# Conference Paper

A MAGNETIC AIR CIRCUIT BREAKER FOR 350 MVA., 3000 AMPERES AND 4.16 KV

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# A MAGNETIC AIR CIRCUIT BREAKER FOR 350 MVA., 3000 AMPERES AND 4.16 KV

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## Synopsis

This paper describes a new and higher rated magnetic air circuit breaker for 4.16 KV applications. The higher interrupting rating of 350 MVA and the higher continuous rating of 3000 amperes, as compared to the previous high of 250 MVA and 2000 amperes, is needed for the greater concentrations of power supply and loads in central station auxiliary service where the highest ratings of turbo generators are used. This development also makes available a higher rating of magnetic air breaker for distribution systems in the 4 KV class where it may be necessary to have heavier concentrations of power than has heretofore been feasible.

## General

The 2000 ampere maximum continuous rating in 4.16 KV switchgear has fulfilled the maximum continuous rating requirements of the industry for many years. However, as long as approximately 7 years ago it began to be necessary to do much skillfull design work in central station auxiliary circuitry to accommodate the highest requirements with the 2000 ampere rating. In a few cases, auxiliary blowers were built into 2000 ampere switchgear for increasing the rating to 2500 amperes. In some cases parallel operation of existing ratings was tried. These obviously were stop-gap measures for it was apparent that, with the increased continuous load requirements, the demands for efficient operation would result in increased interrupting capacity requirements.

An industry survey indicated that a logical rating from the users point of view would be 350 MVA., 3000 amperes, at the present standard rated voltage of 4.16 KV. Complete rating factors agreed upon are as follows:

| | |
|---|---|
| Rated KV | 4.16 |
| Maximum design KV | 4.76 |
| Minimum KV for rated MVA | 4.0 |
| Three phase MVA | 350 |
| Continuous amperes | 1200 & 3000 |
| Momentary current | 80,000 amperes |
| Four-second current | 50,000 amperes |
| Amperes at rated voltage | 48,000 |
| Maximum Amperes | 50,000 |
| Insulation Level | |
| Low frequency withstand KV | 19 |
| Impulse withstand crest KV | 60 |
| Rated Interrupting time | 8 cycles |

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In respect to the now well established practice of developing magnetic air circuit breakers in standard basic designs for application only in metal-clad switchgear, the new 350 MVA breaker is no exception. Following a practice since the first metal enclosed magnetic power air breakers were introduced in 1931 by the company with which the authors are associated, the new unit is of the horizontal drawout type. This was not merely following precedent. As the weight and size of the breaker unit increases, as it almost inevitable must with such an increase in rating, the advantages of horizontal drawout becomes increasingly apparent. Since the weight of the withdrawable unit does not have to be lifted but merely rolled into place, the drive mechanism can be much simpler and therefore less subject to troubles than with other types of gear; and, since the weight of the breaker is supported by the floor and not by the cell structure, construction of the cell is simplified. In addition, location of the contacts and arc chute makes inspection and maintenance easier and therefore less expensive than with other constructions. This is further evidenced by the fact that most manufacturers of this class of equipment now make the horizontal drawout type exclusively, following the practice established 26 years ago.

Fig. 1 shows a general view of the new 4.16 KV, 350 MVA, 3000 ampere breaker with the main barrier removed to show the arc chutes and part of the contacts. The requirements of this new design from the standpoint of interrupting, momentary, and continuous current are considerably higher than the highest previous rating of 4.16 KV switchgear. Magnetic forces vary as the square of the current, which means that the forces encountered by the frame, mechanism, and contacts at 80,000 amperes are 1.78 times those encountered at 60,000 amperes. Also, 3,000 amperes continuous current requires approximately two times the copper section used for 2,000 amperes, when radiation, skin effect, and proximity effect are taken into account. A substantial increase in interrupting capacity is also required. To meet these requirements and maintain the ruggedness and dependability to which users of this class of gear have become accustomed, the adapting of components from existing breakers did not appear to be most desirable. As a better approach, it was decided to coordinate this design with another new design of magnetic breaker (1) which has many similar requirements. Accordingly, new frame construction, new contacts, and a new solenoid mechanism were developed, and features were incorporated from the most recently developed magnetic air breakers (2), (3). Thus, in "wiping the slate clean", best advantage could be taken of extensive experience, and it was not necessary to compromise in order to use existing details.

