**ODU WHITE PAPER** 06 | 2023

# CONTACT TECHNOLOGIES FOR EV CHARGING APPLICATIONS

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# ABSTRACT

Most major countries have now established plans for moving towards elimination of gasoline powered vehicles within the next 10-15 years, with the primary replacement being fully electric vehicles (EV's). As with many emerging industries, global standards for EV's lagged behind the actual development and production of vehicles, due in part to the intense competitive pressure for manufacturers to be among the first to market. In many cases, government mandated timelines for the switch to zero-emission vehicles have further increased the pressure on manufacturers. This paper looks at the impact of this rush to market, particularly as it applies to the interface between the charging station and vehicle.

# THE MOBILITY REVOLUTION

As of 2023, the majority of vehicle manufacturers throughout the world have introduced zero-emission EV product lines intended to combat the threat to humanity presented by carbon emissions. In part, this rapid development of EV's has been sparked by government mandates. For example, in August 2022, California regulators passed rules for a phased approach to the elimination of gas-powered vehicles beginning in 2025 and ending with a complete sales ban by 2035. Of course, it will likely be several years after that before all combustion-engine vehicles are gone from the roads; but as gas stations become increasingly rare, so too will the vehicles that depend on them.

One consequence of this urgency to market is that no global standard has been adopted by manufacturers in different countries for the electrical interface between vehicle and charger. This has resulted in the need for many charging stations to offer multiple connector types (Figure 1). This, in turn, imposes a requirement on manufacturers of electrical contacts used in the diverse types of plugs and sockets, to

Fig 1. Multiple EV Charging Interfaces

offer a wide variety of contacts. ODU-USA, Inc. is one such manufacturer, and we will refer to their contact product lines in this paper when examples are needed.

# CHARGER INTERFACES

There are different types of charging methods. However, conductive charging represents the largest share now and will continue to do so in the future.

Alternative technologies such as static or dynamic inductive charging are less efficient. Battery-swap systems do not have this disadvantage, but they do pose other challenges. Since there is no standard across vehicle manufacturers, widespread acceptance of battery-swapping as a re-charging method is rather unlikely. Such an approach would require charging stations to keep a supply of numerous types of battery in stock, and to ensure that those batteries remain at full charge.

Accordingly, deployment of contact-based charging interfaces – plugs and sockets – is clearly leading the way. However, the rapid market development and regional differences have also led to several different charging standards (Figure 2).

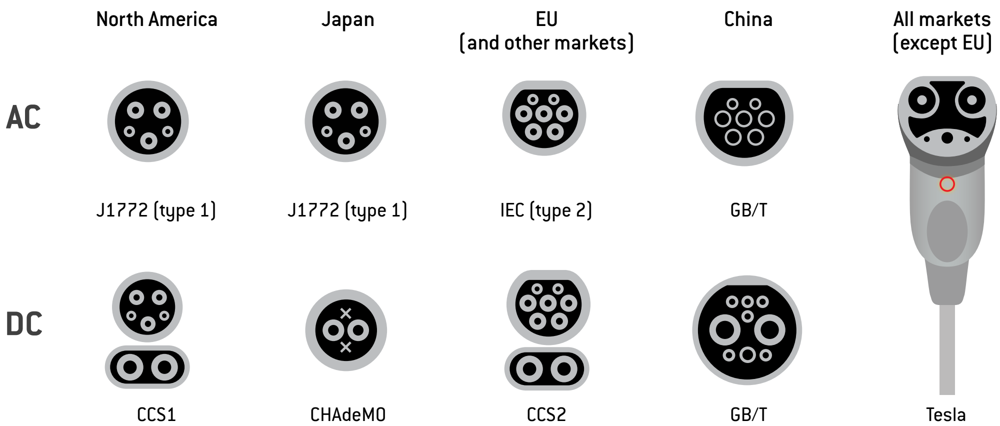



Fig 2. Diverse Pinouts for the EV-Charger Interface

The charging standard developed by Tesla itself occupies a special position. While the other interface specifications have emerged from standards bodies, Tesla took matters into its own hands. Tesla did not invent e-mobility, but it took the right steps to make it accessible to the market. What was missing was the charging infrastructure, which the company tackled on its own, without further ado. Tesla's charging network is now an integral part of the market.

