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quest for an ideal...
A continuing story of progress...

OB and Surge Arresters

OB's quest for improved surge arrester technology began with the introduction of the Thorex series of arresters in 1950. Thorex brought several innovations in arrester technology. It pioneered the use of a series gap that magnetically drove arcs along runners into a cooling chute. Arrester height was reduced by arranging series-connected gap assemblies in double parallel paths. With the height reduction the arrester could be made self-supporting, eliminating the expense of bracing.

The real breakthrough for OB and equipment users came with the introduction in 1957 of the current-limiting gap — an exclusive OB development. The new gap used a magnetic field to stretch individual arcs over 100 times their original length while simultaneously cooling them in heat-absorbing arc chambers.

The current-limiting gap, call Dynagap, drastically changed the role of the arrester. Instead of being merely a lightning protective device, it became a key part of insulation coordination planning. It proved an economical boon to extra-high-voltage arrester design and to the equipment the arresters protected. BIL levels in station equipment could be lowered significantly, saving utilities millions of dollars during the era of EHV expansion when switching surges replaced lightning as the main concern of system planners.

The new construction permitted improvements in switching surge sparkover levels and increased the durability of the equipment in EHV applications.

Next came DynaVar® which translated modern technology in the form of a metal-oxide varistor into a valve block with superior protective characteristics, offering a million times the resistance to normal system current than offered by a gapped silicon-carbide block with the same protective characteristics. Metal oxide varistors are said to form the near-perfect arrester block in that it conducts less than a milliampere at operating voltage, yet is able to conduct tens of thousands of amperes during surge-over voltage condition.

Compared to earlier arresters, even those with the current-limiting gap, DynaVar offers impressive advantages, mainly because of its nonlinearity. It provides greater protective margins, offering the economy of lower BIL levels. The life of the varistor is not affected by repetitive operations. And it weighs less, as little as half the Dynagap units, depending on the model selected. It also can absorb higher levels of energy.

The following pages cover the quest for an ideal arrester, including research and development, the high technology plant where the long-life varistors are made, the plant that assembles DynaVar arresters, the product lineup (which is always growing and improving) and the basic proof of its worldwide acceptance.
An experimental project that clearly demonstrates OB capability was the design and construction of a 1200-kV SF₆ arrester. OB also built a bushing for the same voltage.

DynaVar arresters, introduced in 1979, await test in OB extra-high-voltage outdoor laboratory. Chamber for environmental testing where DynaVar demonstrated contamination immunity is at left.

Introduced in 1950, the new OB Thorex intermediate class arrester featured a preionized resistance-graded gap structure and nonlinear resistance valve blocks.
Apparent with the introduction of DynaVar in 1979 was the reduction in size compared to silicon-carbide arresters. Other advantages, most of them attributable to the nonlinearity of metal oxide, mean better protection and arrester durability.

Early OB station class arrester featured a series gap that magnetically drove arcs along runners into a cooling chute. It provided much higher current-interrupting ability than previous designs.

This substation features Hi*Lite insulators and DynaVar arresters.
The mission of the O-B task force assigned to develop a surge arrester varistor was to take a basic material and to adapt it to the strenuous conditions encountered in high-voltage applications.

The varistor task force used the considerable capability of the Frank B. Black Research Center, especially the Materials Research laboratory.

The laboratory is equipped with a battery of instrumentation for measuring the characteristics of ceramic materials, including electrical and mechanical properties. Also involved was the development of equipment to operate a pilot plant for varistor production.

The zinc oxide varistor has been described as the near-perfect arrester valve material. A change in current by a factor of one million in the most non-linear portion of the disc volt-ampere characteristic will result in a voltage change of only 56 percent.

The development effort centers on the chemical composition of the varistor and its effects on electrical performance and life. The varistor composition includes approximately 90 percent zinc oxide and 10 percent additives. The amount of each additive has a critical effect on varistor characteristics, as do the small amounts of impurities in the composition. Consequently, measurements must be made in parts per million.

Research technicians model the degradation of varistors when continuous a-c or d-c voltage is applied. Once the degradation mechanism is determined, the chemical composition can be altered or the manufacturing process changed to increase varistor life.

Homogeneity of the varistor composition affects energy-absorbing capability and varistor stability. Consequently, much research involves study of homogeneity in terms of chemical distribution in the varistor. The ideal varistor would have a completely uniform distribution of chemical phases with each particle of zinc oxide surrounded with a uniform boundary of additives. Each metal-oxide additive phase differs in chemical composition. In effect, there is a network of microvaristors within the varistor both in parallel and in series which affects the performance of the total varistor.

