Vacuum Interrupters

Introduction

The first vacuum interrupter used commercially was a Jennings device. It was installed as a line-and-load dropping switch for a 138kV transmission line in California in 1955. Jennings has continually expanded its portfolio of vacuum products, including a wide range of vacuum interrupters.

Current interruption in a vacuum is recognized as the ideal switching technology in the medium-voltage range, and it's also applied in high-voltage and low-voltage applications. Excellent switching capabilities and compact design make vacuum interrupters the most economical switching device solutions possible.

Jennings interrupter designs handle a wide range of voltage and current interrupt levels, and high quality and highly reliable interrupters are available for the utility and industrial markets.

Design

Jennings vacuum interrupters feature an evacuated ceramic insulating envelope surrounding two contacts, one fixed and one movable.

The movable contact is operated from the outside through a metallic bellows. Contacts are typically a copper alloy that is developed for use in AC voltage applications. The end plates are made of stainless steel or copper.

Features and Benefits

- **Long life, high reliability** — Vacuum interrupters can be expected to last the life of the equipment in which they are installed
- Controlled contact erosion results in virtually maintenance-free operation
- **Fast interrupting speed** — The interruption mechanism is independent of current magnitude, so interruption can normally be anticipated at the first current zero with no restriking
- **Rapid dielectric recovery** — The dielectric strength of the contact gap recovers more rapidly than the recovery voltage can rise, eliminating restriking
- High cycle withstand voltages
- **Robust, compact design** — Vacuum dielectric enables contacts to be arranged close together so circuit interruptions can be designed in a smaller envelope
- **Environmentally friendly** — Current interruption occurs in a vacuum, so there is no emission of greenhouse or toxic gases
- **Atmospheric contact contamination is eliminated** — Oxides and corrosion layers cannot form in the vacuum environment
- **Noise-free and flash-free** — All arcing is confined within the vacuum interrupter body

Applications

- Load break switches
- Contactors for industrial and motor control (example: Jennings contactors use Jennings vacuum interrupters)
- Reclosers (example: Jennings vacuum interrupters are used in the industry-leading Elastimold® reclosers)
- Capacitor bank switching
- Circuit breakers
- Specialty RF and DC applications

Markets

- Power distribution
- Power transmission
- Industrial
- Airport
- Wind farms
- Power plants
- Steel smelters
- Offshore drilling
- Mining
- Rail

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Product Offering

Electrical Characteristics

CAT. NO.	OPERATING VOLTAGE (KV)	1 MINUTE DWV (KV)	RATED SHORT CIRCUIT CURRENT (A RMS)	RATED CONTINUOUS CURRENT (A RMS)	CONTACT FORCE AT CONTACT SEPARATION (LBS. MAX.)	MECHANICAL LIFE (OPERATIONS)	BODY DIAMETER (IN.)	BODY LENGTH (IN.)	TOTAL LENGTH (IN.)	STROKE (CONTACT GAP, IN.)
RP160A	1.5	12	N/A	165	3.0±20%	1.5 Million	1.19	1.39	2.24	0.080
RP115-2-LS	15.5	95	2,000	200	2.50±25%	250,000	2.38	5.61±0.06	8.53	0.160
RP113-4-LS	15.5	60	6,000	400	16.5+ 25%	1.0 Million	2.41	4.42	6.04	0.200
RP127-4-LS	27.0	100	N/A	200	6.1	50,000	2.41	6.50	9.09±0.08	0.460
RP158	3.6	45	N/A	300	7.7±20%	2.0 Million	2.44	2.81	4.49	0.110
RP133	1.5	30	N/A	450	9.7±25%	500,000	2.06	2.25	3.275	0.090
RP115-6-LS	1.5	125	2,000	600	10.0	1 Million	2.40	3.10	6.21	0.250
RP138-6-LS	38.0	150	2,000	600	10±25%	20,000	2.40	5.78±0.07	8.34	0.375
RP233B	25.0	40	N/A	35A RMS @ 32 MHz	2 lbs. 8 oz.	1.5 Million	1.31	4.18	5.68	0.120
RT1G	30kV DC	50	N/A	200A DC	10.0	100,000	2.125	5.0	6.875	0.090
RT8A	50kV @300 kHz	72	N/A	80A @ 300 kHz 35A @ 30 MHz	10.0	50,000	2.5	8.375	10.25	0.160
RT-22	22kV @ 2.5 MHz 10kV @ 30 MHz	25	N/A	50A @ 3 MHz 22A @ 25 MHz	14.0	250,000	1.4	2.63	3.38	0.070
RP910	15.5	95	4,000	400	10.0	50,000	4.06	7.13	9.19	0.190
RP909	36.0	125	12,000	600	15.0	10,000	4.00	7.12±0.03	10.59	0.380
RP138-8-VCB	38.0	150	12,500	800	19.8	10,000	2.43	6.49	10.735	0.475
RP173	7.2	28	6,000	450	16.5+ 25%	1.0 Million	2.40	4.63	6.84	0.190
RP-175	7.2	28	6,000	450	16.5+ 25%	1.0 Million	3.0	4.75	7.83	0.190
RP-176	7.2	28	6,000	450	16.5+ 25%	1.0 Million	3.0	7.21	10.49	0.190

