

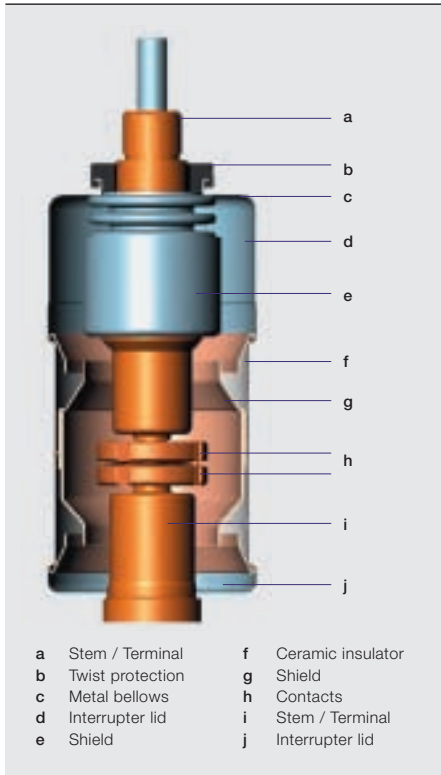


Breaking ahead of expectations

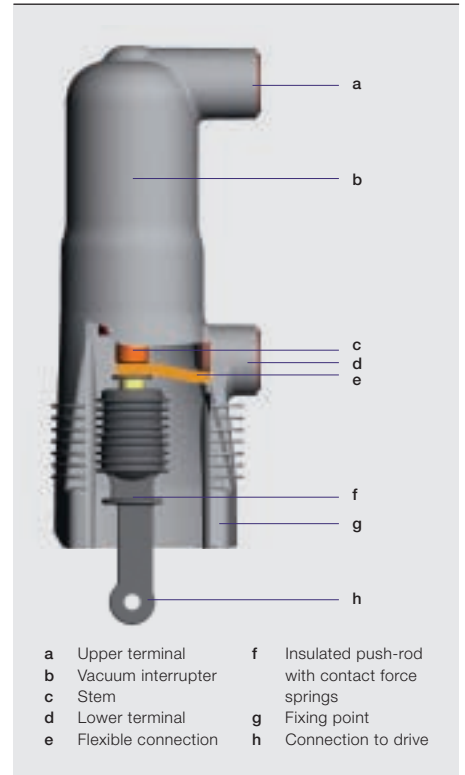
The PT1 pole sets new reliability and environmental standards in vacuum breaker technology

THORSTEN FUGEL, DIETMAR GENTSCH, ARNE KLASKA, CHRISTOPH MEYER – More than a decade has passed since ABB invented the embedded pole for medium voltage applications. These interruption units offer the advantages of high dielectric strength, protection against environmental conditions and maintenance-free operation throughout the product's life. The latest step in this success story is the PT1 interrupter. Thanks to the adoption of thermoplastic material, the PT1 meets all performance aspects of its predecessor type while presenting numerous advantages, ranging from application parameters to its environmental impact.

1 Schematic of an ABB vacuum interrupter (type VG4)



2 General design of an embedded pole



A circuit breaker must fulfill three functional criteria: It has to handle nominal current, break short-circuit current, and block voltages exceeding the rated voltage level.

As the contacts move apart to interrupt a current, an electric arc is initiated between them. In an AC system, this arc extinguishes at the next zero crossing of the current. The contact mechanism is enclosed in a chamber → 1 containing (in today's medium voltage systems) a vacuum.

ABB has been supplying medium voltage vacuum interrupters (VIs) for over 30 years. While, in the late 1990s the market was divided more or less equally between vacuum and SF₆ technologies, vacuum has become the most dominant technology today. ABB currently produces approximately 350,000 vacuum interrupters annually and is a leading manufacturer in this area. Today, ABB's VIs handle nominal voltages of up to 40.5 kV and short circuit currents of up to 63 kA.

Besides managing the electric field inside the VI, the insulation must additionally withstand external power-frequency and BIL¹ voltages (up to 95/200 kV). This performance can be significantly reduced by environmental conditions (eg, dust). This is one of the reasons why, several

years ago, ABB pioneered embedded pole technology. The present portfolio of ABB embedded poles covers the typical requirements of medium-voltage systems up to nominal voltages of 40.5 kV, currents up to 3.150 A and short-circuit currents up to 50 kA.