The action within the varistor occurs because the zinc oxide particles are much lower in resistance than the boundary layers. When high voltage is applied to the varistor, the majority of the voltage develops across the boundary layers, producing the varistor's nonlinear characteristics.

The term “microstructure” applies to much of the preceding paragraph, with microstructure defined as the number and density of phases including porosity; relative amounts of phases; and the characteristic size, shape, orientation, and distribution of these phases. Much electrical testing is done to develop understanding of the electrical response of different parts of the microstructure, and what parts contribute to different phenomena seen in the varistor.

Changing the amounts of additives effects pronounced differences in nonlinearity and break-down voltages.

Processes such as dispersion of additives and zinc oxide particles, screening, burnout of organic binders, and sintering also affect
homogeneity and varistor performance. The research effort exploits a fundamental understanding of the behavior of materials during processing so the materials can be modified or the processing tools changed to improve the product.

In addition to a suitable varistor composition, the experienced staff at the Research Center designed housings and other components for DynaVar. Effects of external contamination had to be studied (DynaVar performs better than previous arresters). A pressure-relief mechanism was designed to cope with today's short circuit currents. Dimensions for grading rings were established. Cantilever strength was tested.

During varistor manufacture, the Materials Research laboratory supports the factory by analyzing raw materials and checking the materials in process.

The success of today's O-B varistor as a highly dependable, stable protective device is just a beginning. Research continues toward developing an even more effective composition and in improving the methods for processing. There is still more to be accomplished.

O-B Research Center personnel developed the DynaVar arrester with its superior protective characteristics. Metal-oxide varistors are made in a controlled-environment plant, located adjacent to the research center to allow continuing interaction between manufacturing and research.
Sophisticated electronic test equipment is used to study behavior and effects of contaminants on grain boundary controlled electrical ceramics. Varistor conduction and degradation mechanisms can be determined by studying the responses of the grain boundary regions.

The thermal analysis equipment shown here is used for both research and production process control for polymer materials. Changes in materials are accompanied by thermal changes. Thermal analysis measures temperatures at which these heat-related phenomena occur in materials.
Technician running x-ray diffractometer, used to study crystal structure which is useful in researching set-up processes.

Accelerated aging tests of varistors are conducted by the research center to determine the aging mechanisms and life predictions. The tests are conducted at elevated temperatures and voltages.
Development engineer uses digital storage oscilloscope to measure 100-kA characteristics of varistors in O-B high-voltage laboratory using 100-kV, 12-microfarad generator.

Polymer materials are tested to ensure consistent polymer characteristics. This tracing test shows the electrical strength of our ESP material.
Technicians preparing polymer-housed intermediate arrester for simulated contamination testing.

Not only materials, but products are also tested, such as the arrester and the insulator on this ferris wheel test.
The Pursuit of Perfection

The pursuit of perfection in a varistor follows a complex path...in selection of materials, in processing, and in several levels of testing.

Varistors are made in a 48,000-square-foot factory where quality is strictly controlled by an elaborate system of in-process and quality control tests. Not only are varistors made in a single product plant, but the process is guided by technicians who first developed the pilot plant operation before varistors went into mass production.

The varistor production team includes supervision and production personnel, process engineers and technicians, plant engineering and maintenance, and technically competent administrators. They have worked as an independent enterprise within the Company, with a free exchange of ideas.

The manufacturing process starts with near-pure materials kept pure as they contact only plastic and stainless steel equipment. Every manufacturing station has a process-control test which, in turn, is monitored by a process engineering or quality assurance group. Test equipment is calibrated routinely and controlled under a stringent equipment calibration specification. The generators for the critical voltage classification tests are even calibrated against the output of another generator.

Weights are checked after every manufacturing step to ensure proper mix of additives and zinc oxide. Logs and charts show a history of every production batch. Besides the four quality-control tests to establish the performance of the varistors based on a sampling of each batch, every varistor is subjected to a sequence of four routine tests.

Nothing can be left to chance. Consider the raw materials. Samples are checked for particle size and analyzed chemically before they leave the supplier. When accepted materials arrive, they are again tested by recognized control methods. Tests determine trace elements that might affect the operation of the finished varistor. Trace impurities are critical, even at the parts-per-million level. Only by precise control of impurity content can the best performance be obtained, as close to perfection as possible.

