Conversion to Vacuum Contact Switches

in Mercury Cell Chlorine Plants

Watteredge, LLC (Westinghouse Industrial and Government Tube Division at the time) began the study and field trials of vacuum contact modules in the early 1970's with full plant installations (Chlor-alkali mercury cells) commencing in 1975. Since that time, upwards of 100,000 VCM's of various designs and applications have been installed. Typical applications include:

- Chlor-alkali cells - Membrane, Diaphragm, and Mercury Cell Process
- Electrolytic Manganese Dioxide
- Copper Refining
- Magnesium Production
- Rectifier Isolation

In all cases, the VCM has provided superior performance and life characteristics in comparison to air-contact and other switch technologies in the electrolytic process industry.

VCM Types

WX-32823:

"Standard" VCM, Rated 6.25kA. Support Plates constructed of Epoxy-Coated Cold Rolled Steel. This VCM has been the primary workhorse of Watteredge, Inc. switches, normally used in all Chlor-alkali mercury cell "fixed" switches, and most other non-metals refining applications. Proprietary alloy of contact material allows for 6.25kA rating vs. 5.0kA rating for most other VCM designs.

WX-33300:

Rated 6.25kA, uses same contact material as WX-32823, but is constructed of epoxycoated stainless steel support plates. Used in metals refining applications where switch will be operated in a NO LOAD, i.e. power source turned off before opening, installation. Normally ceramic and diaphragm region is urethane-potted to reduce corrosive activity on metal component.

WX-34777:

Rated 5.0kA, commonly referred to as a "High Energy" VCM. Contact material utilizes a proprietary alloy to offer good electrical conductivity, but to also limit the effects of high-energy arcing, normally experienced in ON LOAD opening in highlyinductive copper-refining bus systems. Support plates constructed of epoxy-coated stainless steel. Ceramic and diaphragm region urethane-potted to resist corrosive metal-refining environment.

WX-34778:

Rated 5.0kA, same as WX-34777 but support plates are epoxy-coated cold rolled steel. Normally not potted. This VCM is solely for use in Watteredge, Inc. Matrix Portable Jumper Switch elements. The switch element is water cooled, allowing this VCM to carry between 7.0 and 12.5kA. The high energy contact material prolongs the life of the VCM as it operates in Matrix Jumper Switch assemblies shorting and opening on currents from 65kA to 170kA. The Watteredge, Inc. Matrix switch designates anywhere from one to four of these VCM's to be in the "sacrificial" position (one of the last contacts to open, taking the brunt of the electrical arc energy). Normally these contacts are changed out once every 200-300 switch operations at full load (about 1 year of operation in a typical Chlor-alkali plant). Investigation of the contact faces after 300 + operations at full load has shown very acceptable performing as designed and expected.

VCM Application/Selection Criteria

VCM P/N	Current Rating	Max. Resistance	Typical Application	Features
WX-32823	6.25kA	2 micro-ohms	Chlor-Alkali, Non-Metals Refining	Standar VCM
WX-33300	6.25kA	2 micro-ohms	Metals-Refining No-Load Opening	SST Construction Urethane Potting
WX-34777	5.0kA	5 micro-ohms	Metals-Refining No-Load Opening	High Energy Contact Material SST Construction Urethane Potting
WX-34778	5.0kA	5 micro-ohms	Matrix Switch Elements	High Energy Contact Material

Vacuum Enclosed Contacts

Although some obvious advantages can be had by simply enclosing the switch contacts, the complete solution is a permanently sealed vacuum enclosure. Besides excluding completely hostile outside influences, the superior dielectric of vacuum permits a cleaner, quicker current interruption and most important of all, an end to the runaway feedback system of heat to oxidation to higher resistance to more heat. Although not as easily evaluated, the safety feature of a totally enclosed contact system is certainly worth consideration.

Switch Assembly

The external connection the vacuum module also offers an improvement over normal bus connection technique. The outside ends of the contact are dead soft copper. This surface is embedded in the mating flex or bus plate surface by a clamping plate held by four highly stressed bolts. The resulting joint, protected with a joint compound, is effectively a hermetic seal on its own and behaves as a permanent, low resistance connection - even in the fact of high bus temperatures.