Selection Guide

Contactor and Switch Application — Commercial

RP160A	RP115-2-LS	RP113-2-LS	RP127-2-LS
			
1.5kV	15.5kV	15kV	27kV
165A	200A	200A	200A
1.65kA	2kA	4.5kA	4.5kA
	200A*	200A*	200A*

** Capacitive Switch Rating*

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Selection Guide (continued)

Contactor and Switch Application — Commercial (continued)

RP158	RP133	RP115-6-LS	RP138-6-LS
			
3.6kV	1.5kV	15.5kV	38kV
300A	450A	600A	600A
2kA	1.8kA	2kA	2kA
		40A*	40A*

** Capacitive Switch Rating*

RF/DC Application

RP233B	RT1G	RT8A
		
40kV	30kV	60kV
35A @ 32 MHz	200A DC	300A DC
Carry Only	Carry Only	95kV BIL

Circuit-Breaker Application

RP910	RP909	RP138VCB
		
15.5kV	36kV	38kV
400A	600A	800A
4kA	12kA	12.5kA
400A*	600A*	

** Capacitive Switch Rating*

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Description

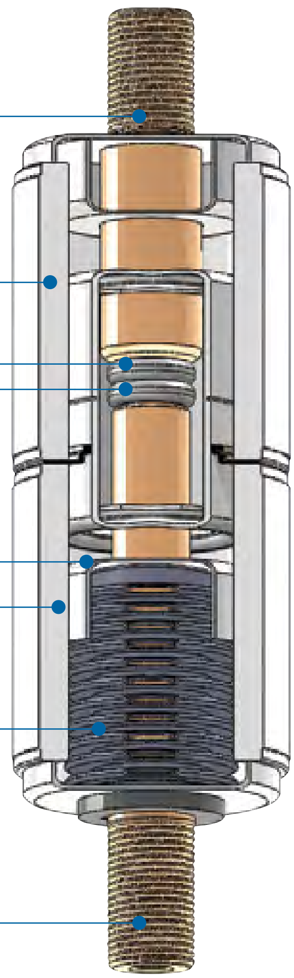
The cutaway illustration at the right is a typical Jennings vacuum interrupter, which consists of an evacuated ceramic insulating envelope surrounding two contacts, one fixed and one movable. The movable contact is operated from the outside through a metallic bellows, and the contacts are cylindrical vapor shields. Contacts are made of specialty alloys. The end plates are typically made of stainless steel or copper.

Operation

When the contacts are opened to interrupt current flow, metal vapor is generated by the passage of current through the contacts. This vapor sustains the arc that is created, maintaining down to or near current zero. As the arc extinguishes, the metallic vapor rapidly diffuses outward and condenses on the cool surface of the vapor shields, which serve to prevent the vapor from depositing on the ceramic insulating surfaces. The dielectric strength of the contact gap recovers at a rate that is a function of diffusion. With the contact gap's dielectric strength recovering more rapidly than the recovery voltage can rise, there is little chance that restrike will occur.