## Circuit Breaker Frame

The frame used for this new design(see Fig.2) is simple and rugged. The side members are approximately triangular sheets of 1/4 in. thick steel with flanges bent on their rear edges and with Z-sections welded to their bottom edges to accommodate the wheels. Four steel cross angles are welded between the side members. The solenoid mechanism is bolted to the front cross member and the cross member below the contacts. These angles are 3/4 x 4 x 4 and 5/8 x 3-1/2 x 5 to provide stiffness for high momentary currents. Insulating plates tie the front of the lower bushings to the upper of these cross members. The magnetic forces tending to open the contacts appear in the frame as simple beam loading in the two cross members and as tension in the side members. The front part of the grounded steel barrier required between the high and low voltage compartments, which heretofore has been a part of the frame, has been made a part of the interphase barrier. As a result, when the barrier is removed for contact and arc chute inspection, the solenoid mechanism is also exposed.

## Solenoid Mechanism

To provide the closing power required for the increased momentary rating without excessive closing coil current, a new solenoid mechanism was developed. It uses a 5 inch diameter plunger as compared to the 3 inch diameter used for the lower ratings of 4.16 KV breakers, and the plunger is slotted to reduce the eddy currents and maintain the speed of operation. The basic trip-free scheme used so successfully for the past eleven years has been adapted to this new mechanism. This scheme consists of a four-bar linkage operating about a single pin. In this new design, the trip-free operating lever is a heavy casting of ductile iron to which the operating rods are directly coupled. All pins and latch parts are of hardened, corrosion-resistant steel. The mechanism frame is a departure from conventional design. It is made from four round steel bars extending the full length of the device. The solenoid end-plate bolts to the rear ends of these bars. The yoke section is a group of punched steel plates fitted over the bars and welded in place. Four steel bars arranged in a rectangle are welded close to the front of the frame to provide rigidity and also to provide a mounting for the trip assembly and the latch lever. A steel panel is bolted to the front of the round longitudinal bars. This panel supports the interphase barrier, and provides a mounting panel for the auxiliary switch, latch check switch, solenoid cut-off switch, operation counter, and up to five independent tripping devices. The advantages accruing from this construction of the solenoid mechanism are rigidity, simplicity, and the utmost in accessability.

## Circuit Breaker Contacts

In order to get the best practical contact performance with ample margin above the 80,000 ampere momentary requirement, an entirely new design of circuit breaker contact was developed. Fig. 4 shows a close-up photograph of the movable and stationary contacts. The design is very compact so that both the main current carrying contacts and the intermediate and arcing contacts fit entirely within the throat of the arc chute. With this construction, any restriking associated with arc interruption occurrs within the throat of the arc chute and thus will enter the arc chamber and be interrupted.

In Fig. 4 it will also be observed that the main contact is of the parallel finger construction. The stationary fingers have plane surfaces while the mating part of the moveable main contact has cylindrical surfaces. Thus, the current through the contact assembly flows in a multiplicity of parallel paths through high pressure line contact. This makes for efficient current distribution through the assembly and gives the assembly very high short-time current carrying ability.

Again referring to Figure 4, placement of the intermediate and arcing contact members between the two sets of fingers makes for extreme compactness. This compactness also means that the change in impedance when the current transfers from the main contacts to the intermediate and arcing contacts is small, which inturn results in very low pitting or burning of the main contacts, even on the highest currents. Additional reduction of impedance is obtained by providing three separate parallel secondary and arcing contacts, each capable of independent motion. On account of the high momentary and 4-second requirements of this rating, and the desirability of liberal performance margin, this same design of contact assembly is used on the 1200 ampere rating.

The movable contact member consists of 4 blades of copper, hinged at the bottom and making ring contact through silver plated surfaces with the stationary block of the main terminal bushing.

The main terminal bushing is of the condenser type wound of flame retardent resin treated paper. The main conductors are 2 copper channels butted together to form a hollow square conductor. The joint between the copper and the condenser is filled with flame retardant epoxy resin to fill all voids and aid in thermal conduction. Referring to Fig. 5, the main disconnecting contacts consist of two double rows of fingers. These fingers together with their individual leaf type pressure springs are the same as used on all lower ratings of this type of breaker. Also shown in Fig. 5 are the clamp type bushing supports. These bars are high strength aluminum alloy, chosen for non-magnetic properties to reduce heating from the high continuous current.