A 90° rotation of the switch drive shaft produces the required contact motion through an eccentric cam and link combination. In the closed position, the 100 or so pounds of atmospheric pressure bearing on the contacts adds to the positive cam pressure applied through the link and belleville overtravel washers. The belleville washers have the unique property of a nearly constant force spring. This insures that the proper force will be applied to the contacts in spite of wear and drive misalignments. It also permits interchanging the vacuum modules without need of mechanism readjustment. The basic vacuum module pole is rated at 6.25 kA continuously. Higher current ratings are achieved by grouping two or more such modules in an assembly. Figures 2 to 4 are photographs of typical two, and three module assemblies.

Section of a Vacuum Switch Assembly

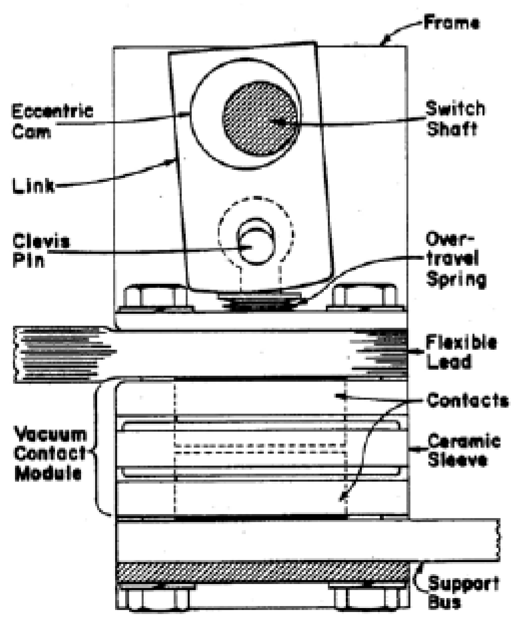

Figure 1

Figure 2

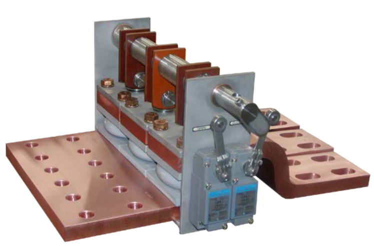

Figure 3

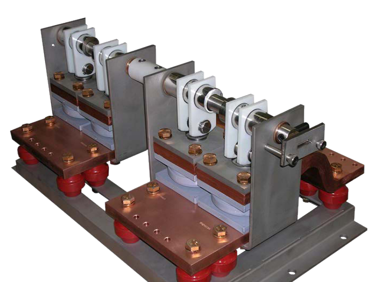

Figure 4

Switch Assembly

As is often the case, a new development, besides producing its intended result, brings with it some worthwhile spin off. The singularly low contact resistance of vacuum contacts is a typical example.Because the contacts are totally free of any contamination, one expects a low resistance; the measured resistance is even lower than expected. The improvement comes from a welding phenomenon in vacuum.

When two clean surfaces are brought together in a vacuum, they weld. If the surfaces are switch contacts closing on a high current, the weld is quite extensive, thus accounting for the low contact resistance. This weld could present a difficulty during opening, in fact, the welding phenomenon is what delayed the introduction of the vacuum switch. The solution was a high conductivity contact material which both welds and separates easily. The result is a significantly lower millivolt drop across the switch, less power lost, lower operating temperature, and ultimately, longer life.

In addition to the lower millivolt drop, this property brings two other significant improvements to the user:

First, the runaway condition mentioned earlier is absent in the vacuum switch. Added load on the vacuum switch will simply cause it to run hotter and, subject to the limitations of the external parts – flex and bus bar – there appears to be no limit to the switches current carrying capacity, short of melting it – over 800ºC. This means the vacuum switch will survive the inevitable temporary overloads encountered in mercury cell room service.

