PPA

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PPA

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Pacific Power Association, Suva, Fiji Islands. The PPA is an inter-governmental agency and member of the Council of Regional Organisations in the Pacific (CROP) established to promote the direct cooperation of the Pacific Island Power Utilities in technical training, exchange of information, sharing of senior managment and engineering expertise and other activities of benefit to the members.

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**Cover Page Photograph - "Allied Members Informal Meeting, Cook Islands, 2019".**

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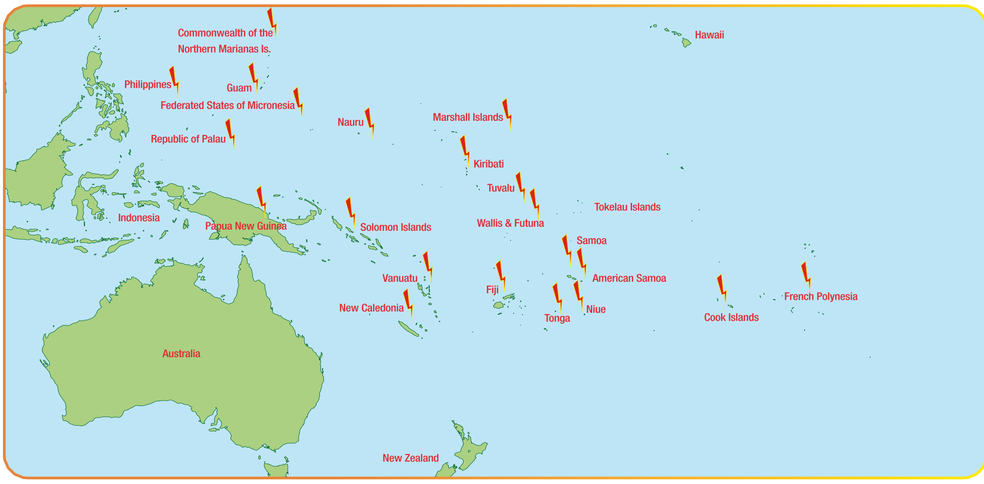


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# Editor's Note

**Gordon Chang**
Acting Executive Director

This issue of our magazine brings to a conclusion 12 months of endeavour by our Association, including our Utilities, Allied Members and Secretariat to improve the quality of life in the Pacific Island Countries. In addition, the PPA staff would like to take this opportunity to officially bid farewell to Andrew Daka after 10 years and 8 months being the Executive Director of the Secretariat. The Secretariat would like to wish him all the best in his next adventure.

At this time, we look back at the past 12 months and realise that again the challenges our utilities have had to address in support of our stakeholders, became more daunting and solutions more complex with the impact of COVID-19, and the devastating effects that it has brought with it.

Whatever the challenges, it is clear that the utilities must continue to work hard to improve their processes and as a result their operating performance.

Our gratitude also needs to be extended to our Allied Members for their continued support of the PPA Annual Conference and their way of support in sponsoring the conference, PPA Magazine and the PPA website resulting in the success of these activities. We also take this opportunity to welcome our new members who have joined PPA this year and wish the members who have withdrawn their membership all the best and hope that they will re-join or renew their membership with the PPA family again soon.

Again, our Association is most appreciative of the relationship with the World Bank who have continued to work with the PPA Secretariat in implementing the remaining activities in the SEIDP Project and also have agreed to the extension of the project date to February 2021 due to the COVID-19. In addition, the Secretariat is working with the World Bank with interested member utilities in implementing a Pacific Disaster Assistance Program Fund.

May God Bless you all and my best wishes for a Happy and a Holy Christmas, safe travelling and continued successes in the New Year.

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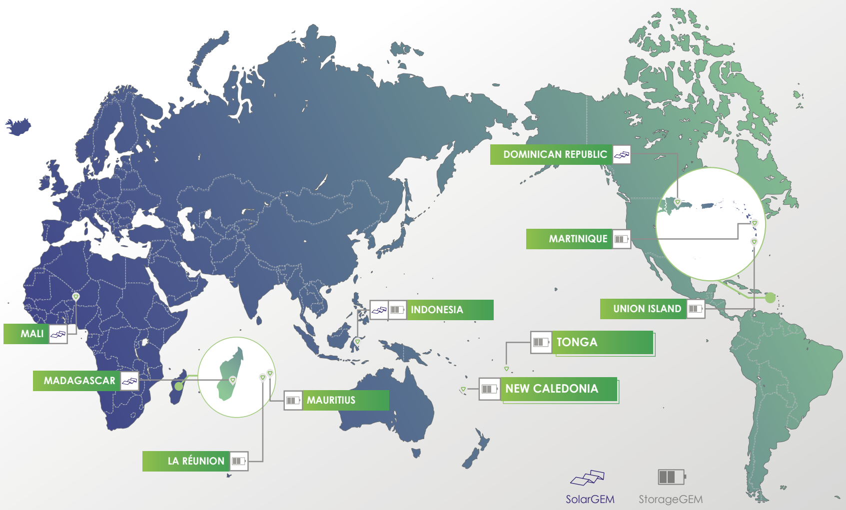


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# Product Developed for Generator Project Colab with Terra Cat and Fuelchief

Praneel Lal
Marketing Manager - FuelChief

"Fuelchief are an above tank fuel provider to the APAC region, and have had a strong working partnership with PPA Allied member Terra Power Systems (formerly known as Gough Power Systems), so when we were approached on a project to supply multiple generator sets for their clients, it was a challenge that Fuelchief had to accept." Says Fuelchief's CEO Joe Deck.

Firstly, a bit of background on each company. Terra Cat is a leading New Zealand dealer for Caterpillar equipment, machines, engines and generators and have over 90 years' experience in doing so.

Fuelchief is a manufacturer of compliant custom fuel tank solutions for industries across the Asia Pacific. They have over 40 years' experience in the space and offer premium above ground tanks.

Fuelchief were approached by Terra Power Systems who were requiring a number of customised diesel base/belly tanks to be situated beneath multiple Caterpillar generator sets to meet a customers specific requirement around extended run times and space limitations. Terra Power Systems provided with a number of key objectives for the design and in collaboration developed a full solution that included:

- The base tank needed to accommodate at least 6 tank ports within a spill box area for containment around the tank fill point
- A superior paint finish to ensure longevity of the base tank
- Tank to be no larger than 499L
- Simplicity and lowest possible cost were key to make a base tank option viable

Terra Power Systems Project team met with Fuelchief's Guthrie Deck to further discuss the project onsite with the specified CAT generator that was being proposed for the project.
This allowed Guthrie to see exactly the model which would be sitting above the newly developed base tank. A full scope of measurement were taken to ensure the precise fit of both the base tank and generator to ensure these was no protruding parts hindering any of the generator operation (example, ensuring the lid of the spill box didn't foul with the generator canopy or case the generator hoses to be compromised by the closing of the lid).

## THE DESIGN PHASE TAKES SHAPE

The project was briefed into Fuelchief's design engineer David Lawson, who spent time completing a professional drawing of the base tank concept. Time was taken to ensure all required features were incorporated into the concept drawing with priority given to the functionality of the tank and its compatibility with the Caterpillar Generator it was to compliment. Budget was also crucial to ensure a cost-effective build with minimal amount of parts and ease of assembly.

Feedback on the concept was positive and Terra Power Systems requesting some more detailed features to be added for the clients benefit, such as a fall/slope across the lid of the base tank to ensure that rainwater would run off the top of the tank. The finished tank was then submitted and approved for manufacture.

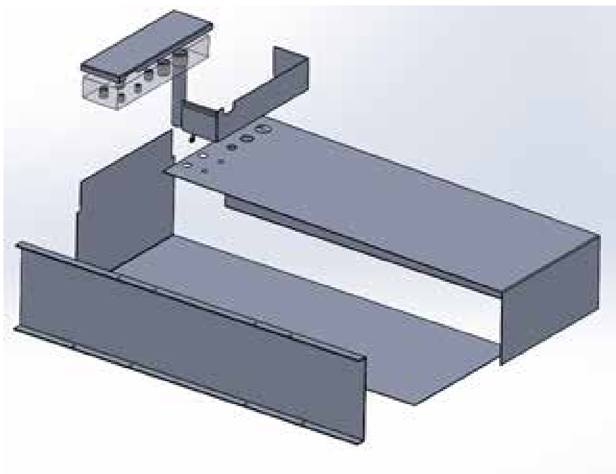


*Image shows: Exploded view of base tank parts*

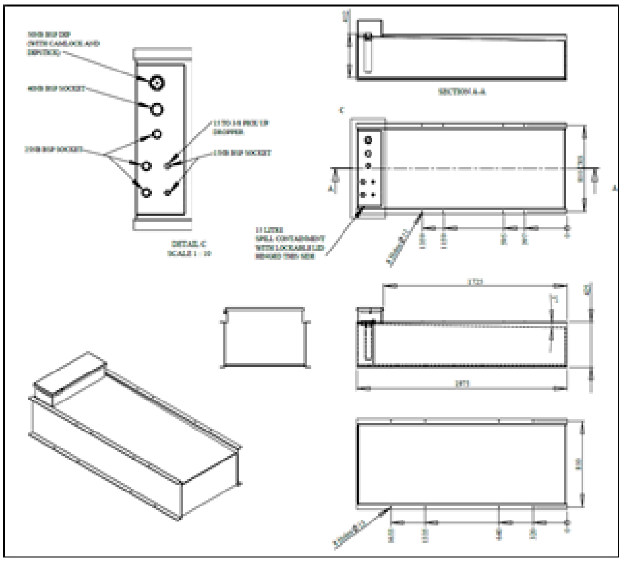


*Image shows: General Assembly drawing of newly created base tanks*

## CONFIDENCE STRENGTHENED THROUGH COMISSIONING OF TANKS

Once the tank drawing was finalised, Terra Power Systems approved an order of the first two base tanks, Fuelchief manufactured these accordingly and dispatched the tanks to them for client. The feedback was brilliant. The base tanks were commissioned to site and fitted perfectly beneath the Caterpillar generator, leaving Terra Power Systems client extremely satisfied.

Due to the first base tanks being customised perfectly to the generator and are fit for purpose, the clients' confidence in Terra Power Systems proactiveness was further strengthened. In turn the collaboration with Terra Power Systems has also strengthened the relationship with Fuelchief as they were able to come to the table as a supplier that could meet expectations in a timely manner.

# Substation Circuit Breaker Testing

Daniel Hurley
General Manager Sales & Marketing - AVO NZ Limited

Circuit Breakers are the metaphorical "safety-valves" of electrical systems; a means of giving harmless vent to excessive energy in a circuit, thereby minimizing the risk of damage to equipment that would otherwise be subjected to non-design conditions. Various power system components depend on the proper operation of a circuit breaker including, for example, expensive power transformers.

Substation breaker testing is an important task for any power utility. The breakers are there to facilitate the flow of current during normal operation and to interrupt current flow in the event of a fault. However, all electrically operated devices are, sooner or later, likely to experience some kind of failure. That failure can be caused by many factors, including ageing and external faults. Testing provides assurances that a circuit breaker will operate and will act within expected tolerances. Circuit breakers are some of the most important components in modern electric power systems. The circuit breaker has to operate within extremely tight tolerances when a disturbance is detected in the network to protect sensitive and costly components and they also have to operate after months or in some cases years of inactivity. To ensure proper function and optimize network reliability, reliable and efficient test instruments and methods are needed. Additionally testing also informs circuit breaker maintenance decisions so that maintenance dollars are spent most wisely and stretch further. Maintenance, of course, is essential to maintain maximum reliability of any circuit breaker.


**Why test circuit breakers**

Some of the most important reasons for testing circuit breakers are to ensure they:

- Provide protection for expensive equipment
- Prevent outages that lead to loss of income
- Ensure reliability of the electricity supply
- Prevent downtime and darkness
- Verify breaker performance

Protection systems are put in place to detect all electrical faults or other abnormal operating conditions and they are coordinated to disconnect the smallest possible part of a power network in the event of a fault. With good system design, it should be possible to quickly restore normal operation.

