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Vacuum Contactor Application Issues

Vacuum contactors are not new; they are well proven and used in many industrial applications around the world.

In this discussion, we'll examine the advantages of vacuum interrupter, user application strengths and cautions.

INTRODUCTION

During the past 35 years, vacuum interrupters have been available for various switching applications. During this discussion, I want to illustrate the types of devices available, their differences, typical applications, and the experiences gained by users.

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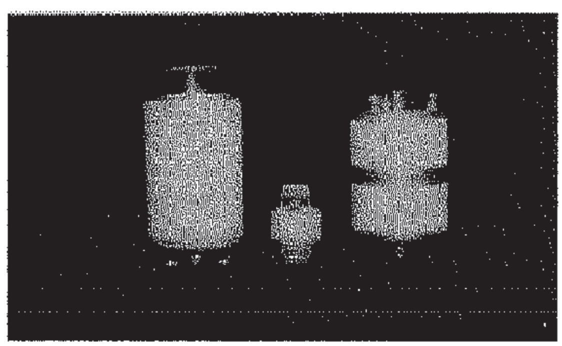
Vacuum switching was recognized as an ideal method of interruption as long ago as 1897. Its application to circuit breakers was considered about 1920. Early development of these vacuum devices was done in the United States, but difficulties in maintaining high dielectric strength without continuous evacuation made these devices impracticable. Improved manufacturing techniques, perfected during the 50's made the devices a commercial proposition and they started to appear in various forms for both circuit breaker and contactor applications in the early 60's.



Vacuum interrupters, circuit breakers or vacuum contactors Figure 1 on the left a typical circuit breaker bottle rated 13.8kV/400amp compared to a vacuum contactor bottle rated 5kV/400amp. The two devices are designed to do different jobs. The circuit breaker to switch high currents (short circuits) infrequently and the contactor to switch low currents (motor current) frequently.

The materials, different methods of controlling the arc and distances the contacts are moved give completely different switching characteristics and electrical and mechanical life expectancies. The

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Many vacuum starter designs, even today, are a hybrid design of the air break starter, the interrupter switch having circuit breaker switching characteristics mounted on a fused contactor truck assembly. To the user, only a few advantages of vacuum switching are realized with this method and without careful application considerations some advantages can be encountered.

APPLICATIONS

So why should vacuum switching be considered? First, let's look at the considerations in engineering applications and user benefits.

History has shown how arcing mediums have changed from oil to air and now to vacuum, for 35 years a proven technology. The work done in the USA found that vacuum as a switching medium has these advantages:

I. Low arc energy
II. Short arcing time
III. Small movements required for arc isolation
IV. Arc containment

These features mean, in practical terms:

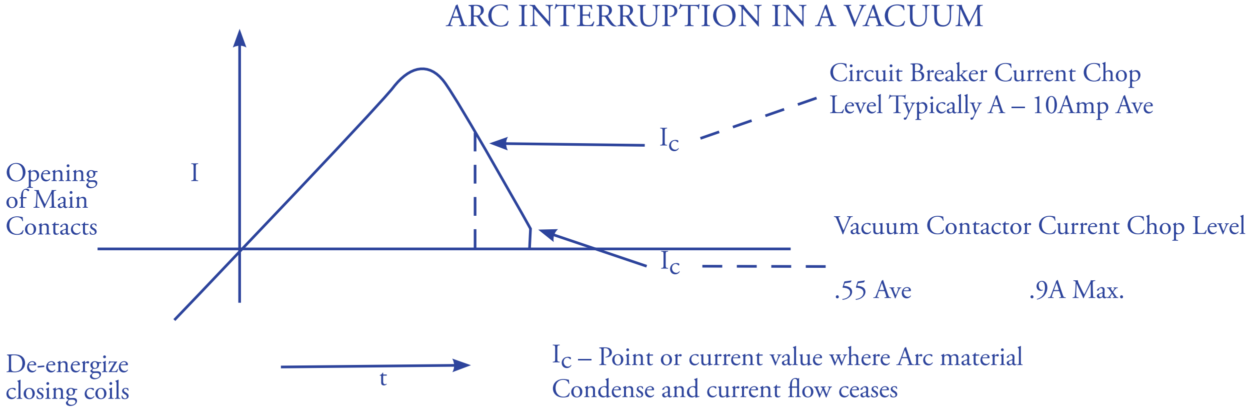
I. Long electrical and mechanical life
II. Extremely compact size
III. No arc chutes or blow out coils

