

# Vacuum Bottle Technology and Testing



by Rick Youngblood  
American Electrical Testing Co.

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**V**acuum technology has been in existence for over 60 years but has only become common since 1965 when Eaton and Toshiba placed the first vacuum interrupters in commercial service. Since that time many other manufacturers of interrupters, such as the joint venture of Meidensha, Fuji, and Hitachi, manufacturing the JAEPS (Japan AE Power Systems Corp), ABB, and others, have begun production. These interrupters or bottles, as they are commonly called in the United States, are employed by manufacturers such as Eaton Cutler Hammer, Square D, GE, ABB, Federal Pioneer, Rheinhausen, Turner Electric, and are used in everything from motor starters to circuit switchers. In the utility industry the most common applications are circuit breakers, load tap-changers, reclosers, capacitors, and line switches. Their main features are high reliability, excellent switching capabilities with long electrical and mechanical life, short contact operating stroke, very low contact resistance, no arc, flash or noise, and low chop. They are also very universal in application, and virtually maintenance free with operation counts between 5,000 and 1,000,000 before end of life. Just as in conventional contacts, electrical degradation is limited by increased fault duty rating and arc resistant contact materials. Voltage designs range from 3.3 to 72.5 kV with a BIL/LIL of up to 325 kV and current ranges as low as a few hundred amperes to 63 kA.

## Construction

Basic design encompasses two conducting rods with a contact on the end, one stationary and one moveable. The stationary rod utilizes a flange in the end of the ceramic tube helping to offset any heat developed due to  $I^2R$  losses. The moveable rod operates through the use of a bellows design and moves longitudinally in a ceramic tube. The tube is hermetically sealed on each end by the flange and bellows, then is evacuated of air forming the main switching device.

The moveable shaft is designed to provide antitwist protection to prevent the bellows from cracking during installation or operation. (Fig. 1)



**Figure 1**

Unlike interrupters that use oil or gas as the interruption medium, vacuum interrupters have contacts that are designed to work under vacuum. Since there is no oil or gas, the arcing between the contacts consists entirely of charge carriers produced by evaporation and ionization of the contact material. The vacuum arc is essentially a metal vapor arc. If an electric arc burns in gas or oil, it creates decomposition

products. In a vacuum interrupter, pure metals are vaporized and afterwards redeposited on the surface of the contact when the arc is interrupted at current zero.

The inherent advantages of vacuum interrupters are minimal maintenance and environmental friendliness primarily due to the fact that they have fewer and simpler parts than other types of interrupters and are sealed for life. Most are rated for ten years but typically have a life of 20 or more. Contact materials vary depending on the use of the vacuum interrupters but are typically made from copper tungsten, chromium copper, or alloys utilizing stainless steel. The softer of the alloys are used in lower to medium voltage switching and have excellent current breaking capabilities, whereas the harder materials are used in the higher voltage applications. The type of load to be interrupted controls the type of contact design needed. Softer materials designed in a spiral configuration (Fig. 2) are used in standard medium voltage vacuum circuit breakers and have excellent current breaking capabilities. The current is spread across the face of the contact by the spiral magnetic action due to the contact design. Their advantage is in simple physical structure and low power loss at nominal currents.

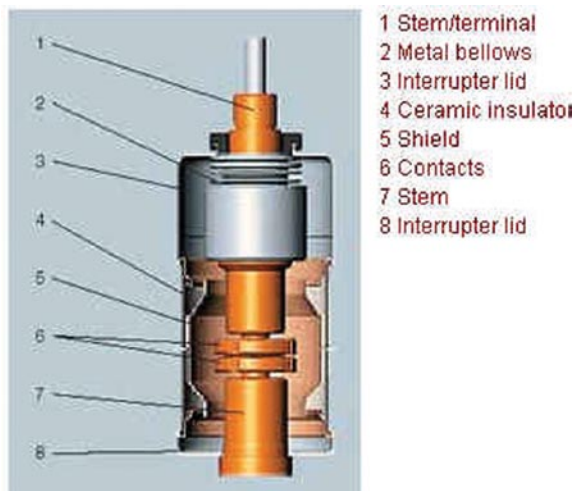


Figure 2

Harder materials are designed in a configuration called axial magnetic field and are used in higher voltages and capacitor switching. They employ designs where the magnetic field is parallel to the current flow increasing switching capacity of the interrupter. (Fig. 3)

Vacuum breakers have less than 30 percent as many parts as comparable SF<sub>6</sub> breakers and an even lower percentage when compared to the older air breakers. More significantly, vacuum breakers have only 10 percent as many inaccessible moving parts. Fewer parts with lower energy mechanisms and totally enclosed breaking contacts mean less maintenance, fewer failures, and higher reliability.

