which we typically consider to be "perfect conductors" such as copper wires or circuit board traces. The contacts within a DC connector are no exception. In fact, the electrical resistance of an interface between two electrical conductors formed by physical contact alone, will generally have a much higher resistance than a continuous piece of either conductor of equal length. This, among other reasons, is due largely to the fact that no real metal surface is perfectly smooth. The interface between two real pieces of metal at a microscopic level is typically littered with imperfections as illustrated to the left. If we consider the interface to be a finite element, and model that element as a resistor, notice that that the effective surface area orthogonal to flow of current from one conductor to the next is significantly reduced by these imperfections. Decreasing the effective surface area results in an increase is the resistance of the element augmenting voltage drops across and heat dissipation by the element for a given electrical current. This is one reason that Gold is often a favored contact material, its malleability allows the imperfections to be flattened out somewhat under the application of marginal pressure. Consider further, that the actual macroscopic element may have a contact point with a smaller cross sectional surface area than the conductor itself to begin with, before even considering the interface imperfections.

Current Rating and Temperature Rating

A connectors current rating and temperature rating go hand in hand. In fact, the current rating is determined by how much heat is generated as current passes through the contact resistance. The idea is to prevent any part of the connector including the contacts and the housing from reaching a temperature which will cause damage such as melting or burning. Returning to equation 2 above, if we assume a connector has a fixed contact resistance, then the heat generated per unit time will increase with the square of current. There exists a level of heat rise as caused by electrical current that is considered unacceptable (typically around $\Delta\ \theta = 30°C$). The superimpositions of the heat rise associated with rated current flow and the maximum rated ambient temperature must be low enough to reasonably prevent the possibility of burning or melting material.

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Current Rating and Temperature Rating Continued

Consider just how non-ideal most connector systems are for heat exchange. The heat sources (contacts) are almost always fully encapsulated in a housing, preventing convection based heat exchange. Further, these housings are very often made of plastic, impeding the transfer of heat via radiation. In fact, the only real path that heat can use to escape the contacts is back up the cable via conduction. This again solidifies the idea that in general, bigger and bulkier connectors (with bigger and bulkier cables/conductors) exhibit better electrical and thermal performance.

Current handling capacity and maximum ambient temperature ratings are improved by reducing contact resistance, and minimizing the thermal impedance between the contacts and free air. Both of these tasks are addressed via selection of materials and geometries.

Voltage Rating

A connectors voltage rating is determined by the strength of the dielectric that separates the current carrying conductors as well as the geometry of the conductors within the connector and of course their proximity to one another. There exists a electric field strength at which dielectric materials, including air, experience a sudden and drastic decrease is electrical resistivity. This phenomena is frequently referred to as breakdown. The geometry of two conductors held at different electrical potentials determines the shape of the electrical field between them. The magnitude of the potential difference, along with the physical proximity of the conductors determines the strength of the field. Field strength increases with increasing potential (voltage) and/or with decreasing separation distance. The field strength at which a breakdown occurs is determined by the material properties. This simple relationship becomes a bit more complicated with alternating currents but is largely sufficient for describing DC behavior.

Once again we see that larger geometries and carefully selected materials facilitate higher ratings. Nominal voltage ratings tend to be rather conservative when compared to the actual breakdown voltages associated with the materials and geometries of the connector. Quite often a connectors rated dielectric withstand voltage is a mere 75% of the actual breakdown voltage, and the nominal rated working voltage is roughly 25% of the breakdown voltage. This does not mean that it is OK to exceed rated voltages. These margins exist to allow for headroom in the event of transient voltage spikes, and to improve long term reliability.

Conductor Count

Perhaps a more fundamental consideration is the number of conductors needed to facilitate the power transfer and any other required functionality. The minimum number of conductors is of course two, but more conductors may be required to improve current handling capacity, provide an earth ground connection to the end product, implement a remote sense feature, facilitate EMI shielding, facilitate redundancy, etc.