In the meantime, Tesla has made its charging standard publicly available and perhaps even wants to displace other established standards with its so-called NACS (North American Charging Standard).

There is also movement in the Asian region in the area of charging standards. The Japan-based CHAdeMO Association and the China Electricity Council (CEC) are working together on a new, more powerful charging standard, better known as "ChaoJi" (Figure 3).

The new charging standard for the Asian region is expected to be more powerful than the existing standards GB/T 20234-3 (China) or CHAdeMO2.x.  A significantly more compact size compared to the Combined Charging System and charging currents of up to 800A at voltages of up to 1.5kV (cooled) are under discussion. This is intended to meet the ongoing requirement for shorter re-charging times.

Fig 3. "ChaoJi" EV charging  adapter from ODU

With the new ChaoJi interface, companies are also gearing up for bidirectional charging or V2G (Vehicle to Grid). The aim here is not only to store the energy in the battery of the electric vehicle for later driving, but also to be able to extract it again as needed. In this way, the battery capacity of the vehicle can be used, for example, to supply the home as well as to stabilize the grid in the event of increased energy demand (Figure 4).

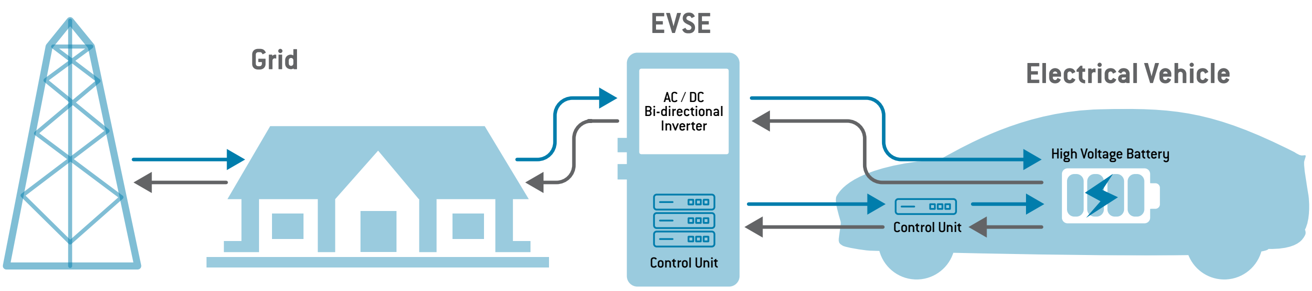



Fig 4. Bidirectional charging system  / vehicle to-grid (V2G)

There are a large number of charging interfaces and thus a wide variety of requirements. What they all have in common is the high stresses caused by current and voltage, as well as the demand for a reliable and durable charging connector - regardless of the standard on which it is based.

But how do you recognize a reliable charging interface and distinguish it from less suitable systems?

# CONTACT TECHNOLOGIES FOR CHARGING INTERFACES

There are a variety of contact technologies on the market, but not all are equally suitable for the high power and frequent mating/de-mating requirements of vehicle charging.  Some of the most common technologies are described in more detail below.

## 3.1 Turned contacts

For lathe-turned contacts, the contact socket is usually designed as a single piece with split-finger segments that allow the slightly oversized pin to be inserted and held securely (Figure 5). In some cases, the pin can be further supported by an additional spring element  on the socket side.

The ODU TURNTAC® family offers a good example of turned contacts.