The second is the constancy of the contact resistance over the life of the switch life. Attention to the millivolt drop of the shorted switches can, therefore, be used as a diagnostic for bad bus joints, improper anode setting, or a defective switch. If, for instance, the vacuum enclosure of a switch is accidentally punctured, that switch will behave as a typical exposed contact switch with perhaps double the normal voltage drop. The problem can be corrected or the switch changed when convenient – note that vacuum failure in a switch is not an emergency condition, the switch will still continue to function.

Transient Performance

The layout of a mercury cell room requires that the cell switch be divided into a number of individual switches according to the anode bus grouping. Furthermore, each individual switch is usually subdivided into multiple contact sets. While this fractionalization facilitates cell design and switch design, it has introduced a major cause of switch deterioration-asynchronism. It is an inescapable fact that across the cell, one contact will close first and one-not necessarily the same one-will open last. The affected switches are subject to highly destructive contact erosion. The degree of asynchronism or more precisely, the time delays between contacts opening or closing, has a direct bearing on the about of erosion. Vacuum contacts have been particularly successful in coping with this. Contacts that would require redressing after only a few operations in air, last thousands of operations in vacuum.

Before considering synchronism in detail, it might be helpful to examine the phenomena of current interruption in both vacuum enclosed contacts and exposed contacts. When contact is made in any switch, current flows through only a few isolated points on the contact faces. Current flow is, of course, constricted passing through these joints. During the interruption sequence, the contacting points are parted, one by one, until a single current path remains. This path is stretched into a filament of metal which quickly melts and explodes, spreading metal vapor and globules about. Figure 7 is the readout of a

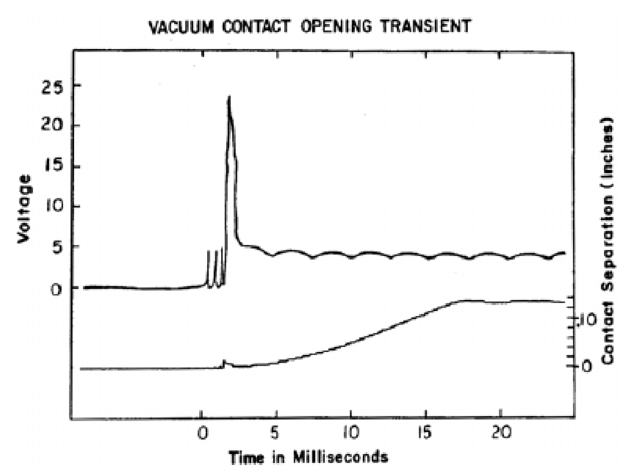

Fig. 7

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digital oscilloscope recording of an opening event. The voltage drop is the upper curve and the contact position is the lower. The short, irregular segment of the voltage curve just preceding the interruption is evidence of this filament in the process of melting and dispersing. Note how little the contacts have moved before the current is interrupted. This is the shower of sparks seen during the functioning of an exposed contact switch. Besides losing material, the exposed contacts suffer oxidation and deposition of oxidized metal. The vacuum enclosed contacts, however, are immune from the oxidation problem. Emitted material remains in the form of clean metal so that when it is deposited on adjacent contact area, it forms a reusable contact surface rather than a high resistance film. As a consequence of the smaller separation of the vacuum contacts, the emission of material is restricted, allowing a higher percentage to be returned to active use on the contact face. Vacuum contacts sampled after a number of high current interruptions show an irregular pattern of pits and protrusions with a matching pattern on the opposite contact face. Instead of reducing the effectiveness of the contact, the irregularity of the vacuum contacts actually seems to improve it after the first few operations. This is due to an increased number of contact points available on the roughened surface vs. the fresh surface. Five thousand operations at rated load in the test produced insignificant wear, perhaps 50 years of life in a chlorine plant.

Obviously, the more current a contact is asked to interrupt, the more erosion will take place. At first glance one might assume that the first switch to close and the last switch to open must take the entire plant load. Fortunately, this is not the case during a typical cell switch operation. There are, of course, transient unbalances in switch loading during the opening or closing sequence.