The manufacturing process starts with weighing the correct amount of materials to be added to the zinc oxide. The additives include compounds in powders of 1 to 10 micrometers in diameter. A batch number is assigned. This batch number will carry through and be printed on the blocks after processing. This allows complete traceability back to the raw materials. The additives are milled to reduce particle size and to achieve a uniform mix. Particle sizes are checked before the additives go into a calcining operation.

The calcined additive aggregate is again milled to further reduce particle size to enhance uniform mixing with zinc oxide.

The zinc oxide is weighed and combined with the additives in a dispersion unit that uniformly disperses the additives around the zinc oxide particles. A homogeneous mixture with uniform distribution of chemical phases enhances the electrical characteristic of the varistor. Zinc oxide is much lower in resistance than the additive boundaries. When voltage is later applied to the varistor, the majority of the voltage appears across the boundary layers, producing the varistor's nonlinear characteristics. Mixing of the slurry determines chemical uniformity of the final product.
Spray drying converts slurry into a free-flowing powder. Powder is checked for moisture, fluidity, and both tapped and bulk density—all of which are critical in developing a homogeneous varistor, with homogeneity being essential to long varistor life.

Next the slurry resulting from the dispersion of the additives and zinc oxide goes into a two-story-high spray dryer which converts the slurry into a free-flowing spherical powder with excellent pressing characteristics.

After the organic binding material is removed from the varistor, a 30-hour sintering operation occurs in an electric kiln which has 13 control zones with 44 recording thermocouples, part of the continuous check on every batch. Sintering takes the 50 percent of theoretical density achieved by the pressing operation and increases it to 98 percent of the theoretical. High density eliminates voids that could lead to electrical failure.

Five varistors of every batch go to Quality Assurance for testing to destruction. Another five go to quality assurance high-current impulse testing and two go to accelerated aging tests.

The end surfaces of sintered varistors are ground to a close tolerance, ultrasonically cleaned and inspected in preparation for metalizing application, which provides uniform conductivity between varistors when they are assembled in the arrester stack.

A very high resistance ceramic collar is applied to the varistor. This collar insulates the varistors to prevent flashover during lightning or switching surge discharges.

After routine testing we have a varistor as near perfection as modern control of materials and processes can produce with the following characteristics:

1. High nonlinearity
2. High energy absorbing capability
3. Excellent high current withstand strength
4. A-C stability

These features translate into an arrester with improved steep front and switching surge protection, high durability and other advantages including reduced size and simplified application.

The very low loss level for MOV varistors made in the O-B plant indicates mastery of a sophisticated production and quality-control system. But most important to the user is assurance that the varistors in O-B arresters will have the long life and protective characteristics required.

The pursuit of perfection continues in the factory where DynaVar arresters for application in all voltage classes are assembled and tested.

After varistor powder has been spray dried, hydraulic press forms a “green” varistor in one of the most critical steps in manufacturing.
To detect any flaws that could lead to electrical failure, all varistors are inspected to exacting engineering requirements.

Tunnel kiln sinter varistors to 98 percent of theoretical density during 30-hour cycle. Forty-four recording thermocouples provide profile of kiln temperatures for the cycle. Lasers check alignment of kiln load.

Low-current long-duration testing confirms energy handling capability of each station and intermediate varistor.
Square-wave test determines varistor's ability to absorb the high energy imposed by a switching surge discharge. Current magnitude of series of discharges is determined by varistor diameter.

In the aging test, samples from every batch are energized and tested at a high temperature for several weeks. Watts loss, time and temperature are monitored and recorded.

Technicians review results of aging tests to ensure samples from varistor batches have predictable long-term stability. In the test, short-term watts loss characteristics are matched against the characteristic curve from previous long-term aging tests.

After electrical testing, varistors are automatically sorted into classification and given a final visual inspection. Sorting simplifies assembly as varistors can be used as modules to attain a given voltage rating in the assembled arrester.
Dedication to Quality in Assembly

The dedication to quality apparent in varistor manufacture continues in assembly of arrester components. The housings for the polymer-housed arresters are molded by Ohio Brass in our proprietary rubber formula. Other components for distribution through station class arresters come from a carefully selected list of quality vendors. Regardless of the source, all components are inspected prior to assembly. Quality control procedures apply throughout the assembly operation. Each work station has procedures and assembly drawings easily visible on quality control boards. A team of technicians ensures proper procedures are being followed.