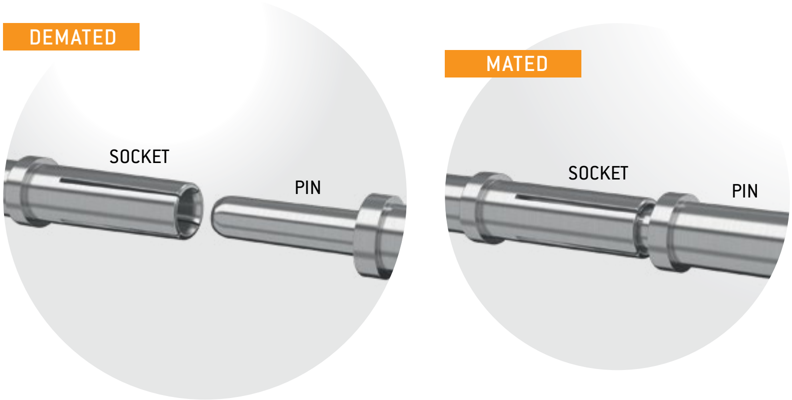



Fig 5. ODU TURNTAC® contacts

## 3.2 Stamped contacts

Stamped contacts are very similar to turned contacts inasmuch as they use split-finger segments to provide pressure on an inserted pin. However, they are additionally designed for automated processing, as multiple sockets are manufactured from a single metallic strip.  Other functions can be integrated while sockets are still on the strip, such as the addition of the blue sealing elements shown in Figure 6.

An example of stamped contacts is the ODU STAMPTAC® family.

Fig 6. Strip of ODU STAMPTAC® contacts

## 3.3 Contacts with lamella-technology

This contact system usually consists of a contact carrier and one or more stamped contact lamellas that are inserted into it. There are various approaches to the design of the lamella, ranging from simple designs (Figure 7) to hyperboloid respectively twisted or even multi-part designs. The carrier is usually a turned part or similar, but can also be designed as a stamped part.

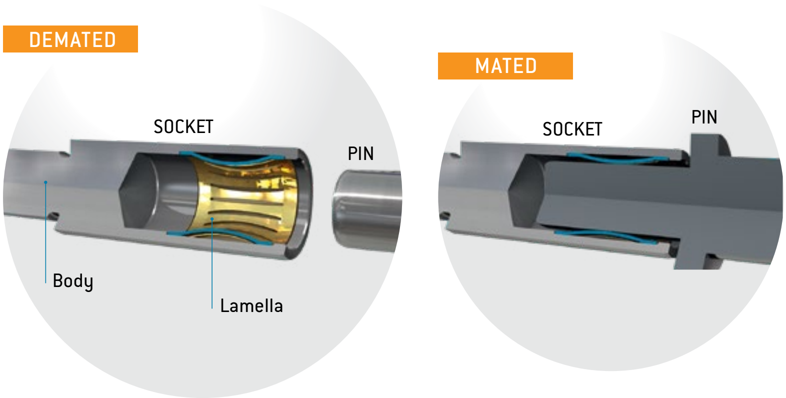



Fig 7. ODU LAMTAC® contacts

# CONTACT POINT AND MATING SEQUENCE

Many dimensions of the individual charging interfaces such as the contact diameter, the plug lengths and the generally available installation space are defined by standards.  An example is the Type 2 interface shown in Figure 8, which is defined by the IEC 62196 standard.  A key feature of each such standard is the sequence in which pins make contact in their respective sockets. The importance of correct contact sequence is explained in more detail below.


Fig 8. Type 2 plug & socket

A closer look at the charging inlet of a vehicle reveals that one contact pin is somewhat shorter than the others; but first, let's take a closer look at the pin assignments:

### PE

In the middle there is a PE contact, which is marked here with a ground symbol. In the event of a fault, it dissipates the short-circuit current until the installed protective device trips. Since the contact is de-energized and voltage-free during normal operation, no touch protection is required.

