MATERIALS PERFORMANCE
CORROSION
INNOVATION OF THE YEAR AWARDS

2021 Award Nomination

Title of Innovation:

NiobiCon™ Underwater Electrical Connector

Nominee(s)

Harvey Hack, Jim Windgassen, Megan Owens, Keith Johanns

Category:

(select one below)

Coatings and Linings	Instrumentation
Cathodic Protection	Testing
Materials Design	Modeling/Risk Assessment
Chemical Treatment	Other—Materials Selection

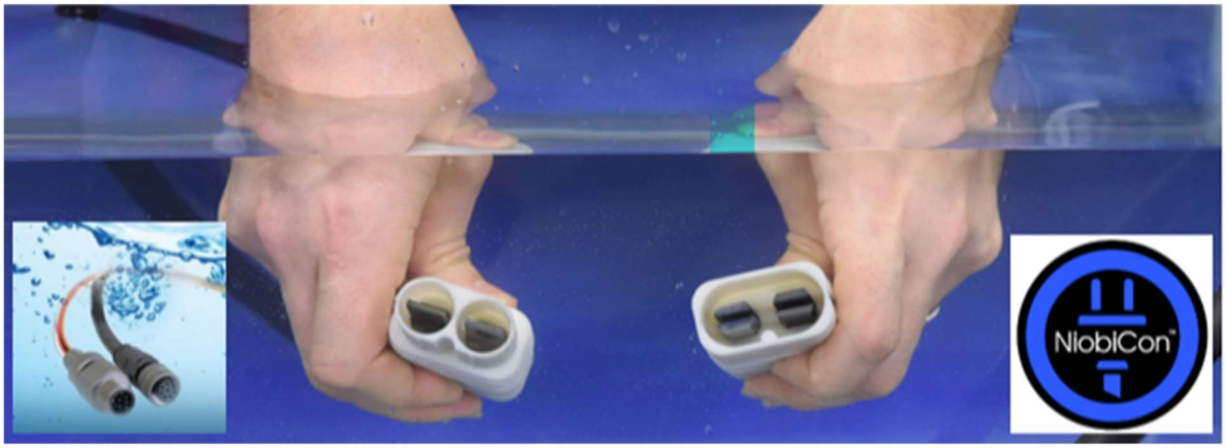
Dates of Innovation Development:

1/2014-Present

Web site: www.northopgrumman.com/niobicon

Summary Description:

Northrop Grumman engineers have developed an innovative wet-mate connector technology that is simple, safe, reliable, and cost-effective. This novel connector technology, referred to as NiobiCon™, allows for power transfer and data exchange without using seals, oils, or complex mechanical components. NiobiCon™ can be mated and de-mated while the fully-powered electrical contacts are exposed to seawater because its contacts are made from niobium, element number 41 on the periodic table. When niobium is in contact with water, it reacts to create a passive film that acts as an insulator, which prevents electricity from flowing into the water surrounding the contacts. Rather than relying on complex designs with seals and oils that are used in traditional wet-mate connectors, NiobiCon™ relies on the water surrounding the contacts to form the insulation. Electrical contacts made from niobium will not corrode or present a shock hazard to a user while touching the contacts with a bare hand. Electronics will not short out when using niobium. Other key features of the NiobiCon™ technology include low voltage operations up to 60 VDC, nearly infinite number of mates and de-mates without maintenance, no inherent depth limit for operation, low mating force requirements, connector designs that allow for loose alignment tolerances, non-traditional designs where no connector shells would be used at all, design flexibility enabling miniaturization, and manufacturing processes that significantly shorten the timeline from order-to-delivery. Therefore, NiobiCon™ connectors can be smaller, lighter, safer, more reliable, and cost effective than current wet-mate connectors.



Full Description

1. What is the innovation? The innovation is an electrical connector where the contacts will not corrode or short out even when fully immersed and powered in seawater or other corrosive media. This new connector technology does not need to exclude water from the contacts, so it requires no seals or dielectric oil.