For station arresters the advantage of varistors being presorted into 50-volt, 10-kA discharge voltage bands becomes apparent at the start of assembly. Varistors necessary to achieve a given maximum continuous operating voltage for an arrester can be selected and placed in a tray. Each tray carries the serial number of the arrester in which the varistors will be used. The list of varistor values accompanies the arrester components as they progress through assembly. Each arrester's varistors are logged in permanent record by batch, date and voltage.

Now each arrester undergoes a series of three tests to verify proper assembly. Each arrester is energized at 1.05 times maximum continuous operating voltage and tested for internal ionization. In the second test, grading current is measured at MCOV level. The third test measures starting voltage. Polymer housed distribution and riser pole arresters are subject to equally exacting standards. The assembled varistor modules are assembled into the molded rubber housings. The end sealing terminals, mounting bracket and isolator attached prior to electric testing. Each arrester is tested to measure its starting voltage. This test energizes the arrester at least to its operating voltage. In addition, the internal ionization is measured.

Finally the arresters are packed for shipment and join the millions of Ohio Brass units on duty protecting power systems worldwide.
Polymer housings of various sizes are molded. This is a batch for PDV distribution arresters.

Distribution arresters are assembled with a fiberglass wrapped module inserted into the rubber housing.

Varistors which have been presorted in 50-volt, 10-kA discharge voltage bands are selected to achieve desired maximum continuous operating voltage for a given arrester station. For station class arresters, records of the varistor discharge values and serial numbers are maintained.
Polymer-housed PVN station class arrester assembly.

Assembled porcelain arresters are evacuated and backfilled with dry air with a dewpoint of -60°C, leaving fewer than five parts per million of moisture. Yellow QC envelopes are still attached to arresters.

Each arrester undergoes a series of three tests to verify proper assembly and integrity of components. Tests include internal ionization, grading current, and starting voltage.
Fully assembled DynaVar standard station arrester (left) with a 252-kV MCOV rating (maximum continuous operating voltage) undergoes routine electrical testing prior to shipment overseas.

Assembly of PDV arresters.

Pallet of PDV arresters ready for shipment. Over 5 million distribution arresters have been shipped worldwide.
And the Final Test... Performance

DynaVar station arresters have been installed in locations all over the world on systems from 2.4 kV to 800 kV... in the Orient, South America, Africa, North America and Europe.

The DynaVar PVR brings the benefits of metal-oxide varistor protection to riser-pole applications on systems through 34.5 kV.

A complete range of polymer housed distribution arresters protects distribution systems.

Properly applied, a DynaVar arrester will last lifetime without deterioration of block characteristics.

System designers have taken advantage of the high-energy discharge capability of DynaVar in such high-energy applications as capacitor banks. In underground cable installations, DynaVar can protect longer lengths of cable than silicon-carbide arresters.

MOV arresters are virtually immune to contamination failure. They are operating successfully in areas where conventional arresters historically failed repeatedly.

With higher protective margins available, the station designer can lower equipment BIL. Transient network analysis is seldom necessary. Calculations can be readily made of the maximum surge voltage for a line. The designer also can worry less about switching surges as a cause of arrester failure because the energy capability of a DynaVar arrester is rarely exceeded. In summary, DynaVar offers a product made by a Company who pioneered in arrester development, a product made under strict quality-control procedures from the selection of raw materials through the testing of the finished product, and a product that has proved itself in service under severe conditions.

ADVANTAGES
- IMPROVED SWITCHING SURGE PROTECTION
- IMPROVED STEEP FRONT PROTECTION
- STABLE PROTECTIVE CHARACTERISTICS
- HIGH SURGE DURABILITY
- CONTAMINATION IMMUNITY
- NO SURGE DURABILITY DETERIORATION
- SIMPLIFIED APPLICATION
- SIMPLIFIED CONSTRUCTION
- REDUCED SIZE
Type PVI polymer-housed inter-arrester installed on a cable riser pole. This is typical of areas with high available fault currents.

FVR riser pole arrester on a cable termination application.

Polymer-housed type PVN arrester installed in underhung position. This demonstrates the versatility of the lightweight polymer units.
PDV distribution arresters mounted on transformers in JOU shipping yard ready for installation.

PDV arresters now have flipper kit available.

ProtectaLite arresters can be used to protect transmission lines from interruption caused by lightning with or without an insulator assembly.
And the Quest Continues...

...in the relatively short history of surge arrester development, considerable progress has been made, especially in the last five years. But the quest for an ideal arrester continues. Modern materials and manufacturing methods have the potential for approaching the ideal arrester.