When a fault is detected by a protective relay and a trip impulse is sent to the breaker operating mechanism, the breaker has to function as specified and interrupt the current as soon as possible or severe damage may occur. The cost of damage caused by a malfunctioning circuit breaker can sometimes reach large sums.

Proper functioning of a breaker is reliant on a number of individual components that have to be calibrated and tested at regular intervals. The trigger for maintenance intervals differs greatly between power utilities but the intervals are often based on time since last test, number of operations, or severity of fault current operations. Environmental considerations such as humidity, temperature and costal locations also play into the maintenance scheme. Mechanical wear and lubrication often affects the performance of breakers, so being able to trend mission critical parameters and compare these with factory thresholds helps to verify proper breaker function.

### Standards

High voltage circuit breaker design and operation as well as type and routine tests are defined by international standards such as:

- IEC 62271-SER ed1.0 - High-voltage switchgear and control gear.
- ANSI/IEEE C37 - Guides and Standards for Circuit Breakers, Switchgear, Relays, Substations, and Fuses.
- IEC/TR 62063 ed1.0 (1999-08) TC/SC 17A - High-voltage switchgear and control gear - The use of electronic and associated technologies in auxiliary equipment of switchgear and control gear. New standard for disconnecting circuit breakers

### Maintenance strategy

Besides conducting and interrupting operating currents, the CB is designed to break fault currents, e.g. short-circuit currents that can be 5 to 20 times the value of the rated current, within about 50 milliseconds.

Whatever form of maintenance approach is selected, the most important goal is to achieve maximum reliability at the lowest possible life cycle cost.

Since breaker testing, many times, is based on comparison and trend analysis it is important to strive to have the same conditions from test to test. High precision signal acquisition is also necessary, together with high measurement accuracy and a reliable means of storage for data.

If the set up work required can be minimized and the connection from the test instrument to the apparatus can be simplified, faster testing and evaluation of results can be achieved. Online testing will give a condition check without taking CB out of service. This gives valuable information in a relatively short time. Test methods that are available for on-line testing are:

- Online First trip / close test
- Vibration test/ contact de-bounce
- Main contact timing (offline)
- Auxiliary contact timing
- Control voltage measurement
- Motion measurement (under certain conditions)

**Testing guide**

| Type of CB | Vacuum | Oil | Minimum Oil | | SF6 | | | Air-blast | | | GIS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Voltage levels (kV) / Application | 1 – 36 | Any | 6 – 145 | 145 – 400 | 6 – 40 | 72 – 245 | >245 | 6 – 40 | 40 – 130 | >130 | Any |
| Timing | x | x | x | x | x | x | x | x | x | x | (x)[1] |
| Motion | (x)[2] | x | x | x | x | x | x | (x)[3] | (x)[3] | (x)[3] | x |
| Coil current | x | x | x | x | x | x | x | (x)[2] | (x)[2] | (x)[2] | x |
| DRM | n/a | (x)[2] | (x)[2] | (x)[2] | x | x | x | (x)[2] | (x)[2] | (x)[2] | (x)[6] |
| SRM | x | x | x | x | x | x | x | x | x | x | (x)[1] |
| Vibration | (x)[2] | (x)[2] | (x)[2] | x | (x)[2] | x | x | (x)[2] | (x)[2] | (x)[2] | x |
| DCM | (x)[2] | x | x | x | x | x | x | x | x | x | (x)[1] |
| Motor current | x | x | (x)[4] | (x)[4] | (x)[4] | (x)[4] | (x)[4] | n/a | n/a | n/a | (x)[4] |
| Min. voltage to operate CB | x | x | x | x | x | x | x | x | x | x | x |
| Minimum voltage | x | x | x | x | x | x | x | x | x | x | x |
| Station voltage | x | x | x | x | x | x | x | x | x | x | x |
| Gas density | | n/a | n/a | n/a | x | x | x | n/a | n/a | n/a | n/a |
| Voltage integrity | x | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Air pressure/flow | n/a | n/a | n/a | n/a | n/a | n/a | n/a | x | x | x | n/a |
| PIR contacts | n/a | x | (x)[5] | (x)[5] | (x)[5] | (x)[5] | (x)[5] | (x)[5] | (x)[5] | (x)[5] | (x)[5] |
| Grading capacitors | n/a | n/a | n/a | (x)[5] | (x)[5] | (x)[5] | (x)[5] | (x)[5] | (x)[5] | (x)[5] | (x)[5] |

**Legend**

| | |
|---|---|
| x | Applicable |
| (x)[1] | If accessible |
| (x)[2] | Possible |
| (x)[3] | Optional – if disconnector knife/contact is included in CB design. |
| (x)[4] | Motor current is only applicable on spring drives. |
| (x)[5] | Applicability and presence of grading capacitors as well as PIR contacts are depending on network design and not related to CB design. |
| (x)[6] | If accessible and if not vacuum CB |
| n/a | Not applicable |

**Comments**

| | | |
|---|---|---|
| Motor current | There are three different types of operating mechanisms; Spring, hydraulic and pneumatic. Motor current is only applicable on spring drives. | |
| PIR contacts, Grading capacitors | Applicability and presence of grading capacitors as well as PIR contacts are depending on network design and not related to CB design. Usually not used in distribution networks. | |
| Oil CBs | Well defined travel trace and transducer attachment points. At higher voltages serial contacts per phase but those cannot be accessed, thus only timed as single contacts per phase. If PIR contact those are often sliding contacts in the main tank. No separation possible. Has to be timed as parallel contacts. PIR values can be down to 10 Ω. Coil current traces are essential. Always single operation mechanism if single tank design. | |
| Minimum Oil CBs 6 – 145 kV | 1 contact / phase, single operating mechanism. | Coil currents are essential, as well as operating mechanism damping dash-pots. Travel is essential and it is usually relatively easy to find documentation on transducer attachment points etc. |
| Minimum Oil CBs 145 – 400 kV | 2-6 contacts / phase. 400 kV always separate (3) operating mechanisms. | |

### How to Test

Tests shall be made according to applicable standards, local regulations and best practice. The instruction material and the nameplate for the circuit breaker can also be useful to assist the test. The safety aspect is of high importance – be careful to follow all safety instructions and regulations.

Before testing, make a visual inspection to see if there are any signs of damage.

An important requirement for the CB is reliability. After a long time without being operated, it shall function perfectly when needed. To test this you have only one chance to make a "first trip test", described in fuller detail in Megger's "CB Testing Guide".

The rated operating sequence (also known as standard operating duty or standard duty cycle) is the specified operating sequence, which the circuit breaker shall be able to perform at specified ratings. Breaker manufacturer normally specifies these sequences and corresponding rated times, which are defined as per IEC 62271-100.

### Safety

The best way to improve personnel safety when working in a substation is to increase the distance between personal and devices with voltage. Regulations and laws require all objects to be grounded on both sides before any maintenance work. For circuit breaker maintenance the most basic and important test, main contact timing, is performed without this basic safety prerequisite. Conventional technology does quite simply not permit a safe way of timing a circuit breaker but now it is possible to test much safer using the DualGround (DCM) technology (We will not cover Dual Ground in detail in this article but enquire with AVO New Zealand to learn more).

### Items to be tested / inspected

- Operating mechanism / Electrical accessories
- Arcing and main contacts
- Arcing chambers
- Main circuit - Busbars - Isolating contacts
- Grounding pliers (only for draw out power circuit breaker)
- Grounding connection (only for fixed power circuit breaker)
- Auxiliary circuit power supply voltage

### Test methods and parameters

- First trip test
- Contact Timing
- Primary injection test
- Motion
- Static resistance measurement (SRM)
- Dynamic resistance measurement (DRM)
- Synchronized switching
- Coil test
- Minimum voltage test
- Minimum voltage required to operate breaker ("Min Ops test")
- Vibration testing
- Vacuum bottle test
- Primary testing
- Oil test
- SF6 leakage
- Humidity test
- Air pressure test
- Power factor / Tan Delta / Insulation

### First trip test

A good and time effective way to check the condition of a circuit breaker is to document its behaviour at the first open operation after it has been idle for long time. The measurement and connections to the circuit breaker are carried out while it is still in service. All of the connections are made inside the control cabinet. The biggest benefit of using first trip testing is to test "real world" operating conditions. If the circuit breaker has not operated for years, first trip testing will reveal if the circuit breaker is slower due to problems in the mechanism linkages or coil armatures caused by corrosion or dried grease. With traditional methods, the testing is carried out after the circuit breaker has been taken out of service and has been operated once or even twice.

### Contact Timing

Simultaneous measurements within a single phase are important in situations where a number of contacts are connected in series. Here, the breaker becomes a voltage divider when it opens a circuit. If the time differences are too great, the voltage becomes too high across one contact, and the tolerance for most types of breakers is less than 2 ms. The time tolerance for simultaneous measurements between phases is greater for a 3-phase power transmission system running at 50 Hz since there is always 3.33 ms between zero-crossovers. Still, the time tolerance is usually specified as less than 2 ms, even for such systems. It should also be noted that breakers that perform synchronized breaking must meet more stringent requirements in both of the previously stated situations. There are no generalized time limits for the time relationships between main and auxiliary contacts, but it is still important to understand and check their operation. The purpose of an auxiliary contact is to close and open a circuit. Such a circuit might enable a closing coil when a breaker is about to perform a closing operation and then open the circuit immediately after the operation starts, thereby preventing coil burnout. The "a" contact must close well in advance of the closing of the main contact. The "b" contact must open when the operating mechanism has released its stored energy in order to close the breaker. The breaker manufacturer will be able to provide detailed information about this cycle.

**Minimum voltage required to operate breaker (min ops test)**

It is a measure of how much force that is needed to move the coil armature. In this test, you are not interested in contact timing parameters, only whether the breaker operates or not. You start on a low voltage sending a control pulse to the breaker. If not operating, you increase the voltage with say 5 V and try again, and so on. Once the breaker has operated, you note the voltage at which operation occurred. Next time maintenance is done, you can compare your results with the old test value to determine changes.

For more information on the other CB tests see - The Megger guide to insulating oil dielectric breakdown testing.

Effective circuit breaker maintenance requires well-organized, accurate testing. The ability to accurately compare circuit breaker tests with previous test results is essential. It is, therefore, imperative to conduct tests in exactly the same way and under the same conditions as those conducted earlier. Comparison can then provide a clear picture of any deviations and changes, thereby indicating whether or not the circuit breaker should be kept in operation or taken out of service for further investigation.

Comprehensive, accurate testing also requires analytical tools and efficient reporting. It must be possible to validate test results in detail and then easily compare them with other test results. The test data are valuable information that must be safely stored, including data backup on media that can be used for years to come.

Ask AVO New Zealand how we can assist with training or application support for your Circuit Breaker and substation testing requirements.