2. How does the innovation work? Traditional underwater connectors make their electrical contacts from the same materials that they use in air, brass or copper typically, and then try to exclude the water from the contacts with seals or oil. NiobiCon™ makes the contacts from transition metals such as niobium which develop highly-insulating passive films in water and other corrosive media and which can experience relatively high applied voltages without these films breaking down. The contact-to-contact scraping that occurs during mating removes this film locally, allowing good electrical contact, and upon de-mating the film re-forms in milliseconds, thus maintaining the insulation. Therefore, these connectors can be fully powered while mated or de-mated without shorting electronics or having the contacts corrode.

3. Describe the corrosion problems or technological gap that sparked the development of the innovation. How does the innovation improve upon existing methods/technologies to address this corrosion problem or provide a new solution to bridge the technology gap? Traditional electrical connectors used in water can short out or corrode if the seals fail, have a short life span, and are mechanically complicated in design. Northrop Grumman Undersea Systems employees Jim Windgassen and Harvey Hack developed a novel connector that address these long-standing issues within the underwater connector market. NiobiCon™ connectors operate safely using a simple design while the live electrical contacts are fully exposed in aqueous environments, such as saltwater. NiobiCon™ connectors will not corrode, short-out electronics, or produce electrical shock when touched. Rather than relying on complex seals and oil to keep water from the bare electrical contacts as in a traditional wet-mate connector, this technology relies on water being exposed to the connector to form a thin self-insulating passive film on the electrical contacts. Electrochemical testing under different laboratory conditions has proven this technology can be safe and simple, yet without seals, the technology is disruptive to the connector industry both below and above the water.

4. Has the innovation been tested in the laboratory or in the field? If so, please describe any tests or field demonstrations and the results that support the capability and feasibility of the innovation. Multiple tests have been performed in the laboratory to both characterize the insulating properties and formation kinetics of the insulating passive film that is formed on niobium in water and to determine which environments this connector can be used in. So far, the connector has been demonstrated to work well in aerated and deaerated seawater and fresh water, at temperatures from freezing to boiling, and in other chemicals such as urea. Niobium should also be a viable solution in most acidic environments and fertilizer solutions.

The insulating passive film that forms on niobium is extremely thin, on the order of 2.4 nm per volt applied, thus making the film thickness only about 150 nm for a 60V connector application (Freeman, Y., *Tantalum and Niobium-Based Capacitors: Science, Technology, and Applications.* 2018, Springer Publishing, New York, NY). Electrochemical impedance testing has proven that the insulating passive film that forms on niobium is stable in thickness but increases in resistance over time (refer to Figure 1). Demonstrations prove that this thin film can be easily scraped off when mating contacts touch, and that the film re-forms in milliseconds when de-mating occurs. The leakage currents into the environment are so low, on the order of microamperes (refer to Figures 2 and 3), that connected electronics are not affected and there is no shock hazard from touching powered contacts in the water. The resulting film will not break down until applied voltages exceed 120 V. Therefore, a conservative maximum operating voltage of a niobium connector in water is 60-75V.