Additional Features

Some applications may require a bit more than a path for current from their power connectors. In some cases, high retention connectors may not be enough to provide an adequate assurance than the connection will not be inadvertently broken. For cases when uninterrupted power is critical, and the power supply is operating in an environment that is not void of motion or human error, it may be best to select a locking connector. There a great number of different locking connector schemes, and many different power connector form factors can be offered with locks.

More often then not, it matters what orientation a connector is mated in. To prevent crossing signals or creating reverse polarity events at the inputs of end devices, it is often desirable to have a keyed connector, one which can only be mated in one orientation. Not all connectors are inherently keyed. There are plenty of connectors on the market that will allow users to seat them in a number of different (and perhaps undesirable) orientations.

There are numerous other features available in the DC connector market that can improve the performance of the overall end product. We see occasional requests for connectors with certain ingress protection ratings, attesting to the connector system’s ability to keep water or dust particulate out of areas that it does not belong. Some connectors are even offered with built in filters that improve electromagnetic compatibility.

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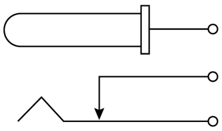

Production Feasibility

As is typical for many types of products, added functionality and/or deviation from a standard or norm will have an associated cost. Many connectors require the use of special tools for assembly, and more complex connectors take more labor to assemble. For this reason, special connectors can sometimes be difficult to implement on very low volume production runs.

Common Connector Systems

A handful of connector systems have emerged as the predominant connectors of choice in the power supply industry based on their versality and low cost. Most off-the-shelf power supplies available for purchase today for use in commercial, industrial or medical markets will use one of these connectors.

USB

USB type connectors are widely used for very low voltage commercial applications. USB type connectors are favored for their low profile, low cost, and ubiquity. They are easy to source, easy to use, and can facilitate the transfer of both power and data. USB type connectors are most typically used in 5V systems and generally cannot accommodate currents in access of 5A.

Barrel Plugs

Probably the most common connector seen at the output of low-power AC/DC adaptors such as wallmount power supplies and small desktop adaptors is the barrel plug. Barrel plugs come in serval different form factors but are typically only suitable for SELV level voltages (up to 60VDC) and typically are not adequate for carrying more than 5A of current. Some connector manufacturers have designed high-current barrel plugs capable of carrying as much as 12A continuously.

The most common barrel plugs are 5.5mm in outer diameter, either 2.1mm or 2.5mm in inner diameter, and typically between 9 and 12mm in length. These plugs come in many more shapes and sizes than these standard dimensions, can often be ordered in right-angle or straight configurations and may include additional features for improved retention strength such as fork-tongue inner contacts and/or double beveled (kinked) sleeves. Barrel plugs are typically rather mechanically rigid and frequently have mating cycle ratings as high as 5 or 10 thousand insertions.

Mini-DIN and Similar

Mini-DIN connectors, or similar connector systems are often used for lower-medium power level applications where the barrel plug is no longer appropriate, or in applications that may require locking systems, higher conductor counts, or continuous shielding. These connectors are commonly appropriate for power adaptors rated between 100W and 200W. There are numerous pin-counts available as well to facilitate extra signals such as Earth Ground or remote sense.

Crimp-Terminal & Housing Type

For higher power applications (greater than 200W) it is typically necessary to employ a crimp-terminal & housing type connector scheme. These connectors can be as big or as small as the application demands, both physically and in terms of current handling capacity. If more current handling is required, more pins can be used. Connectors like these commonly include locking and keying mechanisms but will also usually exhibit lower mating cycle lifetimes. Again, one of the major benefits is low cost.

What Connector Scheme is Best for Your Next Design?

At Protek Power, both our sales and our technical support staff are available to help our customers identify the most appropriate connector scheme for their application. Talk to one of our team members today about your project and we can work together to identify the best power connector system for your design.

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