As you can imagine, little data on this phenomenon exists and measurements on site are quite difficult. However, a computer simulation of a cell room was made, the results of which are pre-sented in Figures 8 and 9. The curves shown in Figure 8 represent the current distribution in the cell after the first switch is closed but before any other switches close. This current would rise to approx-imately double the normal plant load if no other switch closed. Of course, as other contacts close, the load is shared. The extra current comes from the battery effect of the cell adding to the normal load. Although the battery discharge current tapers off quickly, it per-sists long enough to be a consideration during switch closing. The maximum current a switch can carry during a transient of this type depends on its ability to withstand the magnetic forces trying to pop it open. A single contact in a vacuum switch assembly can close on well in excess of 50 kA. This allows considerable margin of safety with typical drive systems – even if the shaft must be hand-operated in emergency.

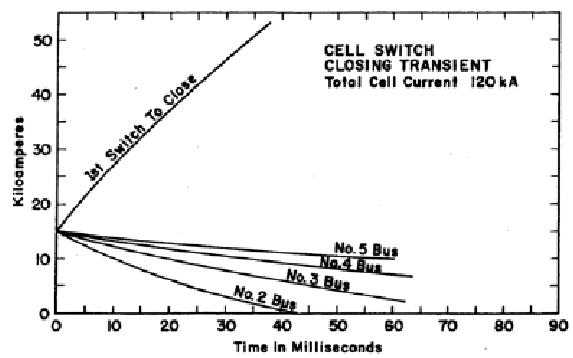

Fig. 8

The opening sequence is pictured in Figure 9. The assumption here is that all 8 switches are connected in tandem, each with a nominal backlash, and the openings proceed from one end to the other. This could also represent half of a 16 switch cell driven from the center. Note that as each switch opens, it loads its neighbors until the last switch is carrying approximately 2 _ times normal current when it opens. With shorter delays between switch closings, the overload on the last switch is reduced – in fact, if all contacts open simulta-neously, there will be no problem. Of course, this is not possible and even a wellsynchronized switch set will deteriorate.

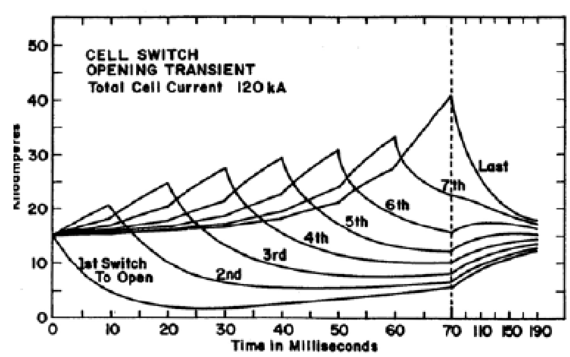

Fig. 9

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Transient Performance (cont)

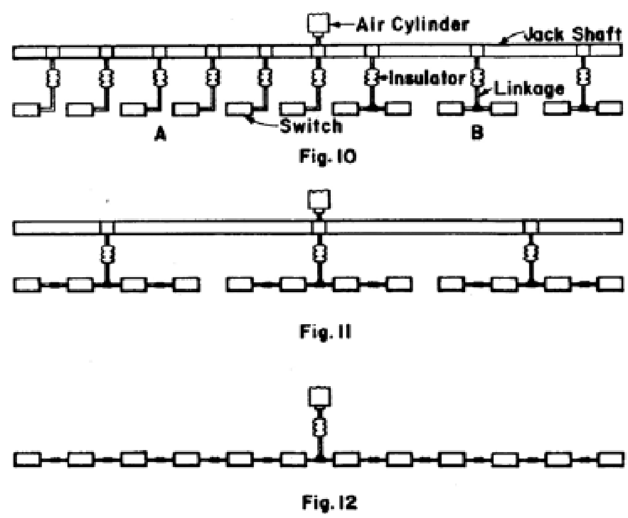
The vacuum switch handles the problem in a unique manner. The last set of contacts to mechanically separate is not necessarily the last contacts to carry current. In a vacuum, the filamentary bridge of metal formed during interruption frequently reforms several times within the first few milliseconds. See Figure 7. This is a random phenomenon which has the effect of reducing the current buildup in the last contacts to physically open. This effect, together with the already good interruption capability, is the reason for the vacuum switches superior performance in chorine cell switching..

