Joslyn Clark

Applying Vacuum Contactors To Motor Circuits

Advantages of vacuum starters make them candidates for new and retrofit application

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Conventional motor starters often are plagued by overheating, noisy operation and frequent failure. A starter using a vacuum contactor is a viable alternative for 460 to 7000 V applications. It is important, however, to be sure that the vacuum switching device being considered is really intended for motor starting duty. The design, application, and operation of a vacuum circuit breaker: (The same is true, of course, for air-break equipment. But that's been around long enough to be familiar to everyone.)

Of the vacuum device family, the circuit breaker was first to arrive. The most difficult task for any switching device is to provide fast interruption of high fault currents with minimum contact wear and burning. Originally introduced a quarter-century ago, the vacuum breaker offers these benefits by excluding air from the contacts. Most arcing involves ionization of air. The subsequent heat can maintain current flow for longer than one complete cycle because superheated air remains ionized even after current passes beyond a zero point on the waveform cycle.

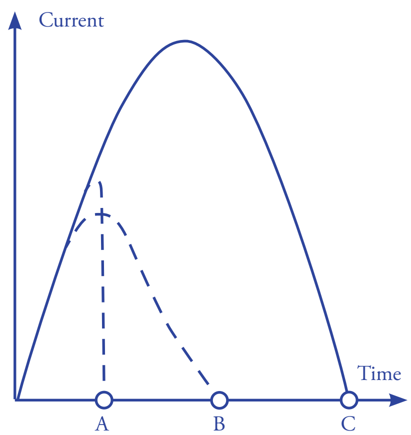


Fig. 1 demonstrates the significance of current chop. Vacuum contacts tend to cut off current flow instantly (point A); the extremely high rate of change in current produces high transient voltage. Conventional current-limiting breaker or fuse allows more gradual drop in current (point B); other interrupting devices don't stop current flow until the first current-zero (point C). For motor starter use, vacuum contactors must be especially designed to act more like the point B interuption.

In a vacuum, some arcing happens but it consists only of vaporized metal from the separating contacts. Arc extinction and complete current interruption occur within a fraction of a cycle.

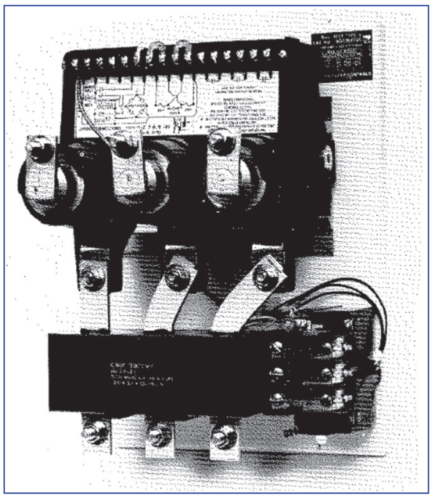
For that reason, the vacuum unit does away with many of the cumbersome, energy-consuming and unreliable features of air circuit breakers. Long contact travel and bulky arc chutes, needed to stretch and cool a heavy arc in air, are not required on a vacuum device, neither are the large magnetic blowout coils. Lower operating forces allow simpler contact opening and closing mechanisms, and absence of intense arcing prolongs greatly the life of the contacts themselves.

One operating problem arose, however, because of the fast interrupting action of contacts in vacuum. In any circuit containing inductance, such as a motor feeder, a sudden rise in voltage occurs whenever current ceases to flow. The more abrupt the current interruption, the higher the transient voltage spike will be. Sooner or later, this condition will break down the insulation in a motor winding.

Whereas the air-break contact opening interrupts current fairly slowly, in vacuum the current is almost instantly "chopped" to zero

Fig. 2 is a typical vacuum motor starter for 480 V circuit. At lower right is overload heater assembly driven by current transformers.
Photo Credit: Joslyn Clark Controls, Inc.