If, from this, there is disadvantage, it is that the vacuum as medium is so good that the arc will, without proper control be extinguished too early. That is before current zero.
Control of the arc is achieved by the selection of correct contact materials for the appropriate application. This phenomenon has been widely known and appreciated by designers and manufacturers for many years. Ideally, the arc should be extinguished at or as near o current zero as possible, the resulting "current chop", whatever the medium, will give rise to a transient on the system. Properly designed contactors incorporating low vapor melting point contact arcing material achieve low "current chop" and, hence, safe switching characteristics.
Devices originally designed for circuit breaker duty, that is switching at high value currents, short circuits, etc. and then applied to a contactor motor switching duty, can if, very careful measures are not taken, cause transient problems to downstream equipment. The user

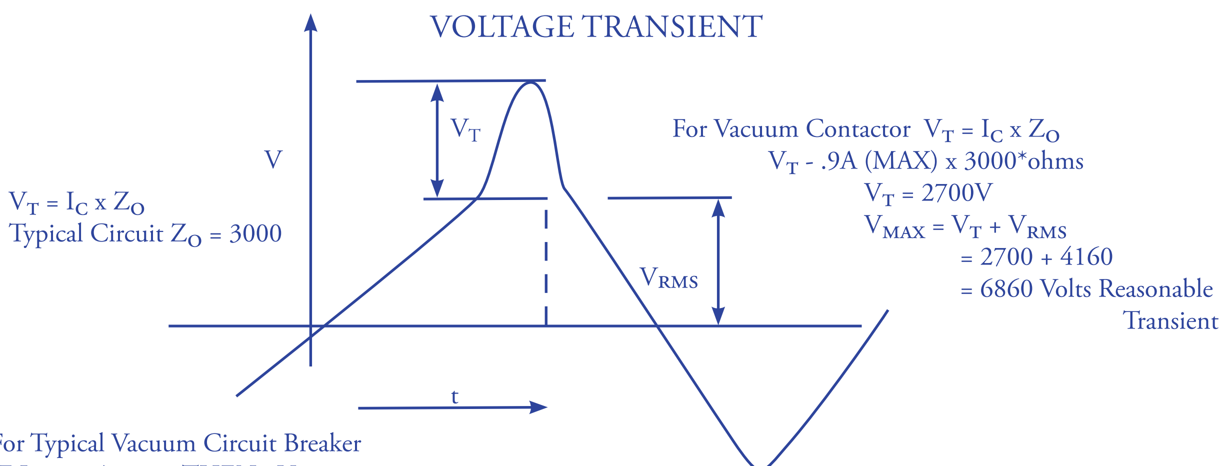
should appreciate these subtle but important differences between vacuum contactors and vacuum circuit breakers when considering vacuum interrupters.

Current chopping is a term that came to our vocabulary with the advent of vacuum switching. Vacuum switching was commercially started back in the 1950's. Earlier switching means in air or oil are, in terms of dielectric recovery rate, relatively slow and as the main contacts would part, the arc would go through several zero crossings before it would finally go out. The dielectric strength across the now open gap is strong enough to prevent a restrike, and thus continuation of current for a further half cycle. With the introduction of vacuum as a dielectric medium that has a completely

ARC INTERRUPTION IN A VACUUM



VOLTAGE TRANSIENT



For Typical Vacuum Circuit Breaker
IF I_C– 10 Amp THEN V_T = 10 x 3000
V_T = 30,000V
V_{MAX} = 30,000 = 4,160
= 34,160 Volts Not an Acceptable Level

different characteristic to that of air or oil dielectrics in so much that it has a very rapid dielectric recovery rate.

ARC INTERRUPTION IN A VACUUM

Upon opening the main contacts of a vacuum interrupter whether it be a circuit breaker or a contactor, high velocity movements are easily obtained because of the low mass and small movements required to obtain arc isolation up to limited high voltages. As such, the arc will be extinguished at the first current zero and within half a cycle. Because of the rapid recovery rate of the dielectric, the arc, in vacuum interrupter will tend to go out before current zero which will result in an instantaneous current drop to zero and lead to an induced voltage or voltage transient being generated to down-stream equipment.

This can be measured by calculating the formula.
= Voltage Transient
= Current Chop
= Surge Impedance
Therefore, if the current chop is .9 of an amp and the surge impedance is 3000 ohm's, the voltage transient will equal 2700 volts on top of the RMS system voltage whether it be 4160 or 5kV. However, if the current chop is 15 amps time surge impedance of 3000 ohms, then the voltage transient can equal 30kV on top of the RMS supply voltage.

You will notice from the above that some assumptions are made with regards to surge impedance values which are difficult to obtain and vary per circuit. In addition, the voltage transient value that a motor or dry type transformer will withstand is difficult to obtain from motor and transformer manufacturers.