Drive Requirement

Although our primary concern is with vacuum switches, we are often asked to recommend or supply the drive system. Since the transient problems previously discussed are largely the result of a less than ideal drive, some judgement must be used in matching switches to the drive system – particularly in retrofits.

The criteria for a good drive are speed and synchronism, that is, all switches in a cell should actuate as quickly and as nearly together as possible. Some systems do this much better than others. One of the best systems in the air actuated jackshaft to which each switch is coupled individually or in pairs as in Figures 10 A and B: one of the worst is a system of individual air cylinders on each switch. It takes little imagination to visualize the results of a single balky air cylinder to the latter case. Most systems presently used lie somewhere in between as in Figures 11 and 12, and have the common advantage of solid mechanical coupling. In general, the more driven joints between the drive and the last switch, the less desirable the system is from the standpoint of switch contact wear. The computer simulation assumes the drive system in Figure 12 where all switches are in tandem, and, thus, must operate sequentially. The speed of the actuating mechanism is of equal importance in evaluating a system. Any lack of synchronism in the switch couplings is magnified by a slower actuation.

CELL SWITCH DRIVE SYSTEMS



These parameters are largely under the control of the user. Routine maintenance items such as good lubrication of the drive and elimination of backlash from worn parts help prevent insidious contact erosion caused by an unnoticed slowdown in the mechanism speed. Fluctuating air pressure or insufficient air delivery can be corrected by an accumulator or larger air lines.

The switch manufacturer for his part must build in synchronism into his multiple contact assemblies. Little is gained by careful alignment of the drive system if the individual contacts within a switch are badly staggered. This internal synchronism has been a prime consideration in the choice of operating mechanism for the vacuum switch. All contacts are designed to open with 1.25^{o} of a specified shaft angle. Translated into a time frame, all contacts open with 2 to 4 milliseconds of each other when driven by a typical system.

Vacuum switch assemblies can, therefore, be adapted to almost any existing drive system. Its very low torque requirement (approximately 9 foot pounds per vacuum module) even helps speed up the system when it replaces a high friction, open contact switch. We do not, however, recommend systems that are not mechanically coupled except in special applications where the total plant load is low – say, under 50 kA.

Drive Requirement (cont)

Figures 13, 14, 15, 16, illustrate how the vacuum switch is fitted into some common cell types.