Fig. 2



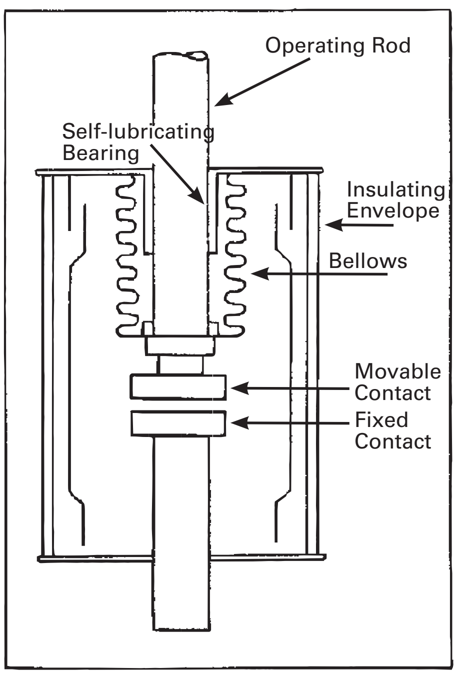


Fig. 3 The cross-section of "vacuum bottle" (one pole of a vacuum contactor) shows that separatio of open contacts may be only 1/16 to 1/4 inch in a motor starter; 5/8 to 3/4 inch for a circuit breaker.

(See Fig. 1). A dangerously high transient voltage appears each time the breaker opens.

That's why some breaker manufacturers – and some industry standards, such as *IEEE* 141 dealing with industrial plant power distribution—have recommended surge protective devices on motor circuits fed through vacuum breakers. Such protection was either built into switchgear cubicles or supplied with the motors. Changes in vacuum contractor technology no longer make this a common practice.

That expensive solution can offset some of the cost advantages of vacuum equipment. However, for motor control, the vacuum circuit breaker, like its air counterpart, has its drawbacks. Its contacts, which are designed to infrequently interrupt high current, are not appropriate for the day-in, day-out switching of much lower motor starting currents. As in the combination starter, long familiar to industrial motor users, fault protection is better provided by an upstream fused disconnect switch or breaker while the on-off motor switching is handled by a smaller, simpler "contactor."

But conventional contactors tend to wear out through frequent usage, and require energy-consuming operating coils. The vacuum contactor was developed to reduce those disadvantages. Although it was first introduced for medium voltage motor control (2300 to 6900 V), several makes of low voltage (600 to 1500 V) units are now available for 460 V motor control (See Fig. 2). These are often used at 900 to 1000 V for mine motor service, or for oilfield submersible pumps.

Vacuum Motor Starters

Increasingly popular in this country over the past 15 years, vacuum motor starters feature two major design differences from the circuit breaker. First, operation is much more frequent, although at lower current. This reduces both unit size and required operating force. Typical operating life is 1 million operations at rated current.

Second, contact design is altered by changing the contact alloy to slightly prolong the arc when the contacts part to reduce the "current chop" effect, almost eliminating the transient voltage spike. The change of alloy could be unacceptable in a breaker because it would prolong the flow of fault current (See Fig. 3 and 4).

Fig. 4

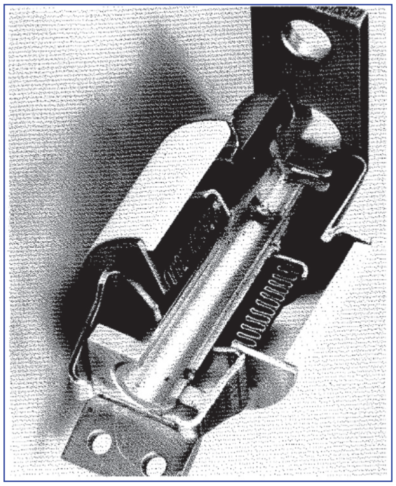


Fig. 4 This vacuum bottle from a low voltage motor starter has been cut away to show the bellows and contact assembly. Note hollow operating stem attached to moving contact. An internal compression soring produces “overtravel” for the operating mechanism, to minimize “bounce” when contacts close. Bellows wall is typically only 0.004 inch thick.

Fig. 6: Only a foot wide, this 5 kV vacuum motor starter will serve a 2500 hp load.