APPLICATIONS

Vacuum contactors today are applied on low voltage and medium voltage systems up to 15kV on:

- Motors
  - Standard and high efficiency induction
  - Synchronous
  - Wound rotor slip-ring
- Transformer feeder switching
- Capacitor switching

Transformer and capacitor switching is often done at higher voltages than 15kV with vacuum contactors or vacuum circuit breakers.

Vacuum Contactor Advantages

Long Mechanical Life	Typically 3 million operations at 30 operations per day Life expectancy of 274 years
Long Electrical Life	Typically 1 million operations at 30 operations per day Life expectancy of 91 years
Low Maintenance	No special maintenance skills or adjustments required
Minimal Downtime	Important in 24 hours operating processes
Arc Containment	No ironized gases reducing risk of flash ovens
Weld Free	Minimal contact bounce, low arc energy and temperatures minimizes risks of contact welding
Impervious to Environment	Contacts sealed from atmospheric contamination such as H_2Chlorine, dust, salt atmospheres. Etc.
High Cycle Duty	Up to 1200 operations/hour
Rugged, Compact, Quiet & Lightweight	Smaller, quieter than conventional air break contactors
Mount in any plane Simple Controls	Ideal for small tight packaging electrically held contactor circuit

Industrial Users

Petro Chemical plants and refineries	Underground Mining Equipment
Petro Chemical exploration and pumping facilities	Induction Heating – Furnaces
Petro Chemical transportation – pipelines	Capacitor Switching – Power Factor Correction
Paper Mills	Hazardous Area Flameproof Equipment
Saw Mills	Crane Control
Textile Mills	Air Handling - Compressor Equipment
Steel Mills	MCC Manufacturers
Mining Underground for Coal Materials	Panel Builders
Mining Surface Coal and Minerals	AC & DC Power Supplies
Water Sewage Treatment Plants	Harmonic Filters
Food Processing	AC & DC Traction
Material Handling	Transfer Switches
Electrical Utilities	Lighting
Locomotive Transportation	Mining Shovels
Stone Crushing and Quarrying	Drag Lines
Cement Plants	Conveyors
Tire and Rubber Plants	Crushers
Water Pumping Irrigation	Wood Chippers
Oil Pumping	Bucket Wheel Excavators
AC and DC Drives	Tunnel Boring Machines
Surface Mining Equipment	Electronic Soft Starters

The inherent mechanical forces in well-designed vacuum contactors allow the product to be used to maximum ratings for all application, allowing the user maximum benefit.
For example, National Standards size rate contactors and then apply an appropriate HP rating with respect to voltage. The table below compares NEMA rating vs. current rating.

NEMA – HP/KW RATING TABLE

NEMA SIZE	NEMA CURRENT RATING	HP RATING NEMA MAX	CURRENT RATING TYPICAL STANDARD SIZES	HP/KW	
				460v	600V
4	135A	100/75	160A 200A	125/93 150/110	150/110 250/185
5	270A	200/150	320A 400A	250/185 300/220	300/220 500/370
6	540A	400/300	600A 600A 700A	500/370 500/350 550/410	575/430 600/470 700/520
H2	180A	1250HP AT 4.16KV	200A	1500HP/1120KW AT 4.16KV	
H3	360A	2500HP 4.16KV	400A	3000HP/2250KW AT 4.16KV	
H4	540A	4000HP AT 4.16KV	600A	4500HP/3350KW AT 4.16KV	
H5	720A	5000HP 4.16KV	800A	6000HP/4475KW AT 4.16KV	

The need to derate due to ambient, altitude, duty cycle, frequency, mounting motor position, voltage environment, and high efficiency acceleration time is not an issue with vacuum contactors continuous current and interrupt ability remain the limits of the contactor rating. The increased HP/KW ratings are considerable.

Transformer switching involves carrying and switching of running currents. The in-rush current seen in transformers in the range

20 – 40 times continuous is not a problem is well designed vacuum contactors

They have due to the inherent mechanical forces to withstand in-rush durations up to these values, without blowing main contacts open. This is the prime reason for derating air break contactors.

Typical 400A contactor in-rush at 40 × -KA for 8MS. Vacuum contactors are tested to with stand 18KA – 50MS per UL 508, therefore no derating. The vacuum contactor can be used to full 400A rating, usually expressed in "KVA" values.

Capacitor switching is another ideal application for vacuum contactors inherently capacitor switching involves problems with high current in-rush and restrike problems. Consideration should be given to both single bank and bank to bank switching.