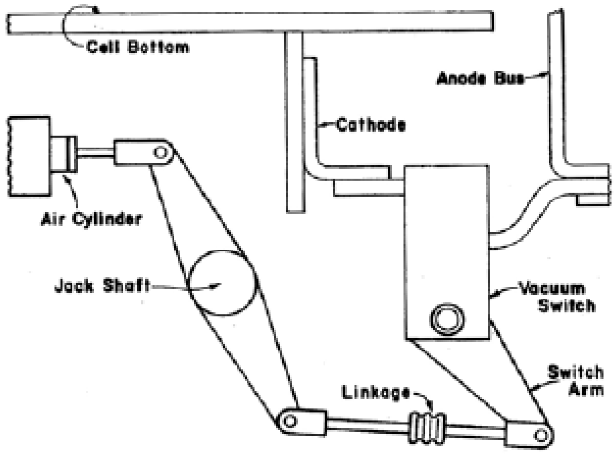


Fig. 13

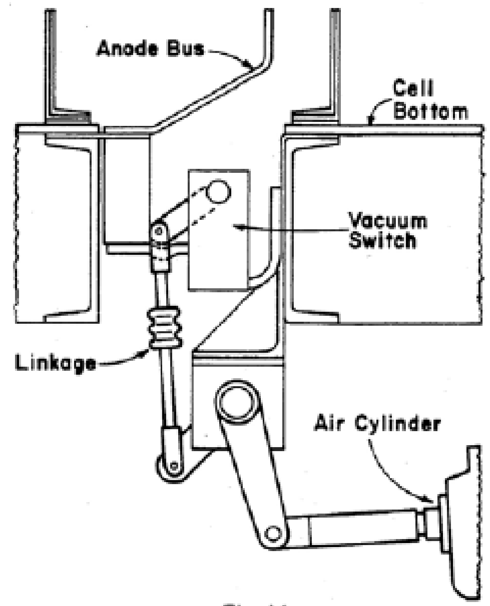


Fig. 14

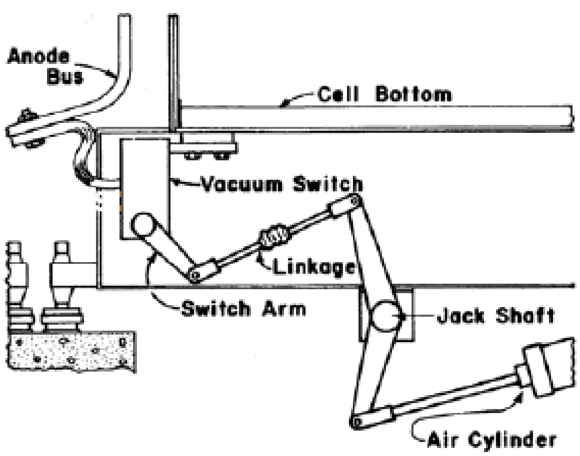


Fig. 15

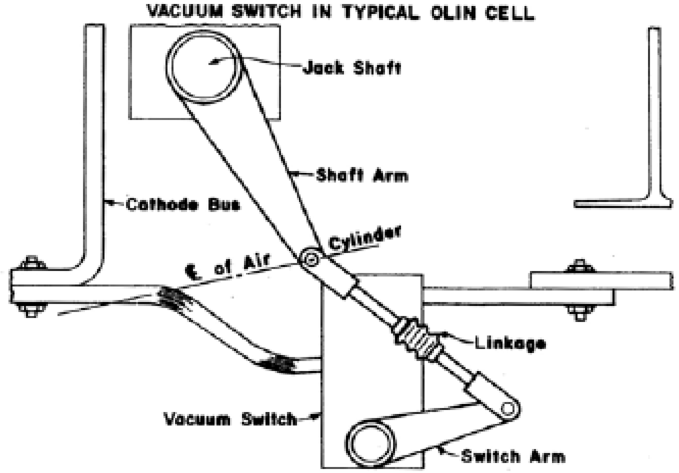


Fig. 16

Safety

It is general knowledge that the chlorine industry places a very high priority on personnel health and safety.

The vacuum shorting switch makes a positive contribution to safety improvement by eliminating flying hot metal and high intensity arcing.

Also, since there is zero maintenance required by vacuum contacts, the need for potentially toxic cleaning solutions and abrasive materials is eliminated.

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SUBJECT:
FIELD SERVICE OF HIGH CURRENT SWITCH

1. RECOGNITION OF A DEFECTIVE SWITCH

1.1 A defective switch may be identified by a higher than expected millivolt (mv) drop across the extremes of the switch as shown in Fig. 1.

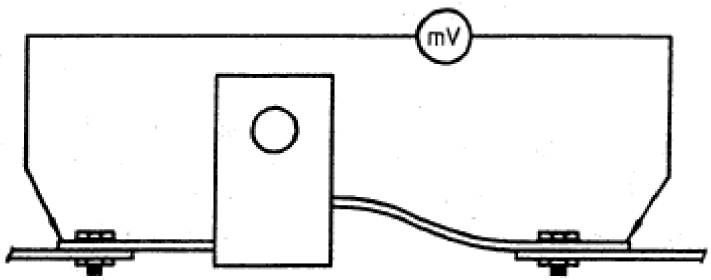

Fig. 1

Maximum mV drops across the extremes of the switch at rated load are shown in Table I.

TABLE I

Vacuum Contact Module Type Number	Max. mV Drop @ Load Across Extremes of Switch
148-32823	75

1.2 The defective switch will run significantly hotter. At rated current, the hottest point on the switch will run approximately at the temperature shown in Table II. This temperature is the rise above the temperature of the buswork to which the switch is attached.