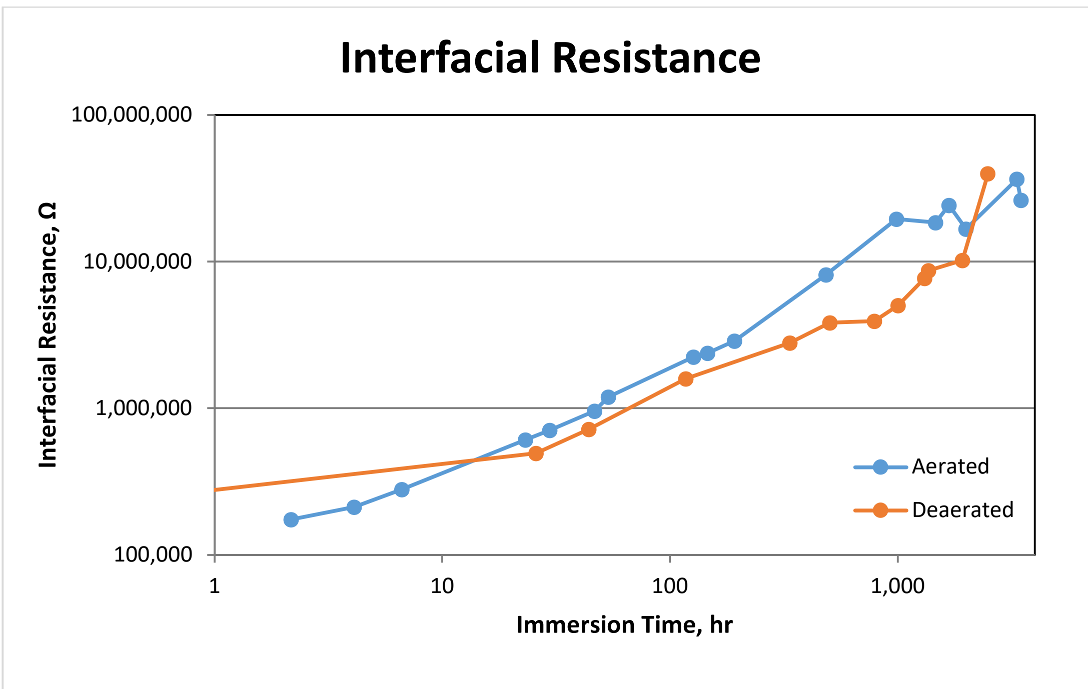


Figure 1 – Interfacial Resistance as a Function of Exposure Time for Niobium in Seawater

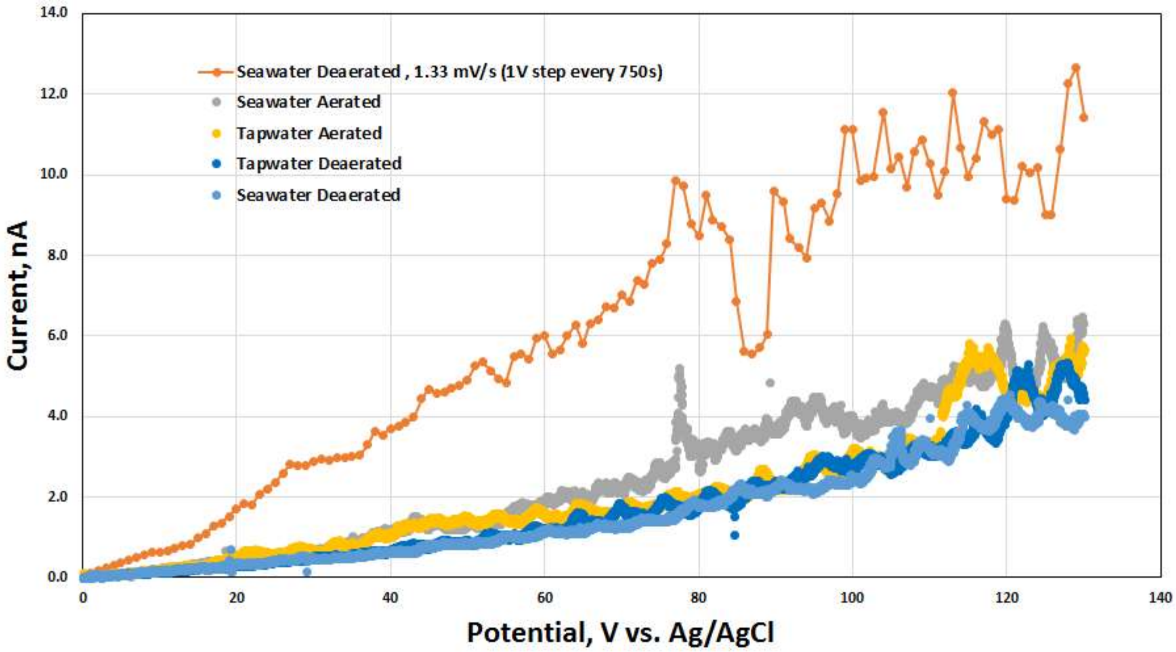


Figure 2 – Niobium Potentiodynamic Sweeps at 1.43 mV/s (25 mV step every 17.5 s)