Fig. 6

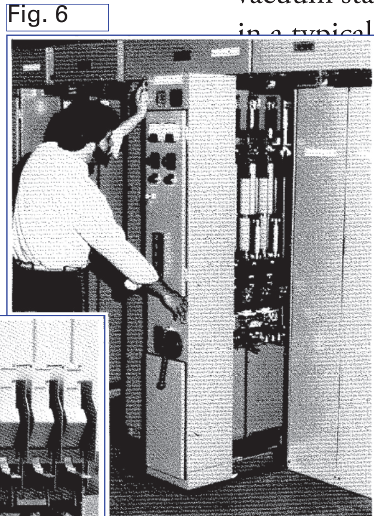


Fig. 5

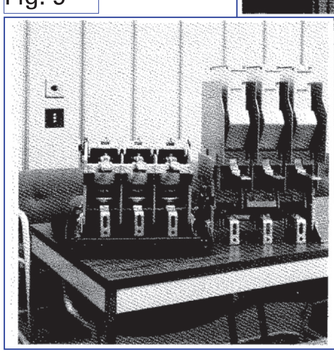


Fig 5: Compare voltage motor starting contactors, vacuum unit (left) and conventional air-break design (right).
Photo Credit: square D company

Even with design change, newer starters still provide faster current interruption, with much less arcing, than an air-break starter. Other advantages of vacuum units include:

Reduced size, Cubicle width may be halved with some designs. A free-standing medium voltage controller takes little over half the floor space; weight and volume for vacuum starters in general will be only 20% to 35% as much as for air-break units (See Fig 5 and 6).

1. Resistance to contamination; no arc chutes to clean.
2. Suitably to frequent operation—up to 20 times a minute.
3. Less noise, because of reduced mechanism force and travel, and lower holding coil power.
4. Reduced contact maintenance. In a typical severe application, vacuum starter contacts lasted more than a year and a half; air-break contacts needed replacement twice a month.

Another advantage, seldom considered years ago, is now becoming important to many users. Because of its low operating power, and the absence of heavy-duty continuously energized blowout coils, a vacuum starter can be an impressive energy saver. For a 100 A rating, in a typical 400 hp motor circuit, an air-break starter may use 620 W ...he corresponding vacuum unit only 180 W. in one 1500 ... motor circuit, actual air-break contactor losses were 1057 ...400 W for the vacuum device.

...nufacturer cites these loss figures for a vacuum starter ...to an air-break unit requiring 1000 W:

...g full load on the circuit three-fourths of the time, the ...it would save about $230 annually at a national average ...7 per kWh.

...Air-break equipment

Contacts	6 W
Fuses	120 W
Operating coils	240 W
Relay/CTs	120 W
Connecting cable	15 W
Total	501 W

Fig. 7

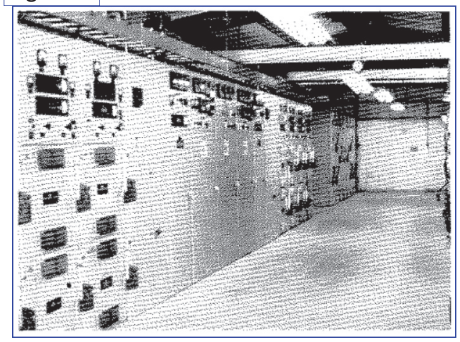


Fig. 7: This lineup of 2300V 400 A air-break motor controllers illustrates where failures frequently resulted from high ambient, cyclic load, and too-high starter positioning in cubicles.
Photo Credit: Union Carbide Corp.

The benefits of vacuum contactor operation can support cost-effective replacement of older air-break equipment. In on large chemical plant, using conventional medium voltage controllers (See Fig. 7), a major starter failure occurred almost every year. Contact assemblies were jolted by severe vibration for cyclic loading of some 1500 hp motors. As line current varied over a 3 to 1 range every 1 ½ sec, contact movement reached 4 ½ mils at a frequency of 10 cycles per sec. Added to this was high cubicle temperature caused by heat from starter blowout coils. Adding cooling fans to the cubicle did not alleviate this condition. Breakdown of one unit often damaged another on the adjoining cubicle (See Fig 8). Main contacts needed frequent replacement.

Replacing these starters with vacuum devices lowered cubicle temperature 30°C, cut vibration to one-fourth its former value, and eliminated starter failure for at least 4 years (See Fig. 9).

Low voltage retrofits can be equally effective. According to a 1985 report, one set of starters for 125 to 200 hp motors was installed 10 years ago in an air-conditioned room. Motor starting frequency ranged from one per hour to one per week. Starter contact life was inadequate. Rapid wear, with occasional welding; required contact replacement every 8 months at $700 per set. A larger size air-break starter would not fit in existing cubicles.