# The Wedge Connectors Dilemma: Fired Wedge Connectors vs Bolt-driven Wedge Connector vs Connectors with the Wedge-shaped Driver Screw

Goran Stojadinovic
Product & Innovation Manager - TransNet

## Executive summary

A brief statement of the problem:
- There are new "wedge type" electrical connectors on the market that make big claims
- Some customers are lured by perceived advantages of the new connector e.g. "no special tool required to achieve all benefits of the wedge connection principle"
- Some customers are puzzled and confused, and they ask open-ended questions –Is it too good to be true?
- Most customers are cautious, and they are asking for clarifications

What is covered in the major document:
- In-depth analysis of the wedge type connectors based on facts –material science, tribology, electrical engineering, electrical and mechanical properties, field experience, lab and field tests, and bench-testing
- Detailed comparison 'apples to apples' which should resolve any dilemma

Background information:
- Reference materials from international studies and labs, results of the lab, field, and bench testing, and previous track record in the field

Concise analysis covers:
- Role of wedge connectors and key requirements regarding contact resistance, reliability, and service life
- Electrical, mechanical, and thermal properties of wedge type connectors
- Different concepts/methods of making electrical contacts and installation issues

Main conclusions:
1. There is a significant difference between the Fired Wedge and other 'wedge' type connectors in terms of:
   - Method/concept of making a connection
   - Electrical, mechanical, and thermal properties of the connection
   - The technology of materials used for connectors
2. The Fired Wedge connector concept is unique:
   - It has superior performance compared with all other non-tension connectors on the market
   - It has a proven track record over decades in real-life applications in the networks worldwide
   - It still withstands the test of time, 20+ years in the NZ market

3. It has a significantly lower lifetime cost, even accounting for the cost of the tooling

## The main purpose of connectors

- The main purpose of any connector is to make a reliable and long-lasting connection by achieving a low contact resistance
- The connectors are critical components of any distribution & transmission network
- At the same time -they are literally the weakest points in any electrical circuit
- The proverb
  "A chain is only as strong as its weakest link"can be directly translated to
  "An electrical circuit (feeder) is only as strong as its weakest component (connector)"
- According to many studies, experiments, and laboratory and field tests –the wedge connectors have shown superior performance compared with other types of connectors (see References and APPENDICES)

## However, not all wedge connectors are the same

There are three (3) types of connectors that claim all the advantages of the wedge connector concept:
1) Fired wedge connector
2) Bolt-driven wedge connector
3) Connectors with the wedge-shaped Drive Screw Mechanism (e.g. self-proclaimed 'Bolted Wedge' connectors)

There is a significant difference between them in terms of:
- Real contact area and Contact resistance

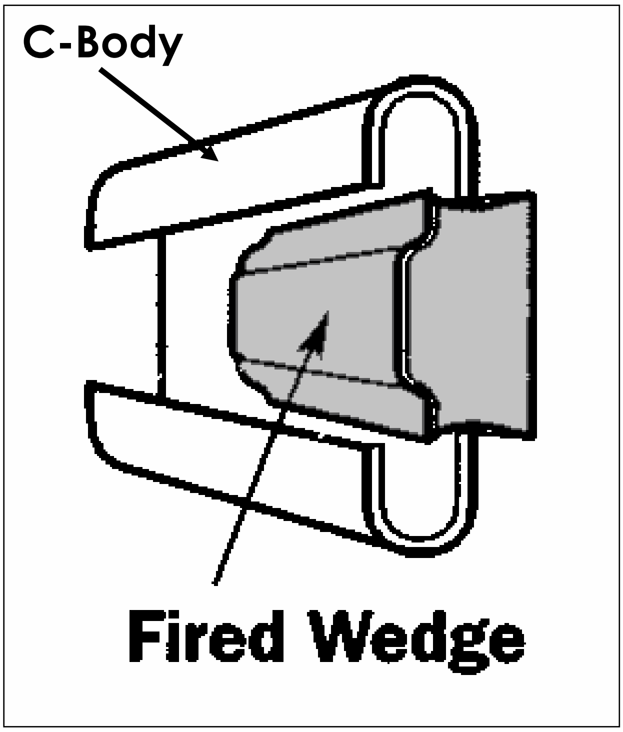
- Reliability and Service life

**Disclaimer**

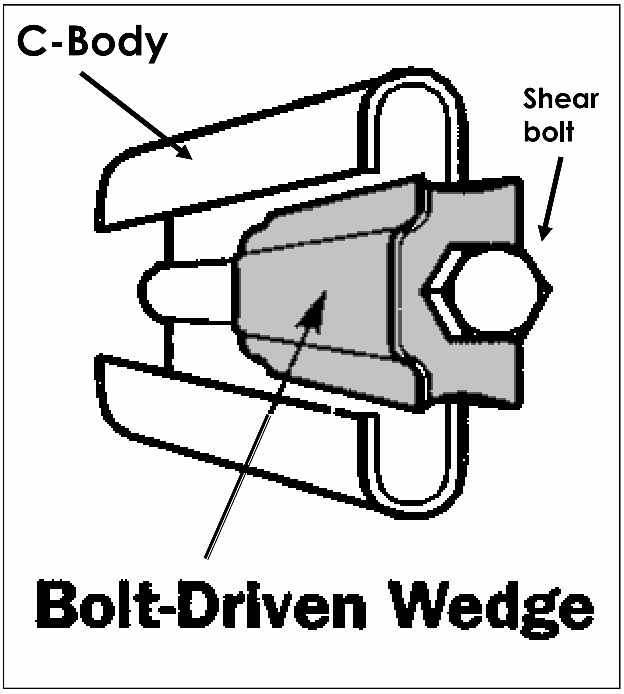
- The purpose of this study is to compare the performance of connectors that claim they are the wedge type and to clarify once for all which one is the genuine wedge connector
- The purpose of this study is not to discredit any product nor any manufacturer
- For that reason, no manufacturer will be mentioned in the text (except if their names are already in the referenced material)
- The aim is to put the truth in plain sight and to put forward findings from the real science and real observations, so that power companies have enough information and can make an informed decision on their own
- It is in the interest of truth and the best interest of the Electricity Industry to clarify the matter and to dispel any 'myth about a miracle new connector that takes all advantages of wedge connectors and is easy to install with no special tool required'
- As we all know, there are no miracles in our industry –only a well thought design and proven record

**How to distinguish these three connectors**

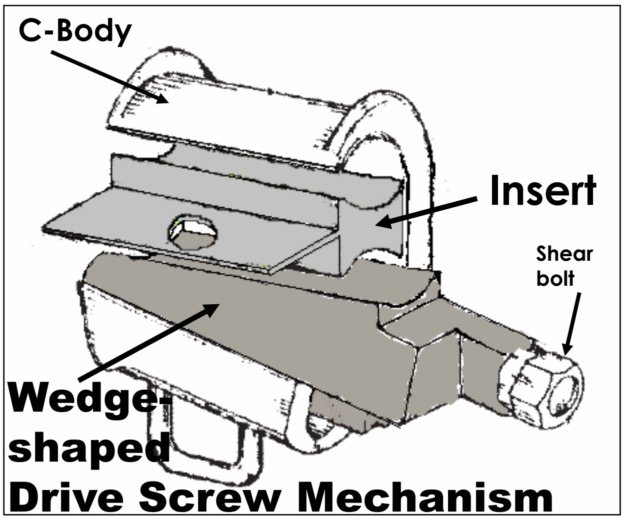
1) Wedge connector (Authentic wedge connection principle)




2) Bolt-driven wedge connector
(Note: This connector is no longer available in NZ for overhead applications)




3) A connector with the wedge-shaped Drive-Screw Mechanism (A self-proclaimed 'Bolted Wedge' connector)




**Basics of the Wedge Connector Principle**

The wedge-connection concept relies on two fundamental factors:

1. The method of creating the contact (e.g. the way the wedge is driven into the C-body of the connector; does it allow for human error and

bad workmanship, etc.)This method directly affects the Contact Resistance of the connector

2. The material of the C-body and its mechanical properties (e.g. can it withstand & maintain the same contact pressure regardless of operational conditions like saline environment, high fault currents, thermal cycling, etc.)

The Material properties directly affect the Reliability & Service Life of the connector

NOTE: If these two basic requirements are compromised, the advantages of the wedge-connection concept are lost or drastically reduced!

### 1. Electrical characteristics Contact Resistance

The contact resistance is the most important and universal electrical characteristic of all electrical contacts. (Ref. #1, #2, and APPENDICES 1 and 2)
It depends on:

- The real contact area
- The method of creating the contact
- The contact pressure (clamping force)
- Workmanship

It is well known that the real contact area (effective contact area that conducts the electricity) is much smaller than it seems to be (e.g. just a fraction of apparent contact area), and it depends on many factors. This is because the contact surfaces are very rough on a microscale, plus they are covered with oxide films and other contaminants that have insulating properties.

### The real contact area

"The most important requirement for good connector performance is for the real area of contact to be sufficiently large so that even with initial and long-term deterioration, a reserve of the contact area is still available to prevent overheating conditions in the joint." (Ref. #1)

Therefore, it is of utmost importance to increase the real contact area. The best and most efficient way to do it is to apply the wedge connection principle as follows:

- Design a wedge connector where all abraded areas are on the direct path of the main current
- Maximize the wedge sliding distance to increase the total abraded area of contact surfaces
- Reduce the thickness of oxide film and other contaminant deposits
- Apply correct contact pressure
- Reduce or eliminate the human factor in creating the real contact area

NOTE: According to many studies and laboratory and field tests, the Fired Wedge connector fully satisfies all the above requirements.
Let's compare the Fired Wedge connector with self-proclaimed 'Bolted Wedge' in several aspects:

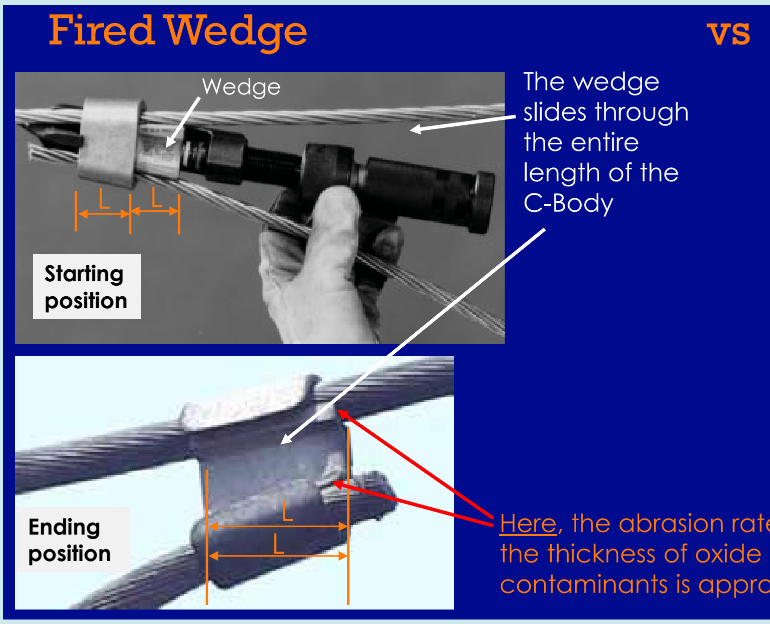
### Sliding distance and beneficial wear of contact surfaces of wedge connectors

"A large number of studies confirm that the wear of many tribo-couples is truly proportional to the sliding distance"(Ref. #1)

- In other words –the longer the sliding distance of the wedge, the more beneficial abrasion and less oxide film, and other contaminants
- Indeed, it has been measured and experimentally proven that the oxide film and other contaminants on unabraded surfaces are approx. 3 times thicker than on surfaces abraded by a fired wedge (Ref. #2)

Note: According to the same studies, the applied normal load is also directly proportional to the wear rate but only within a limited range of loads. (Ref. #1, #2, and Part 2 of this presentation)

**Let's compare the sliding distances**

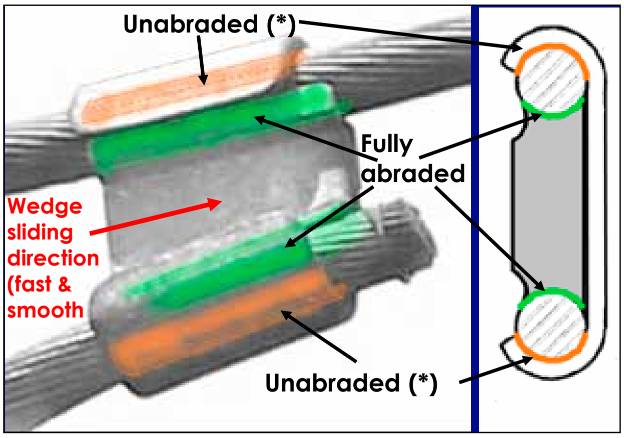



Conclusion: The sliding distance of the Wedge Mechanism
to the Fired Wedge. As a result, the abrasion rate is much lo
the oxide & contaminants layer approx. 3x thicker (Ref. #1,
much smaller, and the Contact Resistance is much higher c