## The Interrupter

It has almost become a cliche that the interrupter is the heart of the circuit breaker. Nevertheless, it is true. The interrupter for this new breaker is of a new design based on the principles of the interrupter of the 750 MVA breaker previously described before the Institute (3). As shown in Figs. 1 and 6, the interrupter is basically of the H magnet design. This means that in the plan view the blowout magnet iron pole faces and coil core are like the letter H. This construction results in the following advantages over other types of magnetic interrupters:

(1) The magnetic action on the arc is stronger.

(2) The magnetic field not only is stronger but more uniform.

(3) The insulation level of the arc chute can be made considerably higher, giving a liberal margin over the required basic insulation level with very economical construction and small space requirements.

As in all other magnetic interrupters built by the company with which the authors are associated, this new interrupter has its main interrupter plates made of zircon refractory ceramic. Again, in common with all such interrupters, this new interrupter contains no asbestos bearing material with voltage across it or which comes in contact with the arc. It is well known that, on account of its high moisture absorbing properties, asbestos is unsuitable for high voltage or for exposure to arcs. On the other hand, the zircon ceramic has excellent electrical properties, low atmospheric moisture absorption, and very high heat shock resistance.

In this new interrupter, the main interrupter plates are not enclosed in a wrapped laminate enclosure. The enclosure consists essentially of flat side plates bolted to end channels. The material used is flame retardent glass mat polyester. This results in maximum mechanical strength, very high dielectric strength, and economical construction.

Other Details

The auxiliary air puffer for speeding the extinction of low current arcs is of the diaphragm type previously described before the Institute (2). A silicone rubber diaphragm, which cannot develop friction and interfere with the mechanical opening of the breaker, is used instead of sliding pistons. This device was given an endurance test at -55°F and was not embrittled or damaged in any way.

Of primary importance in inspection and maintenance operations is the method of raising the arc chutes. The arc chutes are hinged at the rear and are therefore tiltable, a construction first used by the company with which the authors are associated on magnetic breakers in 1929. The attachment for tilting the chutes consists of three very simple and light weight parts as previously described before the Institute for a 750 MVA breaker (3). As shown in Fig. 7, two bars are attached to the drawout levering device arms. These two bars are attached to a round cross bar inserted through holes in the arc chute walls. Turning the levering device shaft with the standard crank raises the arc chutes.

An additional feature of convenience has been added to this new breaker. As shown in Fig. 8, the secondary contacts are operated by a lever inserted in a convenient socket. Insertion of the lever automatically unlocks the secondary contact support, and raising the lever re-engages the secondary contacts. This further increases the ease and speed of engaging or disengaging the control circuits while the drawout unit is in the test position. The same removable lever is also used as a maintenance hand closing lever.

Development Tests

Complete development tests have been made for this new breaker as is customary. These include 60 cycle dielectric withstand tests, impulse withstand tests, radio influence voltage tests, temperature rise tests, momentary current tests, short time current tests, low current switching tests, capacitor switching tests, short circuit switching tests, and mechanical operation life tests. Space does not permit repetition of data from all of these tests. However, as representative of the performance obtained, two series of interrupting tests are tabulated. Table 1 lists a series of consecutive single phase symmetrical opening tests made with 4.2 KV across one pole. Table 2 lists a series of consecutive three phase short circuit switching tests ending with two pairs of close-open tests. Sample oscillograms are shown from each series. Both series of tests were made without maintenance between tests, and at the conclusion of the series, the breaker was in satisfactory condition for many more interrupting operations without maintenance.

## Conclusion

A new magnetic air breaker has been described which has been developed to meet the requirements of central station auxiliary service. With the requirements of this service in mind, an entirely new design has been worked out with particular emphasis on ruggedness, long life, and ample capacity to perform easily up to its maximum rating.

## REFERENCES

1. A 1,000 MVA, 13.8 KV Magnetic "De-ion" Air Circuit Breaker, R. C. Dickinson and Russell Frink, AIEE Conference Paper to be presented at Winter General Meeting, January 1958.

2. A new 5 KV, 50,000 KVA "De-ion" Air Circuit Breaker, Russell Frink and J. M. Kozlovic, AIEE Conference Paper CP55-721.