The vacuum interrupter and its terminals are completely embedded in epoxy resin. The upper → 2a and lower → 2d terminals are connected to the contact arm or the bus bar of the switchgear. As the lower contact must connect to a moveable part, a flexible connection is needed to conduct the current → 2e.

The moveable part is driven by an insulating push rod → 2f connecting to the breaker's drive → 2h. This rod is made of a polyamide material and contains a spring package. The lower part of the pole → 2g is fixed to the housing of the circuit breaker by means of four screws.

The main advantages of this technology (compared to an assembled or open-pole system) are its high dielectric strength as well as better protection against environmental influences, humidity and mechanical forces. The design is compact, robust and modular. Another important advantage is the fast and easy assembly of the pretested and adjusted

poles on the vacuum circuit breakers. Embedded poles are suitable for different climatic conditions and are maintenance free for life. This means the vacuum within the interrupter and the insulation capability of the pole are retained for more than 30 years.

ABB is the inventor of this technology. With close to 1,000,000 units in field service, and an annual production of more than 200,000 pieces, the company is also the leading manufacturer of embedded poles → 3.

Despite the successful implementation of this technology and its huge advantages, ABB is continuously striving to improve it further. The newest member of the embedded pole family is the PT1. In contrast to its predecessors, the embedded pole is not based on epoxy resin but on a high-tech thermoplastic material.

Properties of thermoplastic poles

Function, form and process are among the decisive factors in introducing a new material (or class of material). The selec-

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¹ The BIL (basic impulse level) voltage is an expression of the equipment's ability to withstand overvoltages caused, for example, by lightning and switching surges.

tion of a new material calls for an extensive analysis process.

Selection of materials

The systematic selection process for a material must verify the material's relevant characteristics as precisely as possible, taking into account the component's long lifetime (minimum 30 years). The investigation considers both physical and chemical properties and also considers material consumption aspects and production technology.

As the inner side of the embedded pole's housing is in direct contact with the ceramic surface of the VI, mechanical, thermal and dielectric properties are of particular significance for the PT1. Due to dielectrical considerations, density is the most important property here. Also, being an interface between polymer, ceramic and metal, and due to the large operating temperature range (-30°C – $+115^{\circ}\text{C}$ for operation, -60°C for storage) the difference of coefficients of thermal expansion have to be minimized, while mechanical stability and breaking elongation have to be maximized. The pole is furthermore used as an outer dielectric insulation when the VIs contacts are opened: Consequently, dielectric strength and comparative tracking index (CTI)² have to be maximized as well.

Thermoplastic and epoxy poles compared

Comparing thermoplastic poles of type PT1 with epoxy poles of type P1 revealed important differences as well as similarities.

Use of the thermoplastic material reduced the weight of the complete pole by approximately 35 percent compared with the P1. Looking at only the insulating material, the mass is in fact reduced by more than a factor of three. This was achieved by the following: The reduced density of the thermoplastic (12 percent), its significantly increased dielectric strength (approx. 50 percent), improved mechanical stiffness (approx. 100 percent) and strength (300 to 400 percent). These improvements furthermore allowed a reduction of the volume.

The high injection pressures used in manufacturing permit the thermoplastic material to use short glass fibers. This was not possible with the low-pressure injection of epoxy-resin based compos-

3 ABB embedded pole family



ite. In order to achieve a better mixing of components and a low viscosity, epoxy-resin based composites usually contain quartz powder (SiO_2 particles). Compared to such particles, and considering the same matrix material, fibers permit a higher mechanical stiffness and greater strength in the direction of the fibers due to an improved transmission of forces.

In order to offer customers a smooth transition from epoxy to thermoplastic poles, the outer dimensions of the epoxy poles were kept within those of the thermoplastic poles. Additionally, all functional dimensions are equal. This allows a full interchangeability of these components. The push rods and flexible connections were also kept the same.

In the transition, self-forming screws replaced the metric screws and brass inserts used with the epoxy poles. The new screws have already been used successfully with thermoplastic materials in other industries, eg the automotive industry. They are fastened with a torque of 35 Nm, assuring great stability (100,000 mechanical switching operations without a reduction in stability). This strength corresponds to an epoxy pole fixed with an M10-type metric screw requiring a fastening torque of 50 Nm.