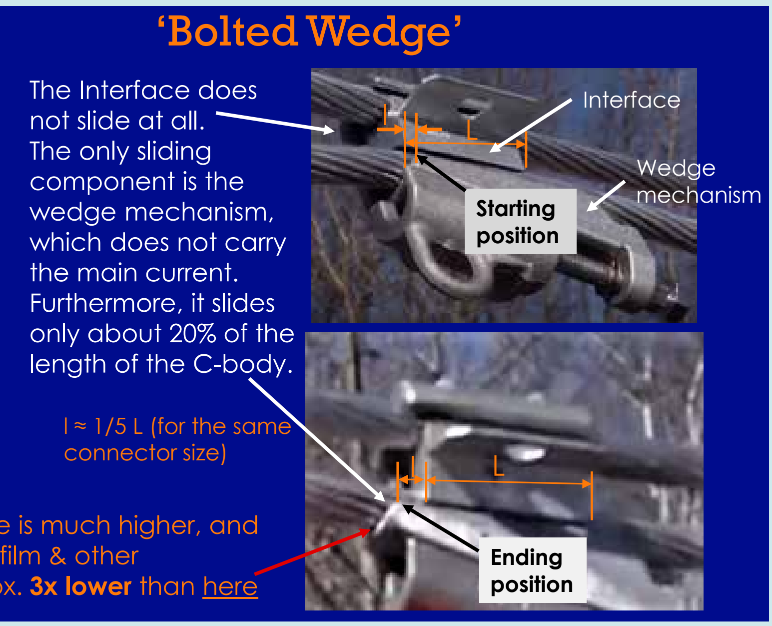
Note: The pictures of 'Bolted Wedge' connectors are from th

**Let's compare the abraded & unabraded contact areas:**

**Fired Wedge vs 'Bolted Wedge**




Key points:
- The contact surfaces between the Wedge and both conductors (the main and tap) are fully abraded
- It means that all contact surfaces that are on the direct path of electrical current are fully abraded

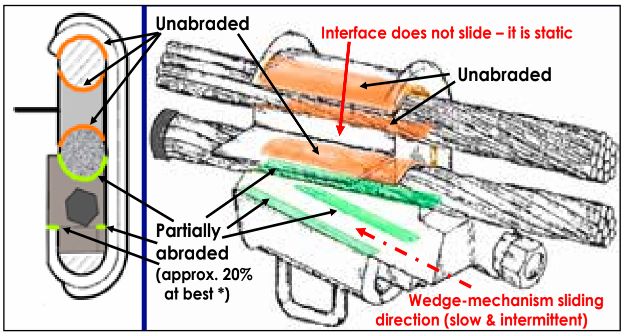



of the 'Bolted Wedge' connector is only about 1/5 compared
wer (e.g. in direct proportion to the sliding distance), leaving
#2). Consequently, the real contact area of 'Bolted Wedge' is
ompared with the Fired Wedge connector.

e online installation instructional videos (Ref. #8)

e.g. they provide low contact resistance

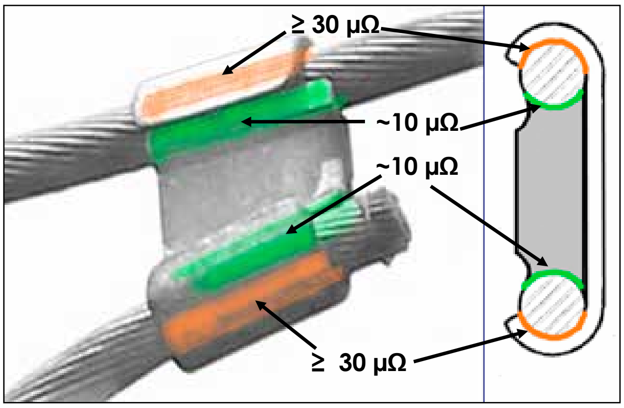
- (*) Note: There is also some scrubbing action on the top and bottom of the C-member when it flexes




Key points:
- The contact surfaces between the Interface and both conductors (main and tap) are not abraded at all
- It means that the contact surfaces that are on the direct path of electrical current are not abraded e.g. they have a high contact resistance
- The only partially abraded surface is between the wedge mechanism & the bottom side of the tap conductor & C-body (e.g. away from the main current)

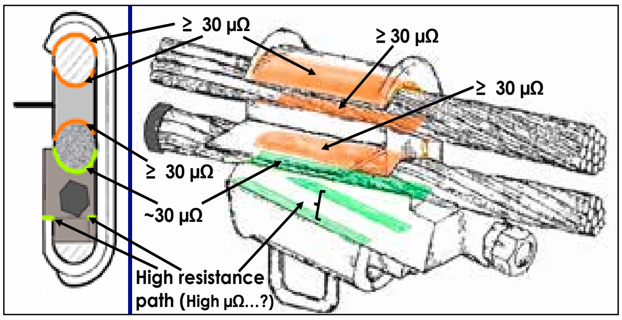
**Let's compare the contact resistance:**

**Fired Wedge vs 'Bolted Wedge'**
Note: The following considerations are based on the available literature and independent lab tests.




Key points: (Note: '~' means approx. or 'in the order')
- According to the lab tests, the oxide layer and contact resistance on abraded contact surfaces is at least three times (3x) lower than on unabraded areas (Ref. #2)
- This confirms the beneficial effects of the

wedge connection principle



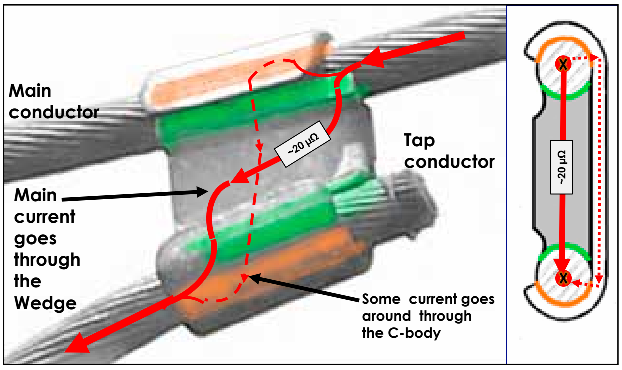

Key points: (Note: Symbol '~' means approx. or 'in the order')

- The contact surfaces that are on the direct path of electrical current are not abraded at all e.g. they have a high contact resistance
- The partially abraded areas are in series with each other and with the top unabraded surface, and they present high resistance path

Obviously, it is of utmost importance to have the fully abraded areas on the direct path of electrical current!

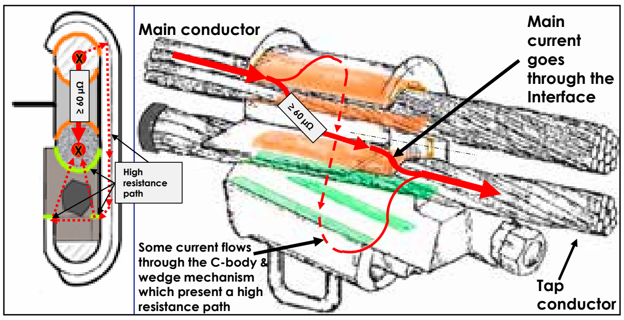
Note: For the values of the contact-resistance refer to the study and experimental data in Ref. #2 (For the remark 'at best *' refer to APPENDIX 4.2 and 5)

**Let's compare the paths of electrical currents: Fired Wedge vs 'Bolted Wedge'**




Key points:

- The total resistance through the Wedge is approx. 20 μΩ (Ref. 2)
- Note: The resistance through the C-body is higher




Key points:

- The total resistance through the Interface is at least 60 μΩ or more (Ref. 2)
- Note: The total resistance through the C-body & wedge mechanism is much higher although some surfaces are partially abraded. It presents a high resistance path

Note: The lab tests have confirmed that the main current flows through the wedge (e.g. through the Interface) (see Ref. 2). Therefore, the Wedge Mechanism of the 'Bolted Wedge' connector is just used to tighten up the connector. The underside carries very little current. The current is carried through the Interface element between the main conductor and tap conductor.

**The total contact resistance of the Fired Wedge connector is approx. 3 times (3x)lower then of 'Bolted Wedge' connector of equivalent size and at the same temperature**

**Bench testing –the Fired Wedge vs 'Bolted Wedge' connector**

Date and venue: 1st -8th September 2020, TransNet's HV testing lab

Objective:

- Measure and compare the contact resistance of Fired Wedge and 'Bolted Wedge' connectors of equivalent size, on the same conductor type & size, and at ambient temperature through to 90 °C

The test set up:

- Instrument: METREL MicroOhm100A MI 3252Test current: 100 A
- Conductor: 9 mm OD (Ferret)
- Connectors: 3x Fired Wedge and 3x 'Bolted Wedge' connectors of a comparable size suitable for the conductor Note: All connectors installed as per manufacturer's instructions

A summary of the results:

| Connector | Contact resistance (μΩ) | |
|---|---|---|
| | @ 20 °C | @ 90 °C |
| Fired Wedge | 27.7 | 38 |
| 'Bolted Wedge' | 94.2 | 114.1 |
| Relative difference (approx.) | 3.4 times | 3 times |

**Observations**

- Multiple measurements have been conducted
- In all cases, the contact resistance of Fired Wedge was consistently lower than of 'Bolted Wedge' by approx. 3 to 3.4 times
- The results for contact resistance between 20 °C and 90 °C follow approximately the same near-linear pattern e.g. the relative difference stayed between 3 and 3.4 times

Note: Due to extremely small values of contact resistance (e.g. in μΩ's) there may be some errors introduced by other factors. However, what was strikingly obvious is that the relative difference in the test readings between the Fired Wedge and 'Bolted Wedge' connectors remained consistently high (e.g. between 3 and 3.4 times).

**Additional observations regarding Thermal performance vs Physical size and total mass**

It took the 'Bolted Wedge' connectors approx. 5 minutes more time to cool down from 90 °C to the ambient temperature than the comparable Fired Wedge. Here is a possible explanation:

- The 'Bolted Wedge' connectors are much bulkier and 1.7 times heavier than the comparable Fired Wedge e.g. 242 vs 142 grams
- Initially, it might look like an advantage because the bigger mass can absorb more heat
- However, we should consider the following facts:
    - The main current flows through the Interface of the 'Bolted Wedge', and through the Wedge of the Fired Wedge connector respectively
    - There is a big difference in the contact resistance of the 'Bolted Wedge' compared with the Fired Wedge e.g. approx. 3 times
    - Therefore, there is much more I2R heat to be released in the 'Bolted Wedge' compared with the Fired Wedge
    - The Interface member of the 'Bolted Wedge' is smaller and 1.4 times lighter than the wedge of the comparable Fired Wedge e.g. 39 vs 55 grams
    - The bigger 'outer' mass of the 'Bolted Wedge' connector (around its Interface) absorbs most of the heat but slows down heat dissipation
- Therefore, it seems that this bigger mass and bulkiness of the 'Bolted Wedge' are 'on the wrong side of the equation'
- Furthermore, it explains why the Fired Wedge connectors have superior thermal properties and are currently the only non-tension connectors rated to Class AA as per ANSI C119.4 Standard (see an explanation and the table on page 27)

Consider a real-life fault scenario:

- In case of heavy fault current and the three-time reclosing by a Recloser, the 'Bolted Wedge' connectors will struggle to recover quickly enough
- In other words, the Fired Wedge connectors have superior thermal properties compared with 'Bolted Wedge' connectors

Note: Although this thermal testing was rudimentary, it still gives a strong indication of what is happening inside of both connectors

**Note regarding the test results and objectives**

- The tests conducted were basic contact resistance measurements, similar to those conducted regularly on the capacitor bank connectors
- No claim is made that these measurements have the lab accuracy in a controlled environment
- However, the measured contact resistance of 'Bolted Wedge' was consistently much higher than comparable Fired Wedge connector (e.g. 3 to 3.4 times)
- In any case, the results speak for themselves

- The author encourages the network owners and all interested parties to conduct similar tests themselves. The test set up is straightforward —a couple of connectors, a piece of conductor, and an appropriate good-quality micro-ohm meter.
- The author is also open for questions, suggestions, and discussion

**Important:**

No name of the product nor manufacturer is revealed because the study aims to compare the design and concept of these two connectors, not to blame nor discredit anyone.