3. A Magnetic "De-ion" Air Breaker for 750 MVA, 13.8 KV, Russell Frink and J. M. Kozlovic, AIEE Conference Paper CP57-225.

Table 1 - Single Phase Interrupting Tests

| Test No. | Test Voltage | Interrupted Amperes | Recovery Voltage | Int. Time Cycles | Equiv. 3Ø KVA |
|---|---|---|---|---|---|
| 86222AF | 4,200 | 840 | 4,200 | 4.2 | 7,000 |
| 86222AG | 4,200 | 1,820 | 4,200 | 3.9 | 15,100 |
| 86222AH | 4,200 | 3,520 | 4,200 | 3.4 | 29,300 |
| 86222AI | 4,200 | 10,200 | 4,200 | 2.8 | |
| 86222AJ | 4,200 | 14,900 | 4,175 | 2.7 | 124,000 |
| 86222AK | 4,200 | 18,400 | 4,150 | 2.8 | 153,000 |
| 86222AL | 4,200 | 24,500 | 4,160 | 2.7 | 204,000 |
| 86222AM | 4,200 | 28,900 | 4,200 | 2.5 | 241,000 |
| 86222AN | 4,200 | 33,950 | 4,130 | 2.8 | 282,000 |
| 86222AO | 4,200 | 38,500 | 4,090 | 2.6 | 320,000 |
| 86222AP | 4,200 | 42,400 | 4,120 | 2.6 | 353,000 |
| 86222AQ | 4,200 | 43,000 | 3,960 | 2.4 | 358,000 |
| 86222AR | 4,200 | 43,750 | 4,200 | 2.6 | 364,000 |
| 86222AS | 4,200 | 46,250 | 4,000 | 2.7 | 384,000 |
| 86222AT | 4,200 | 49,600 | 4,150 | 2.4 | 413,000 |
| 86222AU | 4,200 | 51,700 | 4,140 | 2.6 | 430,000 |
| 86222AV | 4,200 | 52,000 | 4,040 | 2.4 | 433,000 |
| 86222AW | 4,200 | 56,500 | 4,175 | 2.6 | 470,000 |
| 86222AX | 4,200 | 58,500 | 4,150 | 2.9 | 486,000 (1) |

(1) This oscillogram is shown in Figure 9.

Table II - Three Phase Interrupting Tests

| Test No. | Test Voltage | Opening Tests Interrupted Amperes Ø1 | Ø2 | Ø3 | Rest Volts | Int. Time | 3Ø KVA | Note |
|---|---|---|---|---|---|---|---|---|
| 86222EM | 4,800 | 540 | 505 | 523 | 4,620 | 5.5 | 4,500 | |
| 86222EN | 4,800 | 1,130 | 1,120 | 1,190 | 4,710 | 5.1 | 9,900 | |
| 86222EO | 4,800 | 2,440 | 2,600 | 2,460 | 4,720 | 4.1 | 21,600 | |
| 86222EP | 4,800 | 4,450 | 5,150 | 5,100 | 4,810 | 3.9 | 42,900 | |
| 86222EQ | 4,800 | 10,900 | 6,550 | 10,400 | 4,825 | 3.6 | 91,000 | |
| 86222ER | 4,800 | 12,400 | 13,250 | 9,750 | 4,775 | 3.4 | 110,000 | |
| 86222ES | 4,800 | 23,800 | 18,600 | 25,600 | 4,650 | 3.3 | 213,000 | |
| 86222ET | 4,800 | 28,200 | 30,600 | 24,500 | 4,520 | 3.2 | 255,000 | |
| 86222EU | 4,800 | 31,200 | 30,200 | 38,300 | 4,600 | 3.1 | 319,000 | |
| 86222EV | 4,800 | No Record | | | | | | |
| 86222EW | 4,800 | 27,300 | 24,700 | 30,600 | 4,710 | 3.2 | 255,000 | |
| 86222EX | 4,800 | 36,200 | 32,200 | 42,550 | 4,440 | 3.4 | 354,000 | |
| 86222EY | 4,800 | 36,600 | 46,300 | 51,000 | 4,440 | 3.2 | 425,000 | |
| 86222EZ | 4,160 | 1,290 | 1,140 | 1,030 | 4,130 | 4.7 | | |
| 86222FA | 4,160 | 21,500 | 18,400 | 22,700 | 4,135 | 3.6 | 163,500 | |
| 86222FB | 4,160 | 35,100 | 31,700 | 41,300 | 3,750 | 3.3 | 298,000 | |
| 86222FC | 4,160 | 42,000 | 43,100 | 35,100 | 3,750 | 3.4 | 311,000 | |
| 86222FD | 4,160 | 45,700 | 43,600 | 38,300 | 3,710 | 3.1 | 329,000 | |
| 86222FE | 4,160 | 56,900 | 53,000 | 44,900 | 3,710 | 3.2 | 410,000 | |
| 86222FF | 4,160 | 56,200 | 44,150 | 49,500 | 3,590 | 3.2 | 405,000 | |
| 86222FG | 4,160 | 42,700 | 51,500 | 52,900 | 3,570 | 3.3 | 382,000 | |
| 86222FH | 4,570 | 56,000 | 53,750 | 54,200 | 3,980 | 3.2 | 444,000 | |
| | | Close-Open Tests | | | | | | |
| 86222FI | 4,800 | Timing Test | | | | | | |
| 86222FJ | 4,800 | 41,700 | 34,900 | 45,900 | 4,660 | 3.2 | 382,000 | * |
| 86222FK | 4,800 | 37,400 | 43,600 | 36,600 | 4,660 | 3.4 | 362,000 | * |
| 86222FL | 4,570 | Timing Test | | | | | | |
| 86222FM | 4,570 | 50,100 | 47,000 | 59,400 | 4,100 | 3.0 | 470,000 | * (1) |
| 86222FN | 4,570 | 46,800 | 51,500 | 52,900 | 4,100 | 3.2 | 419,000 | * (1) |