A unique phenomenon with vacuum interrupters is auto-maintenance of the vacuum. The metallic ions released from the contacts provide a gettering action. Tests have shown that frequent operation of the contacts produces a steady improvement in vacuum level because the released metallic ions actually remove gas molecules from the evacuated space. This ion-pumping action tends to maintain the vacuum near the high initial value.

Because the loss of vacuum is a rarity, the useful life of the interrupter is primarily determined by the amount of contact erosion. The medium surrounding the contacts, a vacuum, does not degrade the contact surfaces, and the small amount of contact erosion experienced during normal operation leads to an anticipated life that approaches that of the equipment in which the vacuum interrupter is installed. The amount of contact erosion is easily checked in the field by measuring the change in travel of the movable contact.



General Utility Applications

Performance Proven by Power Utilities

Vacuum interrupters are widely used in electrical power generation and distribution systems for controlling 50- and 60-cycle circuits at all voltage levels. In vacuum reclosers, they provide primary protection for the distribution substations. Equipment in which they are used is generally small enough and light enough to be installed on a minimum foundation pad, or directly on poles, with no cross arm support.

There are many applications that require more than a simple disconnect switch but do not warrant the use of an expensive breaker. These include:

- Switching of capacitor banks
- Line dropping
- Loop sectionalizing
- Reactor switching
- Switching of transformer magnetizing current

Such applications require a rapid rate of rise of recovery voltage, which vacuum interrupters are able to provide. Switching substation transformer banks and protecting them against faults is an application particularly suited for vacuum interrupter breakers, at a fraction of the cost of full rated breakers.

Vacuum-type breakers with lower interrupt ratings can be used for transformer differential protection at transmission voltages on systems where fault currents are low enough to permit it. In such cases, the vacuum breaker can be used in conjunction with high power back-up fusing or may be permitted to sustain the fault until remote breakers can trip, thereby preventing destruction of the more expensive breakers at the expense of the lower cost vacuum types.

With an actuator installed to close the vacuum interrupter rather than open it, the mechanism can be used for high-speed grounding. With short contact travel and low mass, the ground can be initiated quickly enough to limit fault damage or maintain system stability.

Vacuum interrupters are finding use in many specialized underground applications where paralleling of high capability circuits may be required.

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Vacuum Interrupters

High Reliability for Low Maintenance Costs

Since the first Jennings vacuum interrupters were introduced, there has been a continuing program to increase the capability and reliability of these units. This program has included improvements in product design and materials used.

Manufacturing

Finely tuned manufacturing techniques prevent contamination of the interrupter parts by submicroscopic particles. The use of a clean room environment, special cleaning techniques and new methods of monitoring the manufacturing environment have been developed as part of the general quality control program that has made Jennings a leader in the production of highly reliable vacuum components.

Materials

Materials used for the bellows, stem, shields, seals, envelope and contacts have been improved to increase voltage and current capabilities. Current chopping has been reduced by improvements in material technology, which minimize switching surges in most circuits.

Changes to the contact design, as well as to complex alloy contact materials, now enable minimal resistance to current flow without interruption until a low current value is achieved. By using ceramic envelopes, Jennings has dramatically increased the ruggedness of vacuum interrupters and their ability to take full current interruption with minimum effect on their life.