It is in the best interest of the Electricity Industry to understand the difference between these two connector designs/concepts and to make well informed decisions in the future.

**Energy losses and the true cost of the 'Bolted Wedge' connector due to an increase in contact resistance over time**

All bolted/compression connectors, including the 'Bolted Wedge' connectors, experience a significant increase in contact resistance over time, resulting in heating and energy losses until they finally fail.

It happens because of: (Refer to APPENDIX 3)

- **High initial resistance** (as with all bolted and compression connectors)
- Degradation of electrical contact interfaces through thermal cycling
- Oxidation of contact areas due to contaminants and environmental effects
- Also -Conductor collapses over time and the bolted/compression and 'bolted wedge' connectors can not follow that collapse

Therefore, due to energy losses alone, the true cost of such a connector over its service life can exceed its original price by order of magnitude. For example, over 10 years in service of such a connector (if it is still there), the average energy losses are approx. US$50 per connector (Ref. #3) Besides -when such a connector fails, the cost increases drastically e.g. costs related to replacements, feeder faults, SAIDI, etc.

In comparison -the true cost of the Fired Wedge connector over the same time increases insignificantly.

Indeed –the rate of the contact resistance increase over time ($\Delta R/\Delta t$) has been measured in laboratory and field tests, as follows:

- Fired wedge connectors: 0 –1 μΩ/year
- Bolted/compression connectors, PG type clamps, etc. : 30 –3600 μΩ/year (Ref. #3)

**Summary of comparison of electrical properties: Fired Wedge vs 'Bolted Wedge'**

- The Fired Wedge sliding distance is approx. 4x longer than that of the Wedge Mechanism
- The abrasion rate is approx. 4x higher
- The thickness of oxide film & other contaminants is approx. 3x lower
- The real contact area of abraded surfaces of the Fired Wedge is much larger
- Moreover, the partially abraded areas of 'Bolted Wedge' connector are in the wrong place e.g. away from the main current; The main current goes through the Interface which doesn't move, and its contact areas with conductors are unabraded

Comparing the paths of electrical current

- Fired Wedge -all contact areas on the direct path of electrical current are fully abraded
- 'Bolted Wedge' -all contact areas on the direct path of el. current are not abraded at all e.g. they have a high contact resistance as any other bolted connector

**The total Contact resistance of the Fired Wedge connector is approx. 3 times lowerthan of 'Bolted Wedge'**

- Indeed, it is easy to realize that applying the same contact pressure on the abraded and unabraded surface would result in different contact resistance

Note: This comparison is for the equivalent connector size & under the same contact pressure of approx. 14kN

**'A picture is worth a thousand words'**

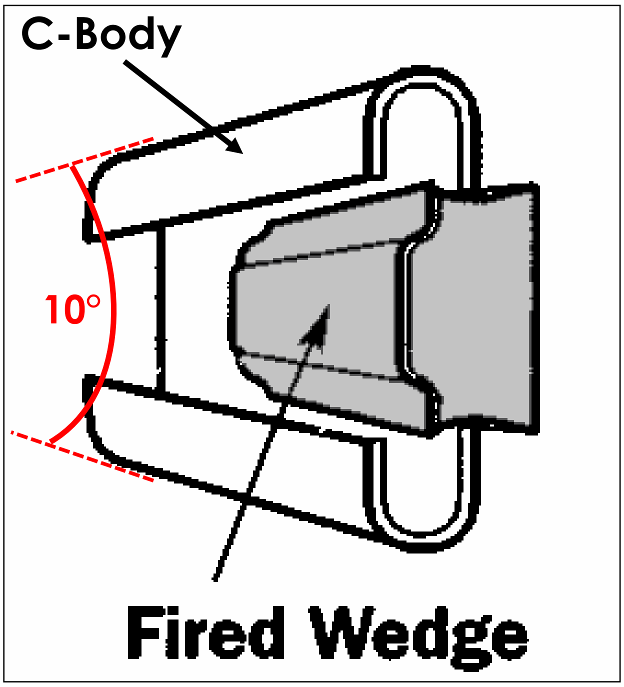
**2. Material and Mechanical Properties of the C-shaped spring member**

- The mechanical properties of the C-body are the most important to the reliable mechanical & electrical function of wedge connectors
- The C-body must provide a spring-effect that is elastic enough to compensate for conductor compaction and thermal cycling due to high fault currents
- It must prevent conductor creeps and keep a near-constant mechanical load on conductors during the service life of the connector
- In other words -it must constantly compensate for the mechanical stresses under severe operating & environmental conditions, including stresses caused by the heat released due to fault currents

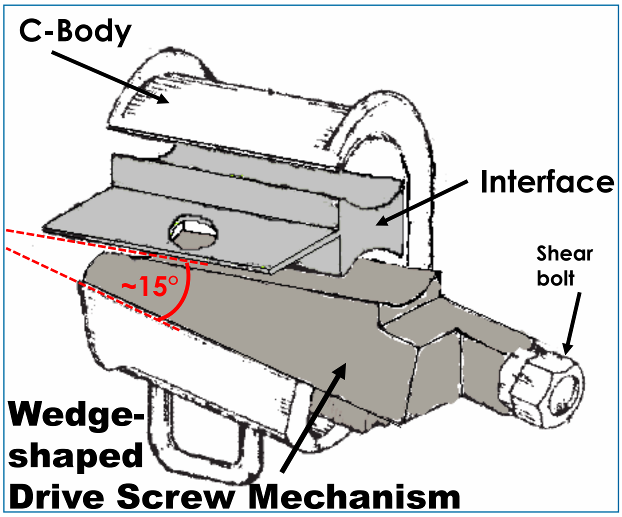
Therefore, the spring-effect is critical

Let's compare the design, materials, compression forces, spring effect, and operation of Fired Wedge connector vs 'Bolted Wedge'

**Let's compare the design**

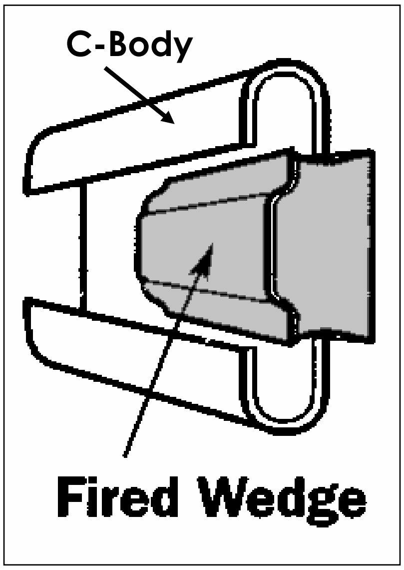



- Two (2) components only(compact, simple, and effective)
- The C-body material is strong enough to withstand the full compression forces, and at the same time elastic enough to retain its spring-effect and compensate for thermal cycling (e.g. it maintains the same compression force) (Ref. #4)
- The wedge sliding angle is 2x5 °= 10 °e.g. requires 50% less effort to install due to the so-called 'wedge mechanical advantage'



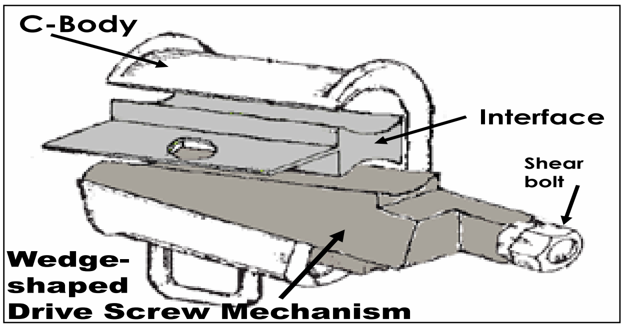

- Four (4) components (bulkier, more complex with potentially more issues, much less effective especially in a harsh environment)
- The C-body material is not good enough to withstand the full compression forces and at the same time to retain its spring-effect (elasticity) and compensate for thermal cycling (e.g. it doesn't maintain the same compression force after exposure to thermal cycling) (Ref. #4)
- The wedge sliding angle approx. 15 °e.g. it requires 50% more effort to install

**Let's compare applications in harsh environment**




Suitable for all environmental conditions:

- Due to beneficial abrasion of the main contact surfaces during installation -the remaining layer of oxide and other contaminants is minimal
- In an extremely harsh environment like coastal saline areas, this connector can be put in a Gel-box cover and fully sealed to prevent moisture ingress



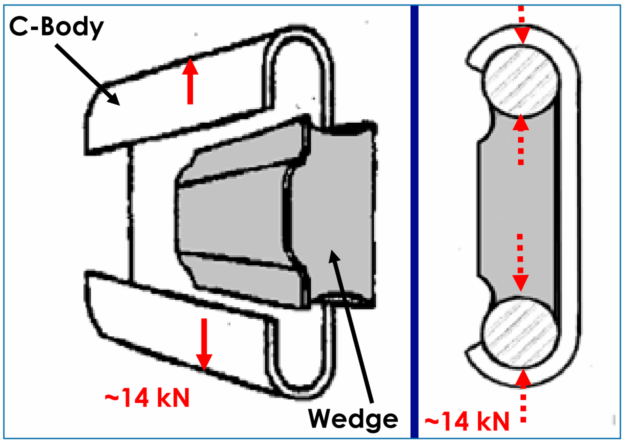

Not suitable for all environmental conditions:

- Since there is no abrasion of the main contact surfaces during installation -there is a thick layer of oxide and other contaminants (a 'gap' on the main current path) which allows for moisture ingress, corrosion, and deterioration

Note: There is some evidence that the wire brushing of conductors is ineffective

- The contact surfaces are particularly vulnerable in an extremely harsh environment like coastal saline areas
- A Gel-box cover would be too bulky and impractical, and that's probably a reason why it is currently not available

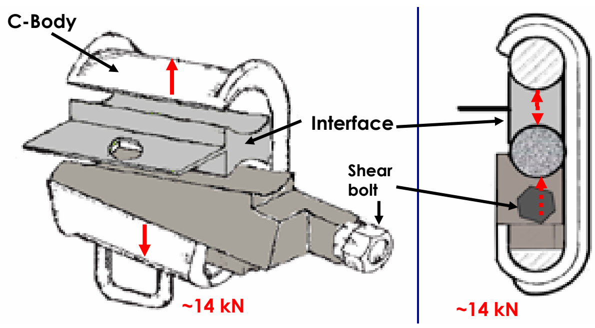
**Let's compare the C-body materials and contact forces**




__Aluminiumalloy AA6061__

- **Wrought alloy** (precipitation-hardened, commercial grade) (Al97.9; Si0.6; Mg1.0; Cu0.25; Cr0.2)
- Tensile yield strength: 276 Mpa(40 000 psi) (Ref. #4)
- A very good spring-effect (e.g. ~ 70% better than A356) which means that the conductor remains under constant pressure regardless of thermal cycling

**Uses:** Structural alloy, commonly used in automotive, aircraft & other aerospace structures(e.g. CubeSats –mini-satellites), marine (e.g. breathing gas cylinders for scuba diving & compressed-air breathing apparatus), cycling, etc.