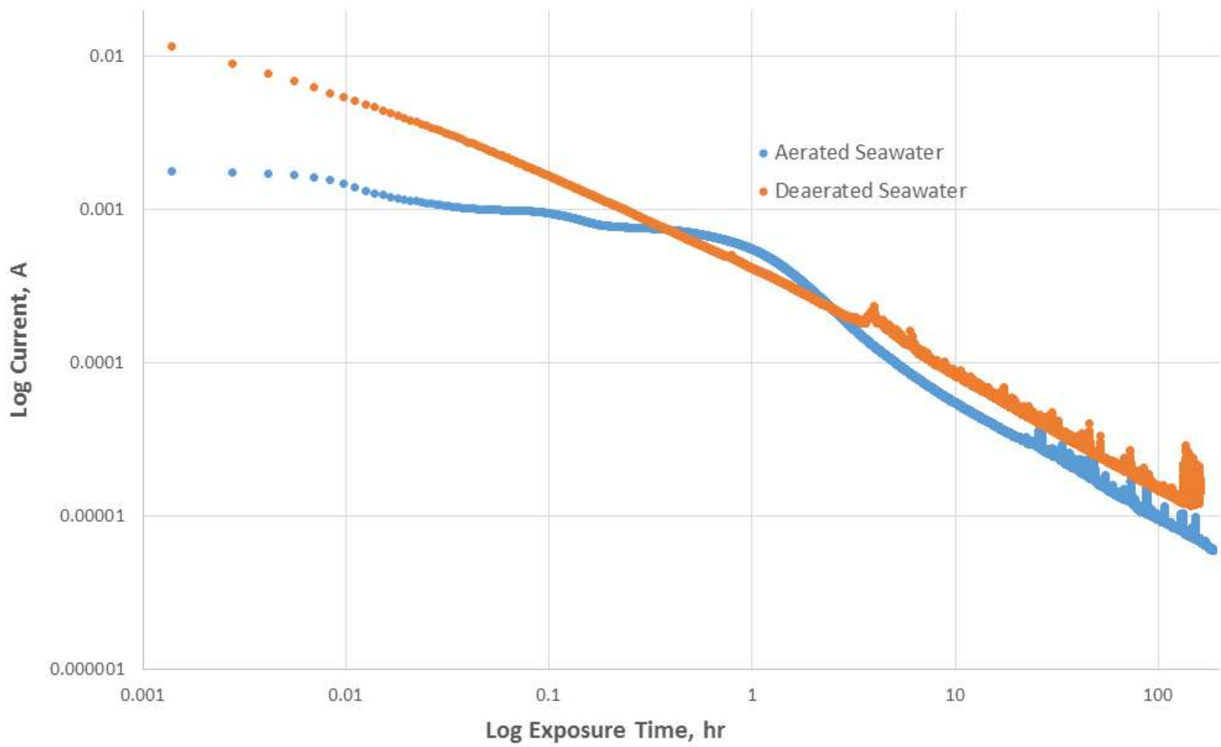


Figure 3 – Niobium at 50 V Constant Potential in Seawater Showing Exponential Decay

5. <u>How can the innovation be incorporated into existing corrosion prevention and control activities and how does it benefit the industry/industries it serves (i.e., does it provide a cost and/or time</u>

savings; improve an inspection, testing or data collection process; help to extend the service life of assets or corrosion-control systems, etc.)? Any place where electrical connections are made that are subject to becoming wet, the NiobiCon™ technology can improve reliability and reduce cost due to the simplicity of design. There is no compressible material in this technology so there is theoretically no limit to immersion depth. Service life is extended because the electrical contacts cannot corrode so connectors cannot fail. This technology also allows for simplification of systems. For example, cathodic protection system anodes can be made to simply plug into their power supply cables without worry about water leakage destroying the contact. Underwater sensors can be simply interchanged underwater without compromising data integrity or requiring additional service time while operating in the field to bring a system up to the surface in order to swap out a connector while in a dry state.