First consider that in-rush current is generated where initially energizing a capacitor. An uncharged capacitor bank offers practically zero impedance when energized, this results in a high frequency transient in-rush current. This explosive release of energy can cause damage to both capacitor and contactor, if it is not limited.

The high mechanical contact forces in a vacuum contactor help prevent contact damage wear and eliminate risk of welded contacts allowing the device to be applied to its maximum continuous capacitor switch rating. For extended electrical life, reactors should be used to limit to in-rush values to lower than contact "BLOW OPEN" values.

Restrikes occur when switching "off" a capacitor bank. They occur as a result of slow opening speed, poor contacts, poor dielectric, or dirty arc chamber on the switching device.

A vacuum container inherently has consistent:

- High Speed Opening (typically 16-20MS)
- Pure Environment (Clean interrupter arc chamber)
- High Quality Dielectric (Vacuum Medium)

When switching off a charged capacitor the contactor is switching obviously the power source; however, once isolated, the energized capacitor will try to discharge across the contact gap into the power source, hence the need for high aped opening and a consistent clean dielectric and arc chamber.

Air break contactors are susceptible to problems due to environment being uncontrolled and arc thus derated accordingly.

Vacuum contactors are usually applied in conjunction with other protection devices such as disconnects, fuses/MCCBs, overload relays and built into combination starters in various designs of enclosure ratings.

These starters both at low and medium voltage often involve mechanically interlocked contactors for:

- Reversing
- Reducing Voltage Starting
- Two Speed
- Two Source –Transfer Switch
- Wye Delta

Applications

Special considerations should be given for these types of applications. A vacuum contactor typically has 0.080" contact open gap for low voltage and 0.150" for medium voltage applications. In circuitry where a contact is connected across phases such as reversing the contact gap is the only separation of a short circuit 0.080" mechanical and electrical interlocking in such schemes is critical to insure that the 0.080" gap is never compromised by poor installation, assembly, or electrical contact racing.

Starter packages should also extend the advantages of vacuum contactors into the starter packages.

- Long life, low maintenance
- Control of arc and ironized gases
- Low energy consumption (heat generation)
- Compact designs (Real Estate Savings)
- Reliable Service Designs
- Fail Safe Capabilities

Two key elements are required to maintain vacuum contacts to keep them free of dirt and dust and keep connections tight.

A dust tight NEMA 12 Enclosure and 15 minutes per year of preventative maintenance (check connection torques) will provide many years of reliable starter service.

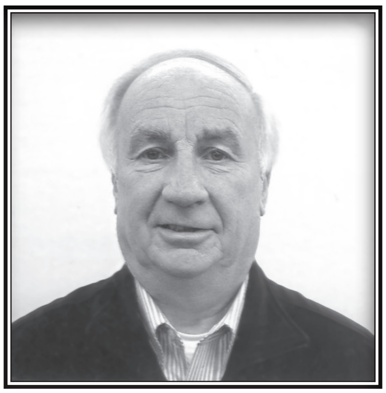
All of these features are available today in individual or motor control center starters designs and are enjoyed and proven by many of the heavy industrial users discussed earlier. To recap, some of these are:

- Electric Shovels
- Furnace
- Compressors
- Refinery
- Platform
- Down Hole Pumping
- Crane Control
- Locomotive
- Marine
- Continuous Miner
- Long Wall Miner
- Rolling Mill
- Capacitor Bank

During this discussion, we have hopefully covered the many advantages offered by switching an arc in a vacuum. The areas of caution are well understood, by designers and manufacturers. Users need to be aware of these areas, hence our reason to present this discussion.

For additional information, please contact us for copies of technical papers discussed today on:

1. Questions and Answers on Vacuum Contactors (includes discussion on loss of vacuum)
2. Chopping Current – A simple explanation and calculations to determine transient voltages when using vacuum interrupters
3. Capacitor Switching – Application precautions and calculations to limit high frequency and high current in-rush values
4. Application of reversing vacuum contactors on crane control applications
5. Retrofit programs to significantly extend the life of existing circuit breakers



John Lett became involved with vacuum power switching in the early 1960s, soon after completing his engineering studies at Aston University in his native UK. Working on Low and Medium Voltage Contactor and Motor Control Center designs, Lett's work in Engineering, Sales and Product Management developed competitive vacuum designs and expanded their acceptance in European markets. In 1978, he moved to the United States to continue this work in North America, where at the time few manufacturers of vacuum power products existed.

Vacuum designs are extensively used today, and at medium voltage almost exclusively used in power switching for motors, transformers and capacitors.

Lett retired from JCC/Danaher in 2009, but still works as a consultant for the company. He considers the next step for vacuum products to be utilized in the 10-15 Kv ranges as new motor designs are developed.