__Aluminiumalloy A356.0-T6__

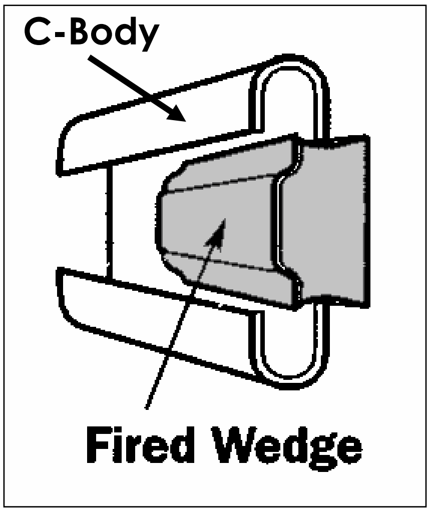
- Sand-cast alloy (e.g. economy method, cheap) (see APPENDIX 4)(Al 92.4; Si 7%; Mg 0.3%; Fe 0.2 (max); Zn 0.1 (max))
- Tensile yield strength: 165 Mpa(24 000 psi) (Ref. #4)
- A weak spring-effect (~ 70% less compared to

AA6061) e.g. this C-member has very little flex and the pressure on the conductor reduces over time due to thermal cycling

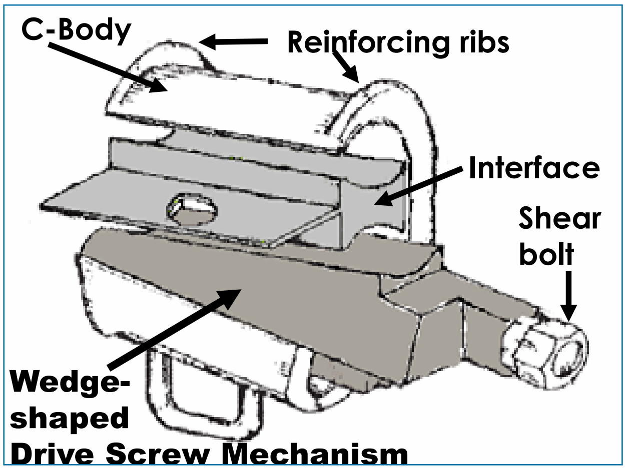
**Uses:** Mainly for non-structural applications like furniture castors and automotive (e.g. cylinder blocks, water pump housing, and car wheels)

**Important Note:** The tensile yield strength determines the upper limit to forces (max allowable load) that can be applied without producing permanent deformation e.g. a higher tensile yield strength results in better spring-effect (elasticity)

**Let's compare the speed of operation and its effect on performance**



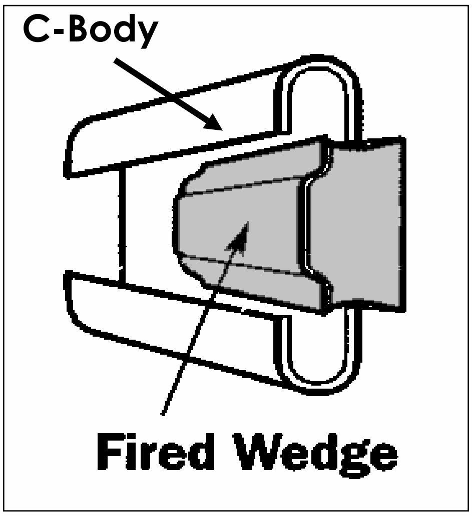

- The Firing Force propels the wedge with high velocity, almost instantly e.g. in less than a second (quick & smooth action)
- It provides a decisive, consistent, and uniform abrasion of main contact areas (e.g. in one go, no stop-and-go)
- The wedge insertion doesn't depend on the installer's skill, and there is no room for human error whatsoever
- This action drastically reduces the thickness of the oxide film and other contaminants, increases real contact area, and reduces contact resistance



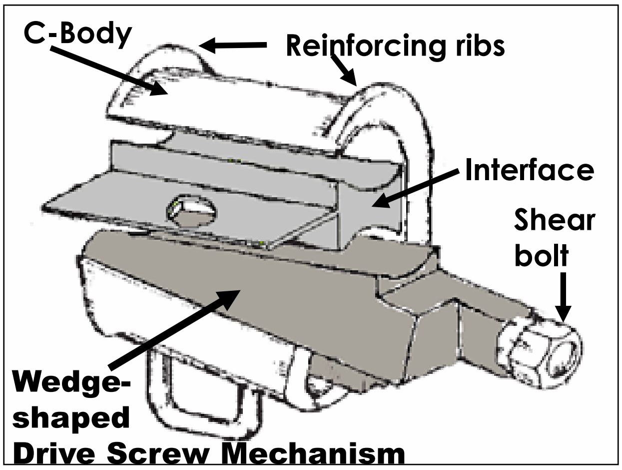

- The wedge mechanism is driven slowly & intermittently with both the regular & impact wrench
- The speed of the insertion of a wedge mechanism by a skilled person:
  - Impact wrench: 9+ sec, with a couple of repeats until the bolt head shears off
  - Manually: 20+ sec, with several stop-and-go until the bolt head shears off
- There is no abrasion of the main contact surfaces on the main path of the current
- In fact -the small abraded areas are away from the main current path and they insignificantly improve the contact resistance
- The wedge mechanism is driven only about 1/5 of the total length of the connector
- Also, this type of motion on partially abraded areas creates inconsistency because of:
  - slip-stop mechanism (stop-and-go), and (Ref. #1 and APPENDICES 4 and 5)
  - 'prow' effect (Ref. #1 and APPENDICES 4 and 5)

**Note: The insertion of the wedge mechanism depends on the installer's skill(workmanship), and there is plenty of room for human error, as follows:**

**Let's compare the wedge insertion methods, and potential human errors (workmanship)**




- Once the installer initiates the wedge insertion, it happens in less than a second, and the creation of contact is independent of his further actions
- There is no room for human error whatsoever




- Shear-bolt (breakaway bolt) provides only a positive indication, but not a proof for correct contact pressure
- It can be highly inaccurate & misleading because it depends on many factors like:
- Coefficients of friction in the thread
- Coefficients of friction between the wedge and C-body and tap conductor
- Conductor size
- Temperature
- The wedge angle
- Speed of wedge insertion, etc.

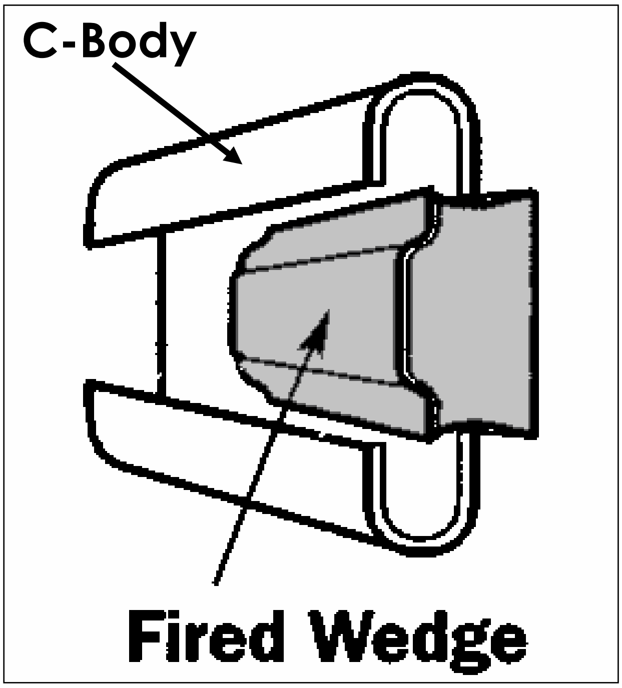
Additionally, the accuracy of a breakaway bolt head shearing off at preset shear point is highly dependent on the tightening method, and is open to human errors, as follows: (Ref. #5)

- Wrench on an angle (other than 90 °) relative to the bolt axis –possible premature shear off
- The drive socket is not fully engaged with the shear-bolt head -the head could simply twist, instead of breaking off cleanly at the specified torque
- Incorrect socket size (e.g. slightly different size between the metric and imperial)
- The impact wrench creates heat from friction and increases a chance of the thread galling

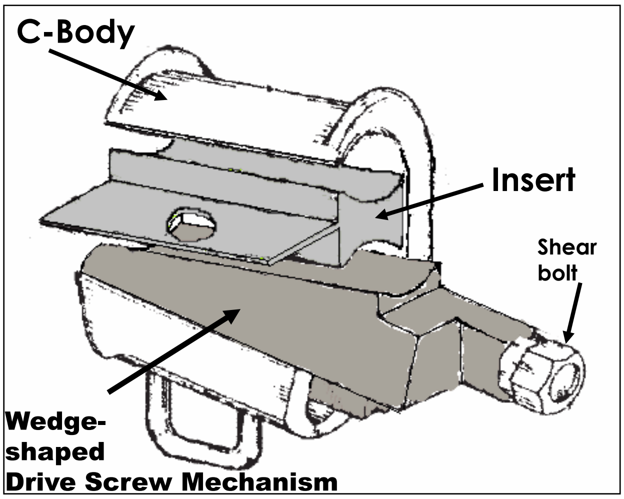
Therefore, the shear off force can be much wider than one specified by the manufacturer (e.g. 10-12 ft-lbs), resulting in the inconsistency of clamping force, and potentially in overtightened or loose connections (if the bolt head shears off prematurely) (Ref. #5)

Note: The manufacturer claims that a 'Bolted Wedge' connector may be reused with changing only the shear-bolt and reusing the wedge mechanism (which serves as a nut). However, most manufacturers in the engineering industry recommend that critical nuts and bolts should never be reused because their threads may have already changed mechanical properties during previous use e.g. changes in friction coefficient, potential thread damage, etc.

**Let's compare the range-taking**



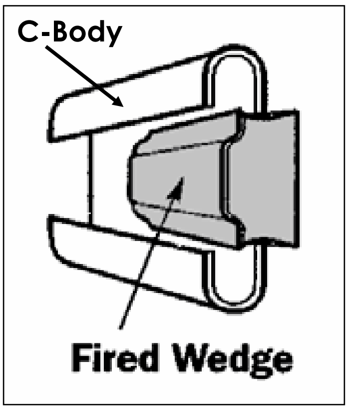
**Narrow range-taking** –several different connector sizes to accommodate various conductor sizes
- Narrow range taking contributes to even more consistent and uniform creation of large real contact area and low contact resistance



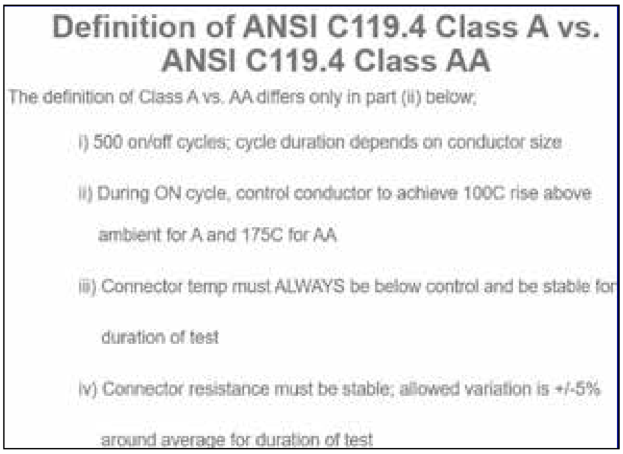

**Wide range-taking** –accommodates conductors "from #6 to 2150" Although well-intentioned, this, in fact, can be counter-productive, and it will allow for more human errors e.g. it changes the relative geometry, contact areas, shear-off point, the sliding distance, etc. Different conductor sizes will potentially have an adverse effect on:

- Compressive strains induced in the clamped conductors e.g. it causes more deformation on smaller conductor sizes
- It will further add to the inconsistency of shearing of shear-bolts due to change in friction between the wedge and tap conductor e.g. it might shear off prematurely or too late (Ref. #5)
- Also, the performance of this type of bolt can be affected by temperature and humidity changes

**Let's compare the connector classes**




**Class AA** connector as per ANSI C119.4
- Tested by independent labs and **Passed** the Class AA
- In fact -the Fired Wedge connector is the only non-tension connector that successfully and comfortably passed this test
- The difference between Class AA and Class A is critical for the long-lasting and reliable operation of connectors


**Definition of ANSI C119.4 Class A vs. ANSI C119.4 Class AA**

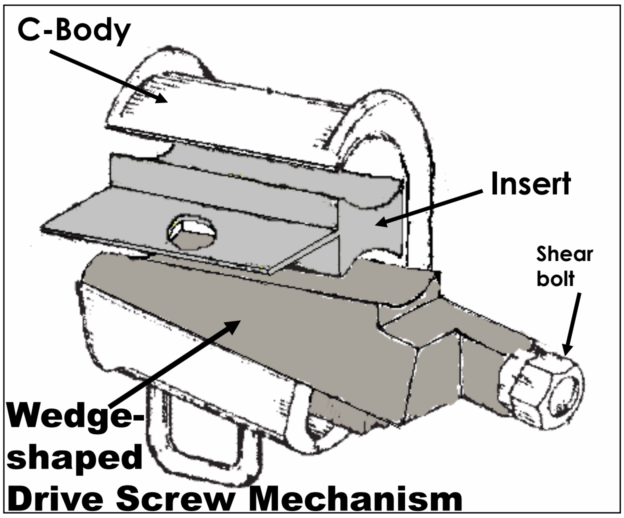
The definition of Class A vs. AA differs only in part (ii) below;

i) 500 on/off cycles; cycle duration depends on conductor size

ii) During ON cycle, control conductor to achieve 100C rise above ambient for A and 175C for AA

iii) Connector temp must ALWAYS be below control and be stable for duration of test

iv) Connector resistance must be stable; allowed variation is +/-5% around average for duration of test