6. Is the innovation commercially available? If yes, how long has it been utilized? If not, what is the next step in making the innovation commercially available? What are the challenges, if any, than may affect further development or use of this innovation and how could they be overcome? A large number of demonstration prototypes and commercial-style prototypes have been built and tested at Northrop Grumman from high current (50A at 50V) to small USB connectors that can work underwater (refer to Table 1).

   Northrop Grumman is in the process of licensing the NiobiCon™ technology to commercial connector manufacturing companies. The first non-exclusive manufacturing license agreement was signed in January 2020 with iCONN Systems LLC, a specialty engineering connector company headquartered in Lombard, IL, see https://www.iconnsystems.com/. iCONN is currently working with prospective commercial and government customers to design, fabricate, and test prototype connectors for their specific applications.

   Two challenges exist which is limiting the technology for expanded market applications, i.e., alternating current (AC) operations and voltages above 120V. When AC is applied to niobium contacts, it leads to the transition metal alternately forming and breaking down the passive film as the current reverses direction. The passive film forming and breaking down cyclically causes higher leakage currents to be passed into the aqueous environment. Methods to enable AC operation are being investigated to demonstrate a functional AC power connector. As previously mentioned, the breakdown potential of the passive film formed on niobium is 120V. Testing is underway to increase the upper limit of a new NiobiCon™ connector through design optimization to several hundred volts which should expand its use in markets such as oil and gas.

   Even with the present design constraints of DC only and voltages below 75V, this technology increases freedom of design significantly. The design of the connector can be as complex as an 8 pin commercial style connector (Table 1, 1.5) or as simple as two open rails (Table 1, 1.9) since a connector shell is not required to keep out water. During demonstrations, the first prototype (Table 1, 1.1), has been mated and de-mated underwater over 1.500 times with no visible wear or degradation in performance.

Connector Form	Image of Connector	Data Rate	Voltage Limitations	Current Limitations
1.1 Original Square Connector		60-80 Mbps using power line ethernet adapter	60-75V DC	55A* Current limited by cable*
1.2 Coaxial High Power		60-80 Mbps using power line ethernet adapter	60-75V DC	55A* Current limited by cable*
1.3 Portable Marketing Case (Bladed Connectors)		60-80 Mbps using power line ethernet adapter	60-75V DC	30A* Current limited by cable*
1.4 Single Contact with Seawater Return (Conceptual Demo)		N/A *Has not been tested	60-75V DC *Demo is limited to 12 V due to LED lights used	Demo is limited by LED lights (150mA). In practice, no foreseen limits
1.5 8-Pin Commercial Style		Unknown rate; Blue ROV command and control + video	60-75V DC	1A contacts* 22AWG
1.6 8-Pin, Bladed		750 Mbps upload 950 Mbps download while flooded *Computer limited speeds	60-75V DC	1A contacts
1.7 Banana Plug		N/A *Has not been tested	5V *Using Ti in lieu of Nb	2A
1.8 USB Connectors		Unknown rate; Able to stream	5V *Standard USB	1A *Standard USB

		high-definition video		
1.9 Underwater Charging-Open Rails (Conceptual Demo)	 	N/A *Has not been tested	60-75V DC *Demo limit is 48V due to power supply	None

Table 1 – Demonstration and Production Prototypes

7. <u>Are there any patents related to the work? If yes, please provide the patent title, number, and inventor.</u> 2 Patents issued: *Electrical Connector Having Male and Female Contacts in Contact with a Fluid In Fully Mated Condition*, US 9197006, Hack; *Underwater Electrical Contact Mating System*, US 9893460, Windgassen, Hack, Matejka. 4 additional patents applied for so far: *AC Power Transfer over Self-Passivating Connectors*, Serial Number 16/200,147 filed on 2018-11-26; *Self-Insulating Contacts for Use in Electrolytic Environments*, Serial Number 16/434,283 filed on 2019-06-07; *Single Self-Insulating Contact for Wet Electrical Connector*, Serial Number 16/784,518 filed on 2020-02-07; and *Signal Connector System*, Serial Number 16/806,575 filed on 2020-03-02