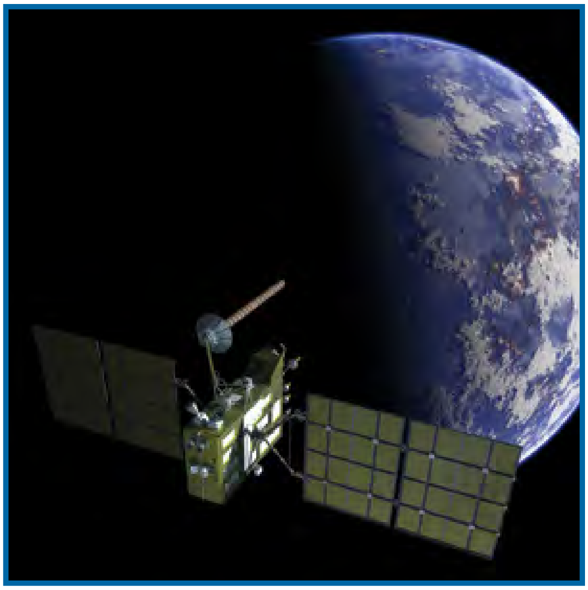
Quality Assurance

In addition to substantial verification of the reliability of vacuum interrupters from numerous installations, Jennings also has a large amount of data generated by its own in-plant, high-voltage, high-current testing facilities. These facilities are able to simulate fault current interruption as well as load test at voltages up to 69kV.

Custom Products

Specifications of standard products are included in this catalog. Various custom products based upon these standard devices are also available, including custom finishing and modification using special materials to meet specific application requirements, as well as various mounting configurations to facilitate their use in different switchgear mechanisms.

If units are to be mounted in series for use at higher voltages, the mechanisms are ordinarily custom designed for the application. Details on the application should be e-mailed to the factory sales engineering department (**jenningssales@tnb.com**) for recommendations.



Ratings

Jennings vacuum interrupters are designed to meet requirements for switchgear applications when used within their specified current/voltage ratings.

AC Voltage

Power frequency operate ratings are line-to-line RMS voltages. In a delta or under-grounded wye connected transformer, the vacuum interrupter sees full line-to-line voltage. In a grounded wye connected transformer, however, it sees only line-to-neutral voltage (which is line-to-line voltage divided by the square root of 3.)

AC Current

Continuous current and maximum interrupting current ratings are all RMS values and should be considered when selecting an interrupter. Continuous line current can be calculated by dividing the total three-phase kVA by 3 and then by the line-to-line voltage. When maximum fault currents are calculated, consideration should be given to the fact that the first half-cycle of current flow in a faulted circuit is asymmetrical by as much as 1.6 times the steady state fault current, which itself depends upon the impedance of the faulted circuit. The asymmetrical current decays to the steady state value in approximately 5 to 8 cycles. Therefore, the faster the circuit breaker opens, the higher the asymmetrical current it has to interrupt. Maximum interrupting current listed in the rating tables assumes an asymmetry factor of 13.

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Mechanical Considerations

Average Closing Speed

Contact stroke is defined as the distance between contacts when they are fully open and there is zero erosion. The distance equal to 33% of the contact stroke is divided by the time required to close the final 33% of the stroke. These specifications enable closing speeds that will give satisfactory performance with reasonable mechanical design. Consult the factory (**jenningssales@tnb.com**) for recommendations if application requirements call for a different speed.

Average Opening Speed

The distance equal to 75% of the contact stroke is divided by the time required to open the contacts to 75% of the contact stroke. Contacts should open fast enough to provide sufficient contact spacing to withstand the recovery voltage when it appears. An opening speed that opens the contacts in one-half cycle generally satisfies this condition.

Operating Life Determination

Interrupter life is generally determined by the amount of erosion of the contact surfaces. Contact wear caused by erosion is frequently determined by measuring the distance from the outer end of the movable operating rod to the mounting end plate, and comparing this measurement to one made when the interrupter was first installed. Another reference that can be used is the distance from the outer end of the movable operating rod to the outer end of the stationary electrical terminal.

Due to normal wipe forces and closing impacts causing a slight initial change in this dimension, the interrupter should be operated normally about 50 times before the reference dimension is measured. This initial change may amount to 3⁄16", especially if there is a slight radial displacement in the closing motion. Any subsequent change in this dimension can be attributed to contact wear.

Mounting Considerations

Vacuum interrupters can be mounted in any orientation and configuration, provided the minimum required axial centerline spacing between adjacent interrupters is maintained for electrical considerations. The interrupter should be supported at both the stationary and movable ends. The external mechanical operator is connected to the steel rod or stud in the center of the movable operator rod. Care should be used in making the mechanical connection and mounting to make sure that high stresses do not occur. Bending, cantilever or torsional forces should not be applied to the interrupter, and the force that the movable operating linkage applies to the movable operating rod of the interrupter must be limited in the axial direction.