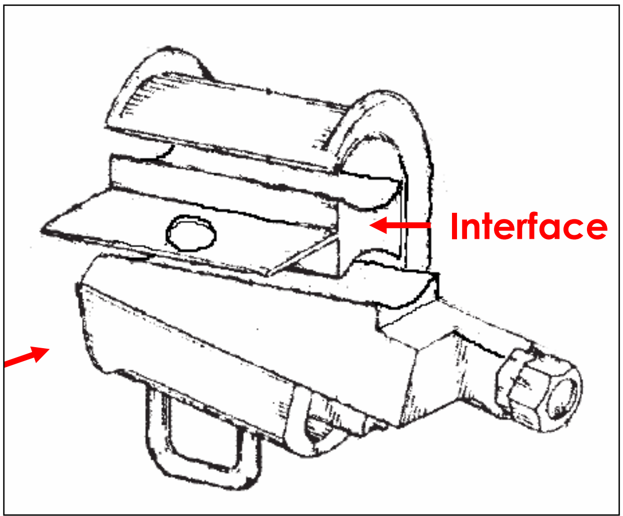

**Class A** connector as per ANSI C119.4
- Tested to Class AA by independent labs but **did not Pass**
- Therefore, the Bolted Wedge connector can not withstand the thermal cycling test e.g. it is not reliable and stable at 175 °C above ambient

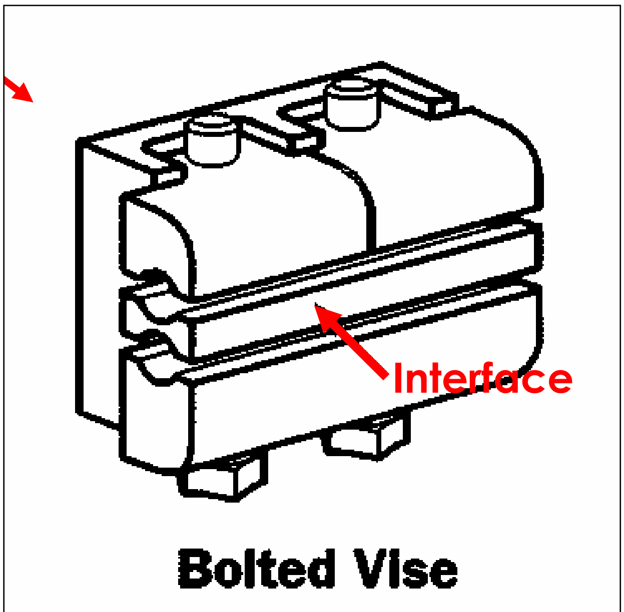
Note: A contact resistance increase to 1400 micro-ohms can increase the temperature by 140 °C. (See APPENDIX 1)

**Can the 'Bolted Wedge' connector claim the benefits of the wedge connection principle?**

The presented test results and other considerations based on international experience strongly suggest that:

- The partial abrasion caused by the wedge-shaped drive screw mechanism on the bottom part of the tap-conductor & C-body does nothing to improve the connector's total contact resistance
- Therefore, in electrical terms, the 'bolted wedge' doesn't have any advantages of the real Fired-Wedge connector principle whatsoever
- In fact, the contact resistance of 'Bolted Wedge' connectors is comparable and/or somewhat better than that of other bolted connectors or PG clamps




In conclusion:

- The so-called 'Bolted Wedge' connector CANNOT claim the benefits of the true wedge connection principle.
- Any such a claim is highly misleading and gives a false interpretation of the real nature of the industry's well-recognized and proven fired-wedge connection principle.
- It seems that the so-called 'Bolted Wedge' connector is just an improvement of the other ordinary bolted connectors e.g. Bolted Vice connectors or PG clamps

- In any case, the network owners can make their own conclusions

**A reminder of the Murphy's law: 'Whatever can go wrong,will go wrong'(after only 14 months in harsh environment)**

**The facts speak for themselves**

The Fired Wedge connectors are superior to all other non-tension connectors because of:

- The biggest Real Contact Area compared with all other connectors
- The lowest Contact Resistance compared with

all other connectors
- The lowest failure rate compared with all other connectors
- The most reliable connector of all known connectors
- The longest service life of all known connectors
- The lowest total lifetime cost of all known connectors (Ref. #1, 2, 3 and APPENDIX 4)

**A decision is yours**

It is now on you –the Network Owner, to make a conclusion and informed decision about the most critical component of your network –the connectors:

- Do you want to improve the reliability and safety of your network (SAIDI, etc.) by installing the best and industry-proven concept and design?

or

- Do you want to please the installers by making it superficially easier for them, while at the same time leaving the most critical component of your network open to more human errors?

In other words –for the most critical component of your network, would you install:

- Materials that are used in the aerospace industry as structural elements?

or

- Materials that are used for furniture castors (e.g. a cheap alternative)?

Don't forget that a circuit (feeder) is only as strong as its weakest connector!

**Note regarding studies, experimental research, and practical field test used in this presentation**

The previous considerations are based on multidisciplinary studies of the electrical contacts by prominent scientists and engineers of the West and the East, with practical applications approach to the subject, and based on real-life experience and case studies.

For example, many studies, experimental research, and practical tests have been conducted at Hydro-Quebec Research Institute and by the Canadian Electricity Association in cooperation with the top international material science and tribology experts.
All of these studies agree that the Fired Wedge Connection principle is superior to other types of non-tension connections in most electrical and mechanical aspects, providing a safe, reliable, and longest-lasting path for electrical current in distribution and transmission networks applications.

**References**


1)'Electrical Contacts –Fundamentals, Applications and Technology' by M. Braunovic, V.V. Konchits, N.K. Myshkin
2) 'Mechanical and Electrical Contact Properties of Wedge Connectors' by J. Schindler (IEEE), R. Axon, R. Timsit(IEEE), IEEE Transactions on components, packaging, & manufacturing technology –Part A, Vol.19, No.3, September 1996
3) IEEE Publication 'Energy losses in power tap-connectors' by R. Timsitand J. Sprechel(ESMO '98 -1998 IEEE 8th International Conference on Transmission and Distribution Construction, Operation and Live-Line Maintenance Proceedings)
4) Material Data Sheets (properties) for Alumin ium alloys AA6061 and A35: http://asm.matweb.com/search/SpecificMate rial.asp?bassnum=MA6061T6and http://www.matweb.com/search/data sheet_print.aspx?matguid=d524d6bf305c4ce 99414cabd1c7ed070
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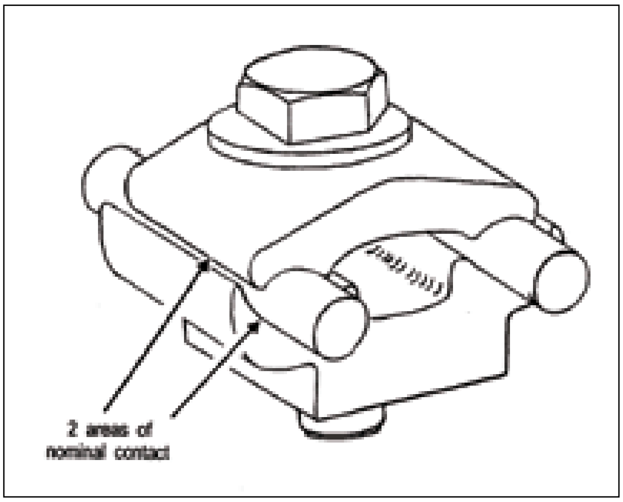
6) 'Electrical connectors for overhead lines -Evaluating assessment and test methodologies to improve quality' by Babakov, Morton and Li, Powertech Labs & Robyn Pascal, CEATI International (published in T&D magazine, fall 2015)
7) Grossmann, Lobl, and Bohme study "Contact Lifetime of Connections in Electrical Power Systems"
8) 'Bolted Wedge' Installation videos on YouTube https://www.youtube.com/watch?v=dYxPpdO6vp4and https://www.youtube.com/watch?v=OSoYsRJezD0

**APPENDIX 1.1: The industry experience -Connection Contact Resistance vs Connection Torque**




Source:
EEA NZ Conference 2017 TRANSPOWER's Paper: 'Islington Substation VAR Static Compensator Fire Investigation'

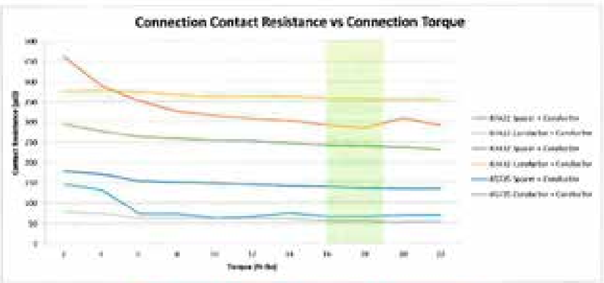


Figure 8: Capacitor terminal contact resistance vs fastening torque

Note: Although the concept of PG clamp is different from the Fired Wedge and 'Bolted Wedge' connectors,they all have a very similar relative geometry and configuration, as follows:

- Two metal parts separating 2 conductors: Clamp halve/halve; Wedge/C-body; and Interface/Wedge mechanism/C-body
- Two areas of nominal contact between each conductor and corresponding clamping components
- The contact pressure of approx. 14 000 N under similarly applied torque of 12-14 ft-lbs

Therefore, the Contact Resistance values of PG clamp for cap-banks can be used as a reference/ benchmark for this study e.g. measured on unabraded contact areas between conductor & metal body, and adjusted to the equivalent connector and conductor size, and under the same clamping force

**APPENDIX 1.2: Industry experience -Typical values of contact resistance vs applied torque on capacitor bank connections**

| Torque | | Contact Resistance | |
|---|---|---|---|
| (ft-lbs) | Conductor Clamp + Conductor | Capacitor Stem + Conductor | Conductor + Conductor |
| 2 | 179μΩ | 125μΩ | 295μΩ |
| 4 | 171μΩ | 127.1μΩ | 278μΩ |
| 6 | 154μΩ | 114.3μΩ | 263μΩ |
| 8 | 151μΩ | 203μΩ | 259μΩ |
| 10 | 149μΩ | 199μΩ | 254μΩ |
| 12 | 145μΩ | 120.9μΩ | 253μΩ |
| 14 | 141.3μΩ | 112.6μΩ | 247μΩ |
| 16 | 139.4μΩ | 109.6μΩ | 242μΩ |
| 18 | 135.8μΩ | 105.3μΩ | 240μΩ |
| 20 | 134.7μΩ | 106.4μΩ | 237μΩ |

Note: Capacitor banks have stringent requirements regarding the contact resistance:

- The contact resistance is measured on each bushing and must be within 150 micro-ohms between the capacitor stem and conductor
- A contact resistance increase to 1400 micro-ohms can increase the temperature by 140 degrees
- However, increasing torque above 14 ft-lbs (overtightening) doesn't improve the contact resistance too much, it can only damage both the connector and conductors

**APPENDIX 2: Testing standards -ANSI C119.4**

According to ANSI C119.4, a connector is deemed to fail when any of the following conditions are met:

1) the connector temperature exceeds the temperature of the control conductor,

2) the connector temperature is unstable in that the difference at any time between the temperature of the connector and that of the reference conductor exceeds by more than 10°C the average difference measured up to that juncture (following 25th current cycle); this will be identified as temperature differential failure (TDF),
3) the electrical resistance of the connector (measured from the equalizers attached to the conductors) exceeds the average resistance over the connector specimens under test by 5% after 25 current cycles; this will be identified as resistance stability failure (RSF).