### L1/N

These two contacts are the live contacts and are therefore protected against accidental contact. In charging mode, they transmit the charging power.  L1 stands for the corresponding outer conductor or the mains phase, and N for the neutral conductor. The positions L2 and L3 are not used here, because a single-phase charging interface is shown in this example.

### PP

PP stands for "Proximity Pilot". This contact enables the charging device or vehicle to recognize which charging cable and thus which cable cross-section is currently connected. A defined ohmic resistance to ground is installed in the connector housing for this purpose. For each size (e.g., 16A, 32A) there is a unique value that the integrated control recognizes.

### CP

CP stands for "Control Pilot" and regulates the charging power during charging operation. It also reports whether the vehicle is ready for charging. This is only the case when the charging plug is fully inserted into the charging socket. This pin is therefore designed to be the last to make contact and only then to permit the charging process to begin. Conversely, it is the first to interrupt the charging process when plugged in, so that unacceptable contact position can be detected. This is also referred to as an "LMFB" contact ("last mate first break").

From these pin assignment details, it is clear that the correct mating sequence is particularly important, especially when it comes to the longevity of the charging connector. Not all contact technologies can meet this requirement. Figure 9 illustrates the distance into each socket type at which complete pin contact is made, the green lines being optimal:

To maintain the correct mating sequence, the contact point must be defined as early as possible and as precisely as possible. Depending on the lamella design, lamella contacts sometimes have notable weaknesses here In some geographical regions, lamella contacts are in particularly widespread use, especially in the industrial sector. As a consequence, they have also become popular in the EV charging application environment, although they are not the optimum solution.

Spring wire contacts are particularly unsuitable for the application, as they can be subject to major process fluctuations due to their high complexity. They also have a negative effect due to the long pin insertion depth before a defined contact to the pin is made.

Turned and stamped contacts, on the other hand, have very early contact points due to their design, and which hardly fluctuate as long as they are manufactured with the appropriate precision. They are therefore the preferred contact technology for charging connectors.

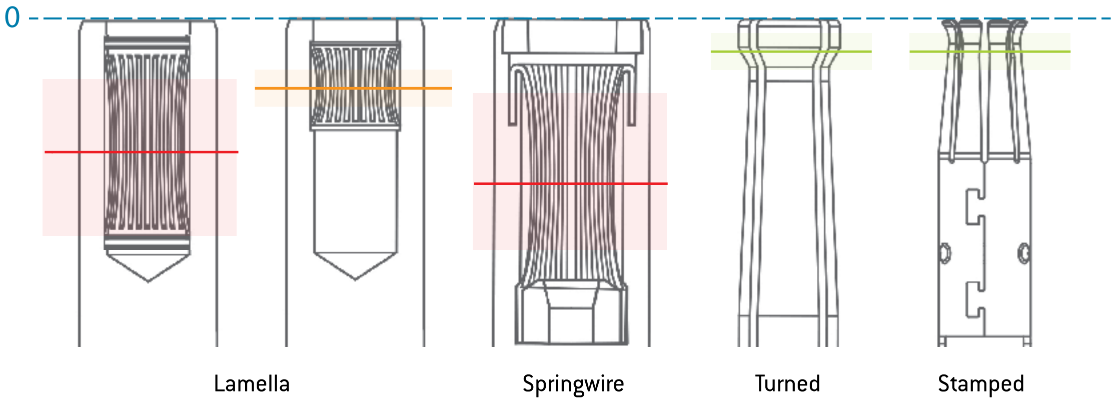



Fig 9. Typical position of the contact point and its related tolerance range

# MATING AND DE-MATING FORCES

Particularly with regard to ergonomics, the mating and de-mating forces represent important variables. Charging cables with high charging power always have a correspondingly large cable cross-section and can therefore be somewhat difficult to maneuver. However, this must not be allowed to result in an implicit need for greater force during the mating/de-mating processes. In order to keep the mechanical stress on the charging plug and vehicle inlet low, there are limits to the permissible total mating and de-mating forces.