* CO-15 SEC-CO made with 102 volts at closing coil terminals currents closed in maximum phase - Test FI, 66,000 amps; FJ, 62,500 amps; FM, 91,600 amps; FN, 79,000 amps.

(1) This oscillogram is shown in Figure 10.

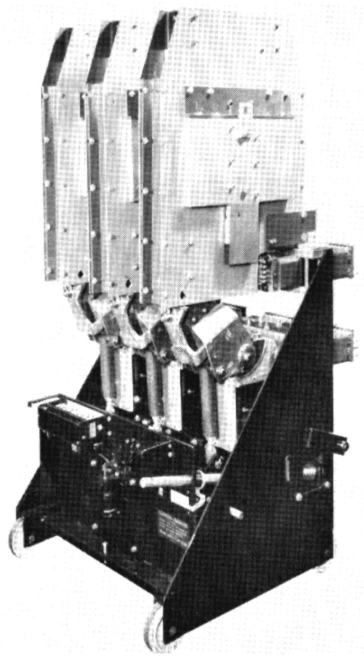

Fig. 1. The new 4.16 KV, 350 MVA, 3000 ampere magnetic air circuit breaker with main barrier removed.

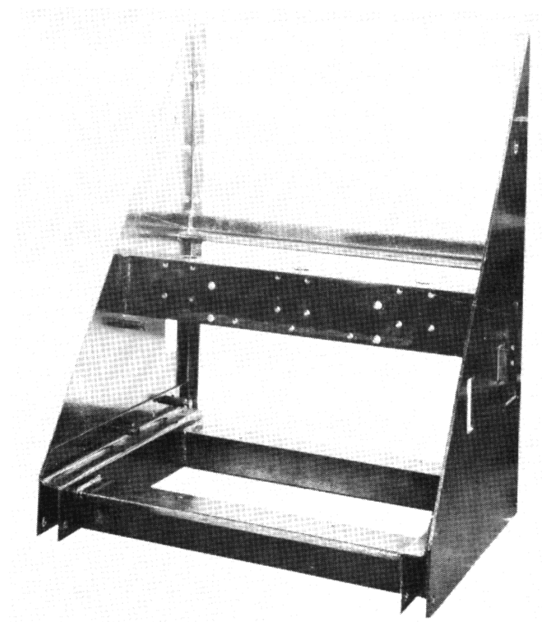

Fig. 2. Frame for the 350 MVA breaker.