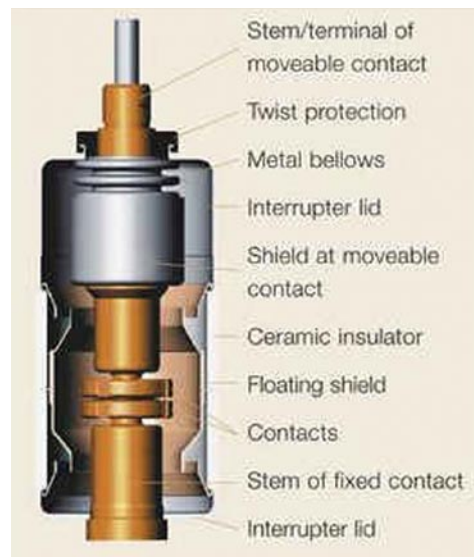


Figure 3

## Testing

For most of us charged with maintenance of systems that use vacuum technology, the design of the bottle is of little concern until it is time to test or replace one. At that time, understanding vacuum interrupter technology becomes more important. ANSI/IEEE C37.60 for production testing and C37.61 for maintenance testing are two sources. NETA uses these standards as a reference in MTS-2005 in the specifications for in-service testing of vacuum interrupters installed in electrical equipment.

Testing procedures can be broken into two categories — Visual/Mechanical and Electrical.

Operation counter including fault adjusted operation from the last maintenance cycle should be known prior to performing any vacuum interrupter (VI) tests. Total life count should additionally be known.

Mechanical operation and alignment should be checked in accordance with the manufacturer's instruction book for that apparatus. Mechanism failures and lubrication issues are more common than VI failure. Insure both the closing and opening operation are free and smooth and operate according to design. Compare bolted resistance values with those of previous tests or similar bolted connections. More than 50 percent deviation should be investigated and corrected. Bolt torques should be in accordance with the manufacturer's published data or, in absence of those values, the appropriate values from standard published data for the type and material being used.

Thermographic pictures should be taken before shutdown and the results used to help determine high resistance connections.

Travel and velocity measurements can be taken and compared to the manufacturer's published data and also to previous test data to determine trends.

Measurements of pretravel, travel, overtravel, and contact thickness help determine integrity and remaining contact life. Most manufacturers of interrupters design in measurements that can be taken on the moveable assembly to determine contact erosion and thickness limits. Many manufacturers use a form of GO/NOGO gage that comes with the equipment into which the interrupter is designed.

Low resistance readings should be taken across each bottle in the closed position and compared to the manufacturer's limits. If not available, use comparisons to previous history or adjacent poles. Additionally, readings of like bottles in equipment of the same make, model, and age can be used.

Prior to the next set of tests, a thorough cleaning of each bottle and bushing should take place.

Insulation resistance values should be taken from ground to each bottle in the closed position in accordance with the manufacturer's published data if available, or standard values for the kV class of the interrupter can be used. If below expected values are obtained, open the interrupter and repeat the test to determine if the insulation readings can be isolated to one side or the other. Cleanliness is very important here. Overpotential testing should not occur until the insulation resistance values meet minimum acceptable levels.

VI integrity tests (overpotential) should be performed across each bottle in the open position in strict accordance with the manufacturer's specifications. **Do not exceed the voltage stipulated for this test.** Provide adequate barriers and protection against X-radiation during this test (See C37.85-1972 and C37.85a-1972). Do not perform this test unless the contact separation of each interrupter is within the manufacturer's tolerance. Be aware that some high potential test sets are half wave rectified and may produce peak voltages in excess of the switch manufacturer's recommendations. Flashover across the external portion of the VI is commonly due to dirt and contamination and should not be mistaken for a failed bottle. If this should occur, reclean the external surfaces and repeat the test. If no evidence of distress or insulation failure is observed by the end of the total time of voltage application, the test specimen is considered to have passed the test.

## Summary

As vacuum interrupter technology continues to progress, the uses in the utility field are limited only by the maximum kV and fault duty ratings that can be designed into the bottles. For those of us having many air circuit breakers and network protectors on our systems, the process of converting to vacuum technology will greatly improve the system reliability without having to totally replace and reengineer the systems. Direct one-for-one replacements make conversions simpler. Additionally, distribution utilities can convert to vacuum technology and reduce the risks involved with oil spills from oil circuit breakers, or greenhouse emissions when handling SF<sub>6</sub>. The combined safety in use, environmentally sound construction, and long life help provide justification for their use by utility planners..

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Rick Youngblood graduated from Indiana State University in 1973 after leaving active duty in the Air Force. Rick joined Cinergy Corporation in 1982 then known as Public Service of Indiana. Rick was promoted to Project Engineer after receiving his BSEE from Purdue University in 1985. In 1987 Rick became the Manager of Technical Services in their Northern Division. Rick was responsible for implementing Cinergy's CMM System and creation of its Predictive and Preventive Maintenance Programs. In 2000 Rick was promoted to Supervising Engineer for Substation Services where he remained until taking early retirement in 2004.

Rick joined American Electrical Testing Company in August of 2004 as Regional Manager heading up the Midwest office located in Indiana. Rick holds a Level III NETA test technician certification.