With the right design, all contact technologies can initially meet this requirement. A quantitative classification is therefore difficult to define. The decisive factor is therefore how this design behaves under mechanical (mating cycles) and thermal stress (charging process).

# DURABILITY

Charging connectors must be designed for at least 10,000 mating cycles in accordance with the applicable standards. If one charging process per vehicle per day is taken as a basis, this corresponds to a service life of more than 27 years. This is much more than the usually expected value for a privately-owned vehicle. The standards' specification is therefore aimed more at vehicles that are used continuously throughout each day, such as those found in car sharing. Assuming three charges per day, the service life is quickly reduced to only 9 years.

Car-sharing is not yet widespread and most people currently use their own vehicles. However, a change in usage behavior and thus an increase in the plug-in cycle requirement are considered likely in the relatively near future.

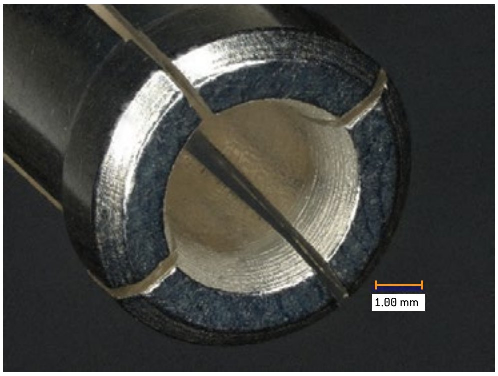
In order to have low wear and thus achieve a useful service life, the right coating system is needed in addition to the appropriate contact technology. A wide variety of opinions is currently circulating in the industry as to which surface coating system is best-suited for maximizing the connector service life. The range extends from multilayer coating systems such as nickel/silver, to silver coatings with alloy additives (so-called 'hard silver'), to silver dispersion coatings in which graphite particles are embedded in the coating. All of these and comparable solutions aim to increase the achievable number of mating cycles and thus the service life.

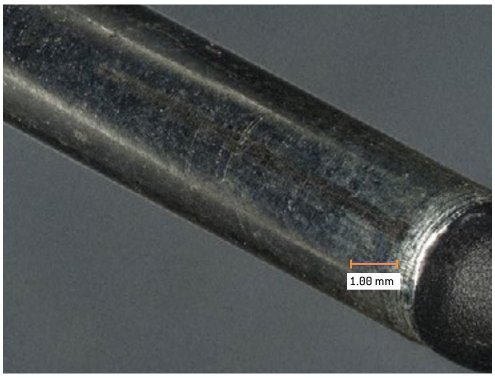
Classic nickel/silver coatings are the most economical solution here, as the two coating materials are industry standards in many other areas. Hard silver is also established in some areas, but is much more limited in terms of availability. Silver dispersion coatings in this application area are still comparatively new.

It is not only the choice of coating that is decisive, but also whether the coating and contact materials are properly matched to each other. The quality of the coating process also has a considerable influence. It is therefore not surprising that poorly designed systems sometimes show massive wear after only a few thousand cycles, while other contact pairs last far beyond the specified number of mating cycles.

This is achieved with an optimal combination of high-quality coating processes and contact technology. Figure 10 shows the results from ODU test report L035387. The ODU TURNTAC socket T3.6 and ODU pin with Ni/Ag plating showed very stable behavior over 20,000 mating cycles, with minimum wear.

When new, it is not immediately apparent whether a contact system is particularly durable or not. In any case, it is advisable for a charging equipment manufacturer to obtain the relevant information and evidence from prospective contact manufacturers.