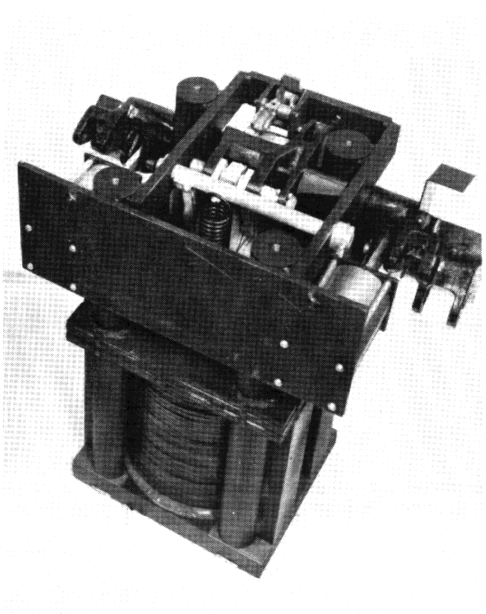

Fig. 3. Solenoid mechanism for the 350 MVA breaker.

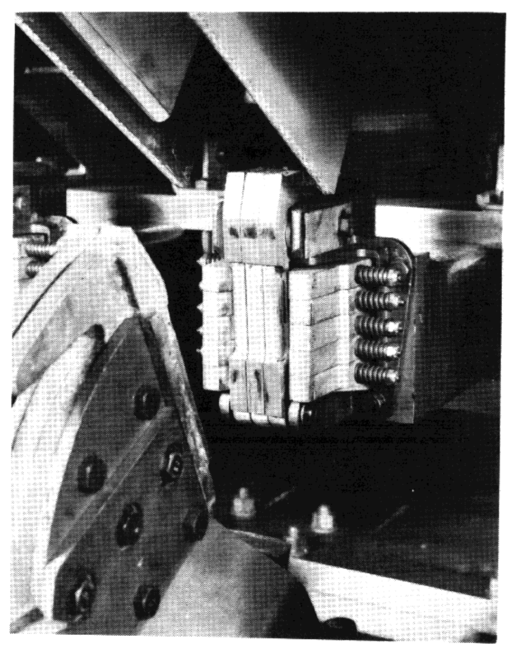

Fig. 4. Stationary and moving contact structure for the 3000 ampere, 350 MVA breaker.

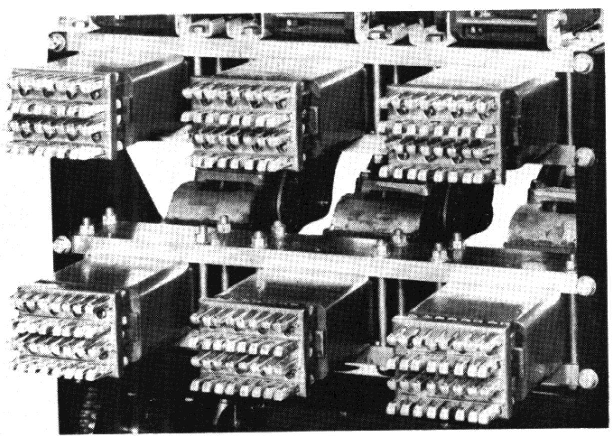

Fig. 5. The primary disconnecting finger contacts for the 3000 ampere, 350 MVA breaker.