Connection to the stationary electrical terminal requires some means of absorbing the impact when the contacts open or close in order to limit axial displacement and assist in restricting contact bounce. Because magnetic forces of short circuit currents can cause contacts to separate after they are closed, an opposing external static force must be applied to the closed contacts. This force, which must remain constant and be independent of contact erosion and linkage variation, can be supplied by a relatively low gradient preloaded spring in the operating linkage. Under some conditions, contacts will tend to weld when closed. For this reason, it is recommended that the kinetic energy developed in the mechanism during the period of unloading the wipe spring be used to provide an impact force to assist in the initial opening of the contacts. Overtravel of the movable contact beyond the specified limit must be prevented or damage to the bellows can result.

A guide arrangement is necessary to limit axial motion of the movable operating rod. The guide-bearing surface should be an insulator to prevent arcing between sliding surfaces. In addition, the design of the operating mechanism should be such that it does not contribute any torsional forces to the movable rod.

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Electrical Considerations

When interrupter and return conductor spacings are not determined by dielectric considerations, minimum dimensions are imposed by electromagnetic interaction. For interrupters with 12kA ratings or higher, a minimum centerline spacing should be maintained between adjacent interrupters, and between interrupters and return conductors. For interrupters having lower ratings, a six-inch minimum spacing is recommended.

A low-impedance electrical connection should be provided between the mounting end plate and the movable electrical terminal. This connection should have a resistance of less than 50 microhms in order to provide a current path around the bellows for any transient current that enters the end plate from the main shield.

Electrical connection to the movable terminal should be made with flexible braids arranged so that the electromagnetic force developed by high current does not apply a rotational force to the operating rod. A non-moving connection should be made to the stationary terminal. Heat generated in a vacuum interrupter is removed by current-carrying conductors. Temperature rise at the terminals can be regulated with a heat sink, although in many applications the bus connected to the terminals is adequate.

Minimum Expected Life vs. Current for High-Voltage Vacuum Interrupters

For moderate loads, life for most units will increase with a decrease in operating recovery voltage. Slower rates of rise will permit the use of increased maximum operating recovery voltages; excessive rates of rise decrease the permissible maximum operating voltage. Maximum operating recovery voltages are based on normal recovery voltages expected for the recommended types of loads. For capacitive current interruption, recovery voltage rises at a sine rate until maximum is reached a half-cycle after current interruption. For load breaks at high power factors, recovery voltage is more rapid, occurring at the rate of 100 to 250 volts or more per microsecond. For higher current and fault interruption, such as required for circuit breaker duty, recovery voltage may rise in the order of 250 to 1,000 volts or more per microsecond.

A decrease in operating voltage may increase the number of reliable operations. The end of reliable life is considered to be when occasional restrikes begin to occur during interruption, although actual failure to interrupt will probably not occur for a large number of operations after this point. At lower voltage levels, 5,000 volts and below, life will approach contact or bellows life. Contact life is then dependent on amount of current and arc time. Synchronizing contact opening within 2 to 3 milliseconds before current zero and synchronizing closing for minimum inrush and bounce will increase contact life so that switching life will approach the mechanical life of the bellows or operating mechanism. Maximum allowable contact loss is given in the specifications for each device.

Surge Voltage Prevention

As discussed under the section “Operation,” the metal-ion plasma in a vacuum interrupter serves the very important function of permitting current to flow in the circuit after the contacts have opened. The metallic plasma stabilizes the arc, maintaining it as the current follows the sine wave pattern down to or near current zero. In highly inductive circuits, arc stability is essential in minimizing a phenomenon known as “chopping,” which can occur with oil, air, gas or vacuum interrupters.

Chopping occurs when the arc is suddenly extinguished and the current drops instantaneously to zero. At high currents, a large amount of energy is stored in the circuit inductance and will resonate at high frequency with the distributed capacitance until dissipated by resistive circuit elements. The transient voltage surges caused by the chopping action can seriously damage the insulation of circuit components. This consideration is especially important in electric power switching because the magnitude of the transient is a function of the rate of change of current across the inductive load.