Fig. 8

Fig. 8: Damage inside 2300 V motor starter cubicles was caused by overheating and vibration at main disconnect terminals.
Photo Credit: Union Carbide Corp.

A cost study indicated that replacement of each starter with a vacuum unit would be paid off in contact replacement savings alone within 15 months. Work was done in 1983. From then until the date of the report, no starter troubles or motor winding failures had occurred.

Other applications have highlighted the long operating life to be expected of vacuum starters. A metal shear, operated every 8 sec, caused air-break contacts to wear out in 2 months; the associated arc chutes needed replacement after 1 ½ years, still had 20% of its useful life remaining.

In a Gulf Coast chemical plant, a vacuum contactor was still in good working order after 3 million operations in 3 years.

Freedom from dirt and corrosion helps lengthen contact life. In one mining application, coal dust was a problem for air-break

Fig. 9

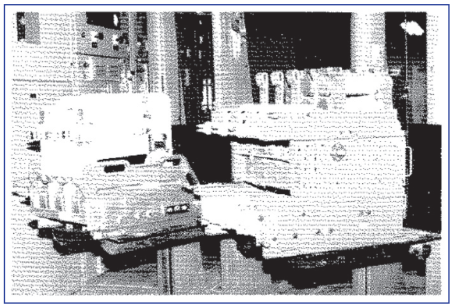


Fig. 9: New Vacuum contactor (right) that fit existing carriage and cubicle was slightly larger than original air-break unit (left). In a new installation, this size relationship would have been markedly reversed.

Photo Credit: Union Carbide Corp.

equipment. But a vacuum contactor needed no maintenance. Even annual inspections were eventually discontinued.

Application Considerations

Gradual contact wear does occur in a vacuum starter, of course, because the small arcs at each operation vaporize some contact material. Since the contacts themselves are invisible within the individual phase chamber or *bottle*, some external means of checking wear must be provided—usually by the position of the moveable contact arm or rod projecting from each bottle, when the contacts are closed. A feeler gauge measurement of arm travel reveals the slight change in arm position caused by wear. Typical contactor maintenance instructions prescribe that check at each half-million operations.

Another cause for concern with any vacuum device is bottle leakage, with subsequent loss of vacuum. Destructive arcing could result in the contacts then opened under load. However, loss of vacuum is more than one of the three-phase bottles is highly unlikely. And if air is present in only one, when the contactor is closed, safe circuit interruption can still be carried out by the other two.

An adequate safety measure, therefore, is to make sure the open contactor cannot be closed if any bottle loses vacuum. So the operating system is normally based on a precise "balance of forces." The total contactor design balances three separate forces acting on the mechanism:

1. Atmospheric air pressure outside the bottle.
2. Magnetic force of the contactor closing coil.
3. Contact opening force in the spring mechanism that takes over when the coil is de-energized.

To close the contactor requires all of the atmospheric and magnetic force. But loss of vacuum in one bottle eliminates one-third of the atmospheric force. Even at 110% voltage on the operating coil, the magnetic force cannot make up the difference, so the contactor will not close.

The importance of atmospheric pressure is the basis for the altitude rating of a vacuum contactor. At too high an elevation, air pressure is too low for proper operation. But standard contactors are typically usable up to 10,000 ft.

Loss of vacuum can be checked by applying a 1 min overvoltage test across the open contacts of a de-energized starter. The small gap between contacts will break down if air is present. Ask the contactor manufacture for the correct test voltage.

For some units, a contact resistance test is also recommended. The "balance of forces" in these designs is such that when vacuum is lost, a closed contact may not open, but will no longer be closed tightly enough to carry full current without overheating. This condition can be checked by measuring resistance through the bottle.

Although the main contacts themselves are remarkably maintenance-free, remember that the complete starter must still include an operating coil, often with an associated rectifier, plus rods, springs, pivots, and all the other mechanical components used with any starter. Those remain exposed to moisture and dirt. Fasteners may loosen, or linkages bind. And auxiliary contacts for low voltage control circuits are also vulnerable.

With those limitations in mind, the user of vacuum motor starters can take full advantage of the benefits of such equipment—especially in hot, dirty, crowded surroundings, with frequent operation and fluctuating load.