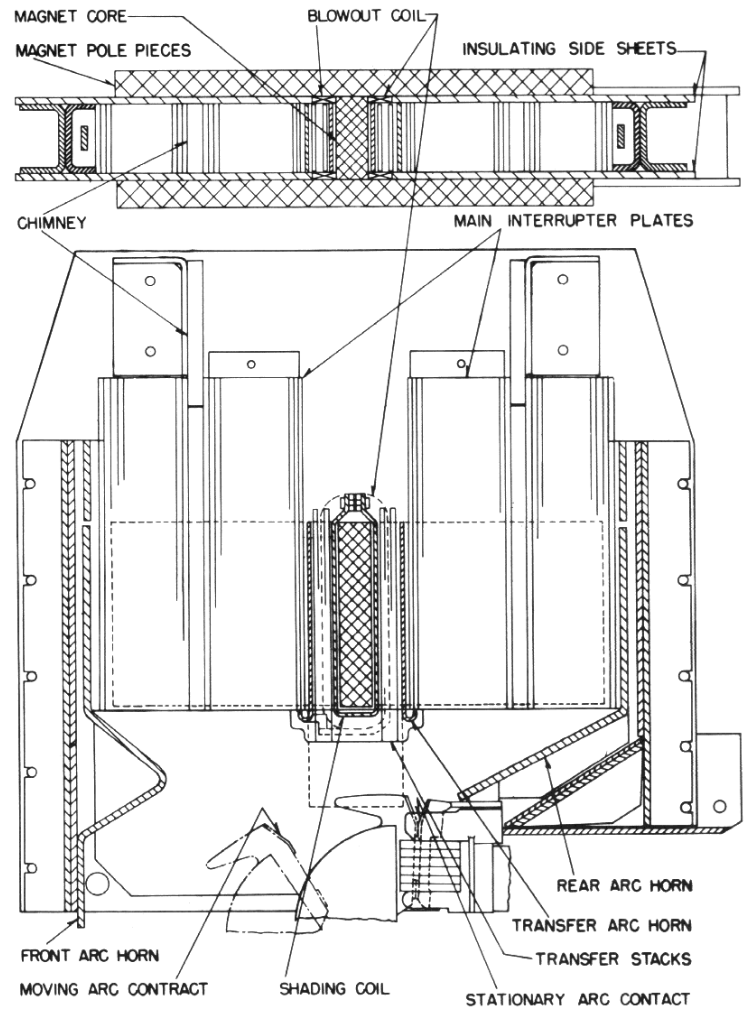


Fig. 6. Schematic cross section of the 350 MVA arc chute showing component parts.

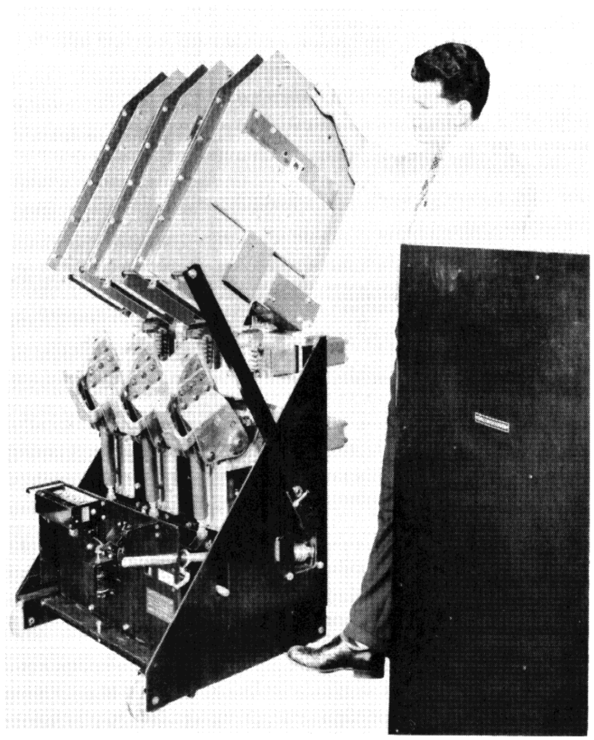

Fig. 7. The 350 MVA breaker with main barrier removed and arc chutes tilted back for inspection and maintenance.

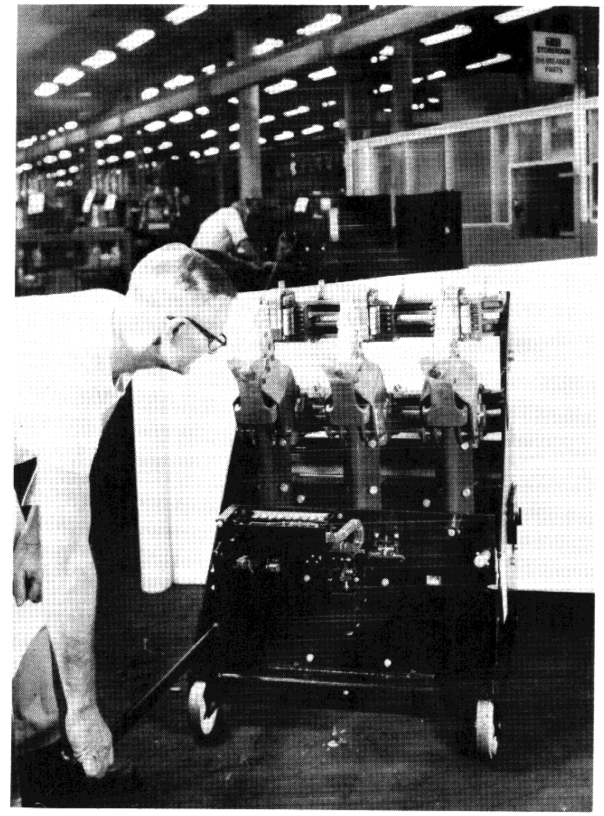

Fig. 8. Method of operating secondary contacts on 350 MVA breaker.