Pure capacitive or resistance circuits are not affected by chopping. Even inductive circuits with moderate resistance (lagging PF more than 15%) offer little trouble because the circuit resistance quickly dissipates the chopping energy. In addition, on highly inductive circuits where moderately large currents of 100A or more are switched, there is little tendency toward chopping. If smaller currents (typically less than 20A) are switched using the latest AC-rated vacuum interrupters, chopping (if it occurs at all) will occur at a rather low current level, and the resultant voltage surges will generally not be severe.

In most applications, the insulation level of inductive components is high enough to protect them from normal surge voltages. Additional protection may be afforded by the use of capacitors, varistors and expulsion-type lightning arrestors. For industrial control-type applications, vacuum interrupters have an average chop current of 0.75A.

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Industrial Applications

The unique advantages of switching in a vacuum make vacuum interrupters useful in industrial applications. Many kinds of test, production or processing equipment have requirements for long contact life without maintenance, for low-cost high-voltage control or for sealed contacts because of difficult environmental requirements. Due to recent advances in vacuum interrupter technology and the availability of new low-cost designs, vacuum interrupters are finding many new uses.

Where voltages are high and fault currents relatively low, a vacuum interrupter switch is an attractive alternative to oil circuit breakers. They are smaller, less expensive to install and maintain, provide half-cycle interruption instead of requiring five cycles or more and eliminate danger of explosion and fire.

Vacuum interrupter switches are useful where dust, high humidity or high altitudes make it difficult to maintain dielectric strength with other types of devices. In airborne equipment, for example, their small size is also an important feature. In environments involving explosive or corrosive atmospheres, they provide an additional safety factor. Even when destroyed by high currents, the arc is still completely contained because not enough gas pressure is developed to destroy the protective envelope.

For dielectric and induction heating equipment and x-ray and irradiation equipment used for processing foods and chemicals, vacuum switches can be used directly in the DC circuits for fast, maintenance-free, push-button disconnect.

Specialized Applications

- Vacuum switches can be used for overloads in the DC plate supply of high-power transmitters with a high-voltage capacitor placed across the switch contacts to generate an artificial current zero. In one such application, several transmitters were operated from a common DC supply. The vacuum switches on one transmitter permitted to drop out of service did not affect the performance of other transmitters.
- Vacuum interrupter switches have found use in dust precipitators. In one application, several dust precipitators are supplied by a single 75kV DC power supply and the plates of each precipitator are vibrated every half-hour to remove the dust collected by electrostatic precipitation. The vacuum switches disconnect the high voltage from the plates so that they will not be shorted out by dust particles. The completely enclosed arc eliminates the major cause of explosions in this type of equipment. Similarly, vacuum switches are being used in electrostatic paint spraying equipment.
- Vacuum interrupter switches satisfy requirements for automatic switching in large industrial equipment such as RF induction and dielectric furnaces. Besides handling the high power levels involved, they also make possible the use for quick current overload protection in the high-voltage secondaries or directly in the DC lines rather than in the primaries where current levels are high even though voltage levels are low.
- Vacuum interrupter switches are being used for operation of electric arc furnaces used for casting steel billets. In addition to providing over-current protection in the 12kV primary of a 1500kV transformer bank feeding the furnace, they also are used to start and shut down the furnace. They may operate as often as 8 or 10 times a day with no backup protection except fused disconnects between them and a 250,000kVA source of available overload power.

RF Switches

Vacuum interrupter switches have demonstrated superior performance for RF applications, such as:

- Band switching of transmitters
- Switching of filter sections and antenna multicouplers
- Antenna reflector switching
- Tap changing of RF coils in induction and dielectric heating RF generators
- Switching of transmission lines

Most of these applications are in the HF band and involve currents ranging from 20 amperes to several hundred amperes. At very high currents, switches should be fed symmetrically to avoid uneven current distribution inside the switch. Vacuum interrupter switches, without an actuator, lend themselves to custom-designed tap changing and filter network switching because a number of switches can be driven by cams from a common shaft.

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