TABLE II

Vacuum Contact Module Type Number	Defective Switch Temp °C Above Buswork
148-32823	25

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SUBJECT: FIELD SERVICE OF HIGH CURRENT SWITCH

2.3 Before demounting a switch for repair, check the tightness of the eight bolts into each vacuum contact module(VCM). The torque should be 42-Ft-Lbs. If the bolts are loose, tighten and repeat millivolt drop measurements.

2.0 <u>LOCATION OF DEFECTIVE VACUUM CONTACT MODULE (VCM) WITHIN A MULTIPLE VCM SWITCH</u>

2.1 If one of several VCM's (Vacuum Contact Modules) in a switch has lost vacuum it will usually operate cooler than the remaining VCM's. The millivolt drop across the VCM faces (See Fig. II) of the bad VCM will be higher than the Max. mV drop as shown in Table III.

Fig. II

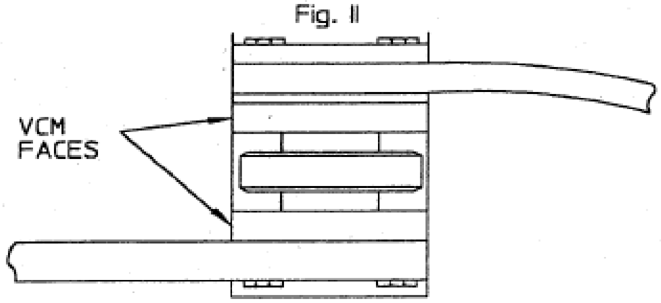

TABLE III

Vacuum Contact Module Type Number	Max.mV Drop Across VCM Faces
148-32823	31.25

2.2 Oxidation and discoloration of switch parts is not necessarily an indication of VCM failure, merely that the switch has been overloaded. If there is a marked difference in degree of oxidation among several units within a single switch, the least oxidized unit is suspect.

3.0 <u>REMOVING VACUUM CONTACT MODULE</u>

Caution - Do not change more than one VCM at a time on a multi-VCM switch.

3.1 Remove the suspected switch from service.

3.2 Mark the position of the drive plate relative to the flexible lead. See Fig. III. <u>CAUTION</u> - Do not rotate the drive plate from this position at any time or realignment will be required. See 7.0.

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SUBJECT: FIELD SERVICE OF HIGH CURRENT SWITCH

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3.3 Close the switch and remove the four silicon bronze bolts from the drive plate. Refer to Fig. III.

3.4 Open the switch and slide flex out.

3.5 Remove remaining four bolts (below) holding the VCM and remove VCM. H

4.0 INSPECTION OF VACUUM CONTACT MODULE

4.1 The failure mode of the VCM is either by wear or loss of vacuum.

4.2 With vacuum intact the contacts are closed. Loss of vacuum will cause the contacts to separate. Separation can be detected by the ability to move the contacts together by hand compression. G

4.3 Wear allows the contacts to rock even though held tightly together by vacuum. This can be detected by appling finger closing pressure at each corner in turn.

F

4.4 Oxidation or evidence of over heating alone is not evidence of failure. Unless accompanied by other symptoms, the VCM may be cleaned, repainted and returned to service.

4.5 During onload operation, material is removed from the contact faces and deposited elsewhere within the VCM. It is normal to measure some degree of continuity across an open VCM and to hear some rattle inside when shaken. E

5.0 INSTALLATION OF VACUUM CONTACT MODULE

5.1 Clean copper contact faces of new VCM and mating surfaces of bus and flex with light sandpaper (220) or "Scotch Brite". D

5.2 Coat surfaces with T&B "KOPR-SHIELD".

5.3 Mount VCM on bus bar orienting the VCM serial number per 148-34477C or 148-34478A drawings. Insert four silicon bronze bolts and lockwashers. Tighten bolts finger tight.

C

5.4 Slide flex between VCM and drive plate. Insert the 4 silicon bronze bolts with lockwashers and tighten finger tight.

5.5 Close switch completely

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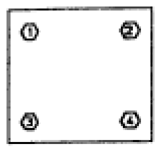
5.6 Using a 3/4" socket on a torque wrench, gradually tighten bolts using the following sequence.