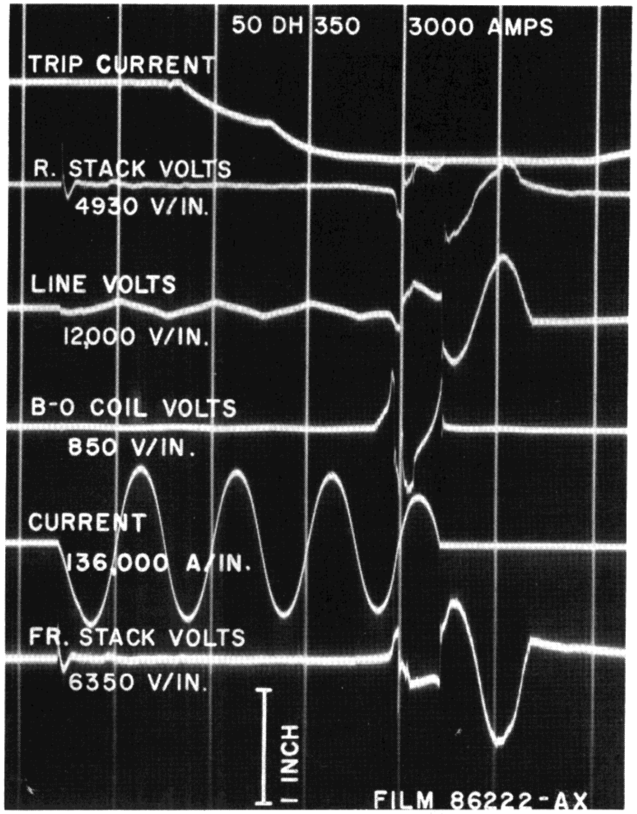


Fig. 9. Oscillogram showing single phase interruption of 58,500 amperes at 4.2 KV.

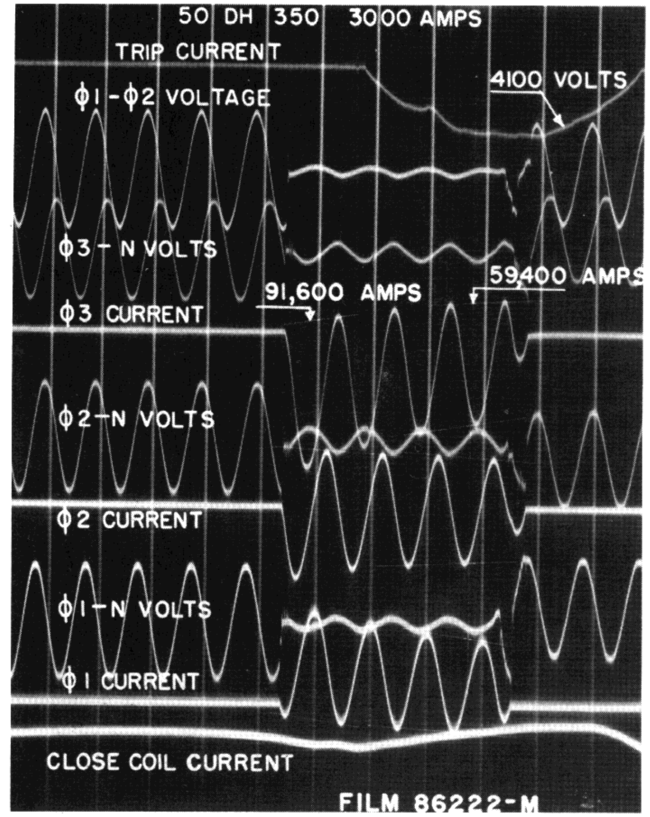


Fig. 10. Oscillogram showing one of a pair from a standard duty cycle with the breaker interrupting 470,000 MVA at 4.57 KV.