**APPENDIX 3.1: Failure mechanism of bolted and compression connectors**

According to the study "Electrical connectors for overhead lines -Evaluating assessment and test methodologies to improve quality" by Babakov, Morton and Li, Powertech Labs & Robyn Pascal, CEATI International (published in T&D magazine, fall 2015) (Ref. #6):

"Most connectors fail due to an increase of electrical resistance over time to a high enough value that a rapid deterioration of the connector occurs, resulting in destruction due to electric overheating. The cause of an increase in electrical resistance is usually a combination of several factors:

- **High initial resistance** due to improper assembly/installation or defective materials
- Degradation of electrical interfaces in the connector through **thermal cycling**
- Oxidation of electrical interfaces due to **contaminants and environmental effects"**

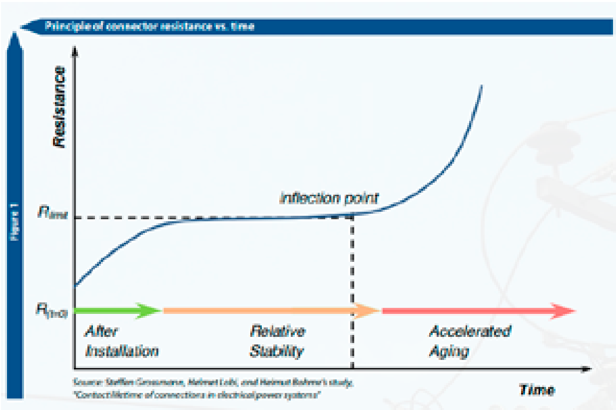
The "Bolted Wedge" connector concept has all predispositions for the rapid progression of the above type of failure once its electrical resistance reaches a critical value, as follows:

**APPENDIX 3.2: Factors that influence rate of change in contact resistance**

As per Grossmann, Lobl, and Bohme study "Contact Lifetime of Connections in Electrical Power Systems" (Ref. #7) there are three factors that affect the rate of change of contact resistance:

- Rate of connector joint expansion/contraction due to thermal and mechanical stress
- Rate of conductor and connector oxidation/ corrosion
- The temperature of the connector

Once the electrical resistance of the connector reaches a critical value, there will be either arcing or overheating, resulting in a quite rapid progression to failure.




**APPENDIX 4.1: A textbook case from 'ELECTRICAL CONTACTS Fundamentals, Applications, and Technology' by M. Braunovic, V. Konchits, N. Myshkin(Ref. #1)**

Advantages of fired wedge connectors:

"Powder activation (e.g. firing a wedge) **provides consistent and uniform performance…**

- Rapid mechanical wiping action as the wedge is driven between the conductors breaks down surface oxides and **generates superior contact points thus reducing overall contact resistance**
- The **spring effect** of the C-body **maintains constant pressure** for reliable performance under severe load and climatic conditions…
- Electrical performance of fired-on wedge connectors are excellent due to the **low contact resistance developed during installation"**

**Note:** A very important advantage of Fired Wedge connectors is the elimination of humanerrors during the most critical part of the installation of a connector e.g. during themaking a reliable, highly conductive, and stable contact

Also, there is no need for a surface preparation, which is dubious and inconsistentpractice, and subject to human errors

**APPENDIX 4.2: A textbook case from 'ELECTRICAL CONTACTS Fundamentals, Applications, and Technology' by M. Braunovic, V. Konchits, N. Myshkin(cont'd) (Ref. #1)**

Disadvantages of bolted wedge connectors:

- "Mechanical wedge connectors (e.g. bolted) are installed with wrenches, require more physical exertion for installation, and show more **inconsistent performance** due to **discrepancies caused by contaminants** on the hardware and **wide tolerances of shear-off bolts**

- Mechanical wedge **spring bodies** are typically manufactured by casting which produces **much less spring action to maintain the connection**
- Higher energy losses due to **higher contact resistance"**

**APPENDIX 5.1: Stop-and-go motion (stick-slip) effect on 'Bolted Wedge' connector performance (Ref. #1)**

Note: It has been proven that the sliding of the wedge mechanism in the "Bolted Wedge" connector does not improve its contact resistance for various reasons (see the study above).
For those who still believe it does -they should take into account the following considerations:

Using a wrench to push the wedge mechanism into the C-body is inconsistent, slow, and intermittent. It depends on the lineman's skills, strength, speed of wrenching, etc.

- As a result, it creates a so-called 'Stick-slip'(intermittent) motion of the contact surfaces relative to each other, because of two different and competing friction forces –Static friction (adhesive) and Dynamic friction (slips)
- In other words –this stop-and-go motion (on micro-scale) causes sharp jerks between the wedge mechanism and the C-shaped spring body, resulting in the friction-induced vibrations
- The friction-induced vibrations accelerate the formation of loose debris of work-hardened metal particles between the surface contacts
- These work-hardened particles are very abrasive and cause high wear and damage to the contact surfaces
- It results in the reduced real contact area and increased contact resistance
- In the harsh environment it can also increase chances of corrosion between contact surfaces and premature failure because even if there is an inhibitor on contact surfaces during the installation, there is always oxygen present between the contacts which builds up an oxide film at the rate of 2 nm per second

**APPENDIX 5.2:**
**The 'Prow' effect in Fired Wedge and "Bolted Wedge" connectors (Ref. #1)**

The "Prow" effect (e.g. effect of a ship's prow on the waterline)

- The initial sliding of the wedge causes the so-called 'prow' formation due to the metal transfer and plastic shearing deformation
- It is effectively a build-up of severely work-hardened metal lumps (the prow) on the C-body surface at the moving front edge of the wedge

Note: The deformation is elastoplastic and hardening. The hardening is especially pronounced if the movement stops or slows down because the metal has time to cool down and stabilize

**<u>In the case of Fired Wedge connector:</u>**

- Since the sliding continuous uninterrupted and under the constant force, the local prow formations are back-transferred to the C-body surface while new prow formations are formed until the end of the movement
- This motion causes the so-called plough effect which is a formation of ridges and valleys which mate with each other and form a large contact surface
- Effectively, the rubbing surfaces adapt one to another, reaching so-called equilibrium roughness and creating maximum real contact surface with a low contact resistance
- Most importantly, a decisive movement of the fired wedge removes a tiny layer of oxide and impurities and does not allow a build-up of that film

**APPENDIX 5.3: The 'Prow' effect in Fired Wedge and "Bolted Wedge" connectors (cont'd) (Ref. #1)**

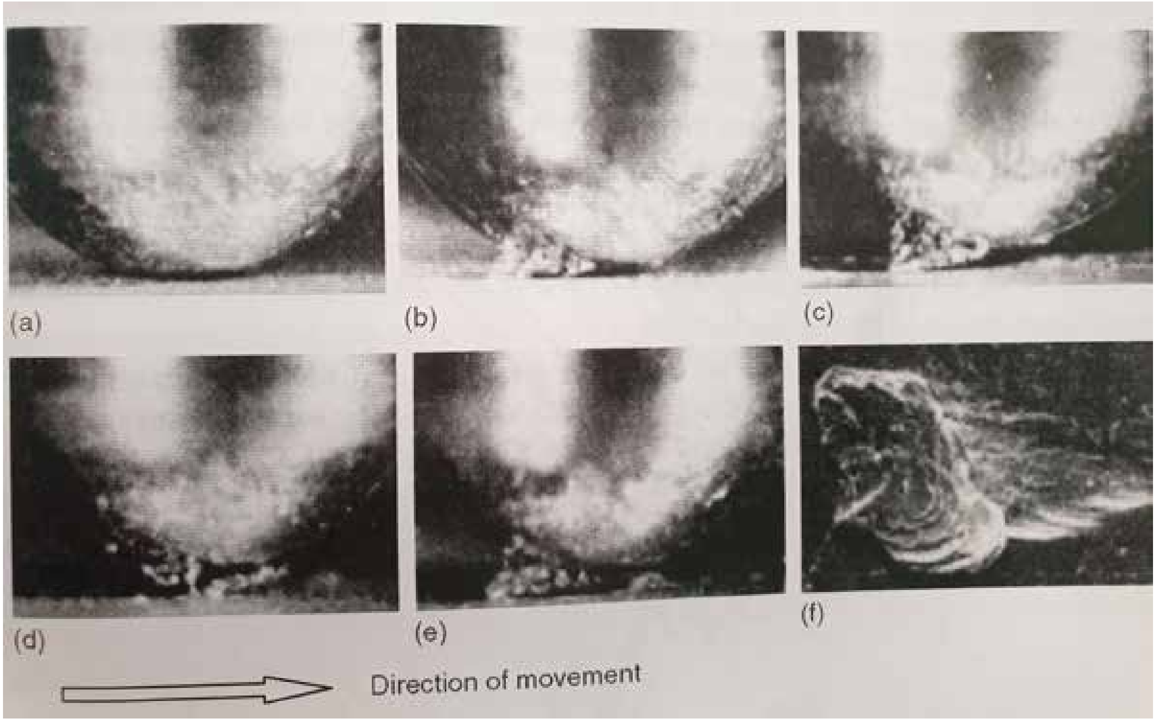
**<u>In the case of 'Bolted Wedge' connector:</u>**

- When the wedge mechanism moves slowly against the C-body and tap conductor, its edges push and raise the inner surface metal layers of C-body and conductor (on microscale) and cause a similar effect as a ship's prow on the waterline
- When the movement is inconsistent and/or stops temporarily e.g. during the slow manual pushing of the wedge by lineman hand/wrench, it allows for work-hardening of that lump (e.g. cooling down) because the pressure is relaxed; it, in turn, causes the work-hardened particles to detach from the C-body; it finally results in a formation of debris (hardened particles) which

are highly abrasive and trapped between the wedge mechanism & C-body, and the wedge mechanism & conductor

- With the next movement of the wrench, these highly abrasive particles are crushed and the contact surface experiences significant cutting and deformation, which in turn significantly reduces the real contact surface
- Effectively, with stops and re-starts, the so-called run-in conditions occur again and cause a high wear rate

**Example of Prow formation (Ref. #1)**




**Real contact area vs Apparent (Ref. #1)**

**TABLE 1.1**
**Effect of Normal Load on Real Area of Contact for Clean Surfaces**

| Alloy[a]/Applied Load | Real Contact Area/Apparent Contact Area ($A_r/A_a$) (%) 10 N | 100 N | 1000 N |
|---|---|---|---|
| Al (H-19) | 0.01 | 0.1 | 1.0 |
| Al (H-0) | 0.05 | 0.5 | 5.0 |
| Al+0.75% Mg+0.15% Fe (H-19) | 0.01 | 0.1 | 1.0 |
| Al+0.75% Mg+0.15% Fe (H-0) | 0.02 | 0.2 | 2.0 |
| Cu (H-0) | 0.008 | 0.08 | 0.8 |

[a] (H-0), fully annealed; (H-19), fully hardened.

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## Farewell to Mr. Andrew Daka, Executive Director, of Pacific Power Association

The Pacific Power Association (PPA) Secretariat Staff and Chairman, Mr. Hasmukh Patel, CEO of Energy Fiji Limited, farewelled Mr. Andrew Daka the Executive Director of Pacific Power Association who has completed his contract this year. Mr. Daka has been the Executive Director for the past nine years from 2011 to 2020. The Secretariat acknowledges the contribution that Mr. Daka has contributed to PPA during his tenure with the Association.

The PPA Secretariat and the Board would like to wish Mr. Andrew Daka all the best in his new journey and future endeavors. And a big Vinaka Vakalevu from your PPA family.

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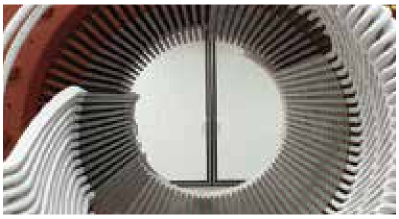

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