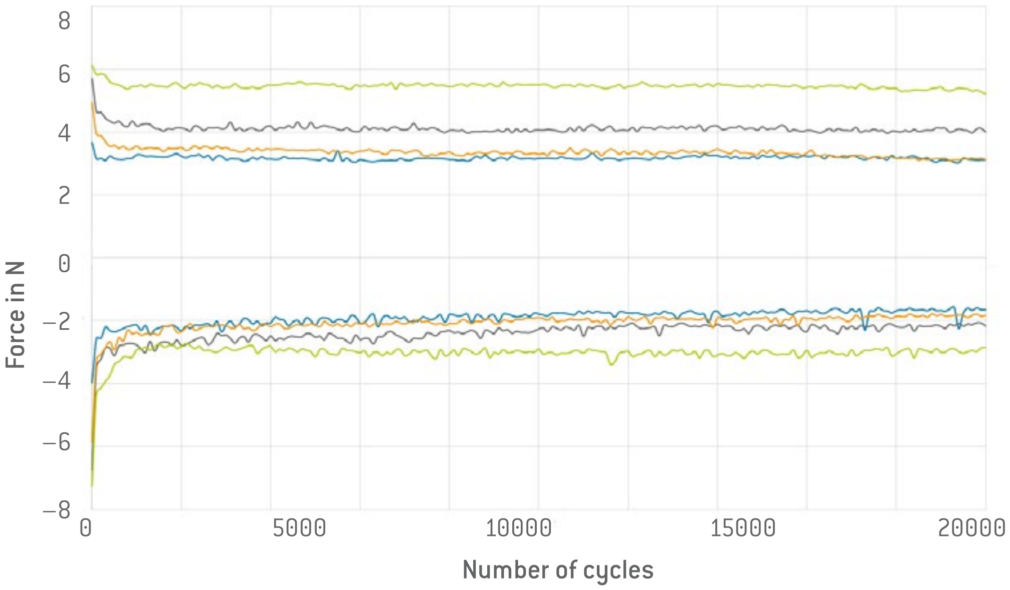




Fig 10. Durability of ODU TURNTAC® contacts

# PERFORMANCE

Charging connectors are available for different charging powers. The higher the power, the shorter the charging time. Here, too, the standards already define the framework conditions to a large extent. The contact manufacturer, however, determines the quality of its products based on the connection technology and the choice of contact materials used. To maximize the life expectancy of contacts, the objective is to reduce power dissipation to a minimum.

The power loss is defined as follows:

$P_V = I^2 \times R$

where:

$P_V$ = power loss; $I$ = current; $R$ = resistance

To keep the power dissipation $P_V$ low, the contact resistance R must be kept low. The current is determined by the charging power and therefore cannot be influenced.

When charging with alternating current (AC), the charging power and thus the charging currents are lower than with direct current (DC). The resulting power losses are therefore also relatively low. For this reason, materials with somewhat lower conductivity, like brass alloys, are typically used here, because they are much more attractive economically than highly conductive materials.

In direct current (DC) charging, on the other hand, the currents are much higher and the resulting power loss is therefore no longer negligible. With today's demand for minimized charging times, and thus higher power chargers, the heat generated due to the losses eventually becomes so great that manufacturers have to take countermeasures. This is where special cooling systems become necessary.

In all cases, a low and constant resistance level is the cornerstone. When it comes to contact resistance, all disciplines finally come together. Starting with the contact technology, through the appropriate choice of base materials and coating materials, to a balance with the mechanical properties. A stable resistance level is therefore by no means a product of chance, but the result of optimum contact design specific to the EV charging application.

# CONCLUSION

There are currently a large number of suppliers of charging contacts in the market. However, due to ignorance of the complexity of contact systems, insufficient attention is often paid to the critical parameters discussed in this paper.  For this reason, connector manufacturers should quickly eliminate many prospective contact suppliers.

The increasing need for high-power charging stations demands equipment of a quality level previously required only for industrial applications. Equipment failure at these high currents  can cause damages or seriously harm the user during the charging process. If you are the manufacturer of EV charging stations or connectors, we urge you to take great care when qualifying contacts for use in your products.  The risks are just too great to ignore!

## FIND OUT MORE

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