Bolt Numbers

1, 3, 2, 4	15 foot pounds
1, 3, 2, 4	30 foot pounds
1, 3, 2, 4	42 foot pounds

6.0 <u>REPLACEMENT OF MECHANISM PARTS</u>

6.1 Refer to Fig. III to identify the drive mechanism components on the switch being repaired.

6.2 Remove spring pins from both ends of eccentric drive shaft.

6.3 Remove pins from clevis pins.

6.4 Rotate shaft until clevis pins are free and remove them.

6.5 Remove the shaft extensions from both ends of the shaft.

6.6 Lift out eccentric shaft with connecting rods.

6.7 Replace defective part and reassemble. If it has been necessary to replace the eye bolt, drive plate, or spring washers (Belleville washers), realignment of the switch will be required. (See 7.0).

7.0 <u>RE-ALIGNMENT</u>

Required only if mechanism parts or flex has been replaced.

7.1 Refer to Fig. III to identify the mechanism components used on the switch being repaired.

7.2 Fig. III alignment consists of rotating the eye bolt, 1/2 turn at a time until the pick up angle specified on the 148-drawing is obtained ±5°.

It will be necessary to remove and reassemble the clevis pin for each alignment trial. It is not necessary to install the cotter pin until alignment is completed.

7.3 Pick up is defined as that shaft angle where opening tension is first applied to the VCM via the clevis pin. It is located by rotating tightly the shaft from closed toward open until the clevis pin just becomes trapped between the eye bolt and the connecting rods.

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SUBJECT:
FIELD SERVICE OF HIGH CURRENT SWITCH

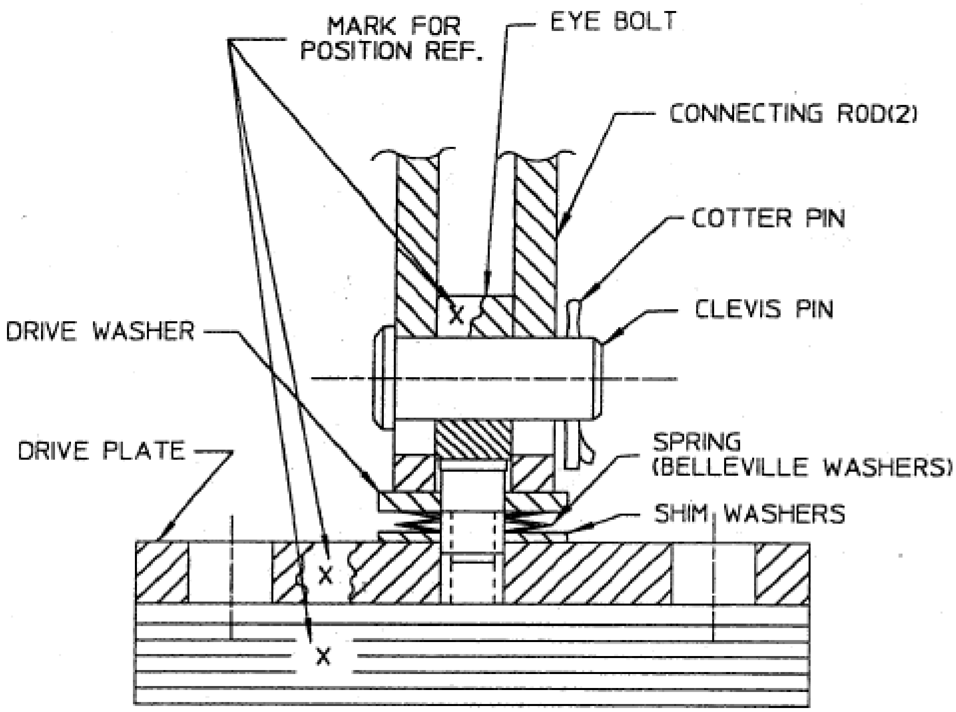

Fig.III

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