Creep and relaxation tests were performed to verify whether, under operating conditions, (increased temperature and contact forces) the dimensions of the pole could change → 4. The poles

were fixed on a steel plate and a force of 5,000 N was applied via the pushrod. This force is 1.7 times higher than the maximum loading in field service. For these experiments, the temperature was raised from room temperature (20°C) to 85°C ; hence the increase of the pole length (0.5 percent) at the start of the experiment. Over the duration of the test (four weeks), the length of the pole remained constant. The length decreased again during cooling of the poles at the end of the experiment, leaving a residual elongation of max. 0.2 percent (which is close to the measurement accuracy). Hence, an elongation of the pole due to creeping or relaxation effects could not be detected.

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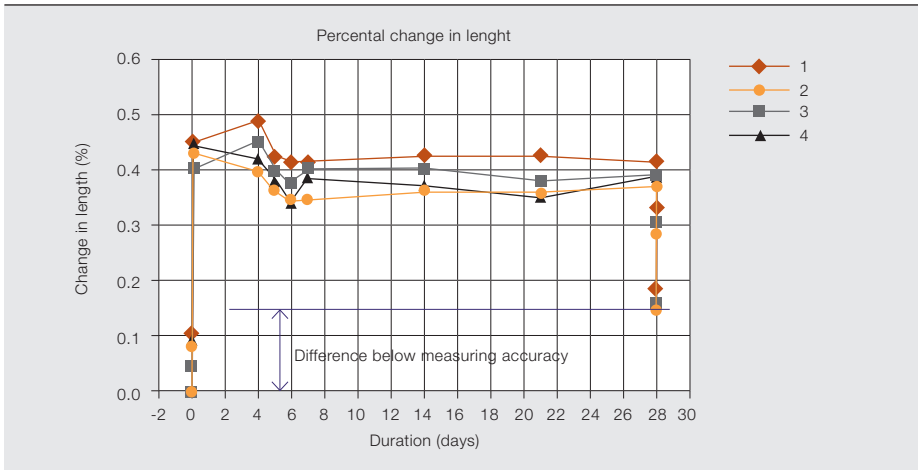
When considering the long-term stability of thermoplastic materials (especially polyamides), the water affinity of the material must be taken into account.

A connected vacuum circuit breaker in off position must still be able to block voltages as defined by the IEC standard even after a significant level of water absorption has occurred. In order to verify this, climatic tests were carried out at in-

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² The Comparative Tracking Index is a measure of the electrical breakdown properties of a material.

4 Results of the creeping and relaxation experiments



These were performed with the embedded pole type PT1 at 5000 N and 85 °C, and show that no measurable deformation occurred. The jump at the beginning and end of the test period reflect heating from room temperature and the return to it.

creased temperature and humidity (increased water absorption for 500 h at 60 °C, 75 percent humidity), in parallel the poles were exposed to an AC voltage of 50kV. All tested poles demonstrated stability under these conditions.

Furthermore, a closing operation with a short-circuit current followed by a re-opening had to be correctly handled by the pole. As the mechanical stability is significantly higher than for epoxy based composites, all tests were passed successfully with the new PT poles.

Production process

The overall concept for both the epoxy resin poles and the thermoplastic poles is quite similar. First, the inlay groups with the vacuum interrupter and terminals for the mold are pre-assembled. Then, these assembled groups are pre-treated (eg, cleaning and testing). Subsequently, the groups are positioned in the mold, which is locked, closed and filled with the material. Due to the significantly different pressures during injection molding, the time required to fill the mold varies. For the epoxy resin-based composite, the filling is followed by the curing time, whereas for the thermoplastic it is followed by cooling. The general flows of production for the thermoplastic is shown in → 5.

The epoxy resin process is a chemical reaction, whereas the thermoplastic setting consists of a cooling-down period featuring crystallization of the material. The temperatures of the molds are approximately the same for both processes,

whereas the injection temperatures of the raw materials are significantly different. For epoxy resin this is slightly above room temperature, whereas the melting temperature of the thermoplastic material is up to 300 °C. Consequently, heat needs to be applied during the epoxy resin process, whereas for the thermoplastic material, it must be dissipated.

As soon as the setting is complete, the mold is opened and the pole extracted. As the adhesion between thermoplastics, steel and other metals is generally very low, extracting the pole is not a problem. The poles are then forwarded to final assembly and testing. At this step, the push rod is added and the transport protection for the VI is mounted. The functional dimensions and the resistance of the pole are checked as a routine test.

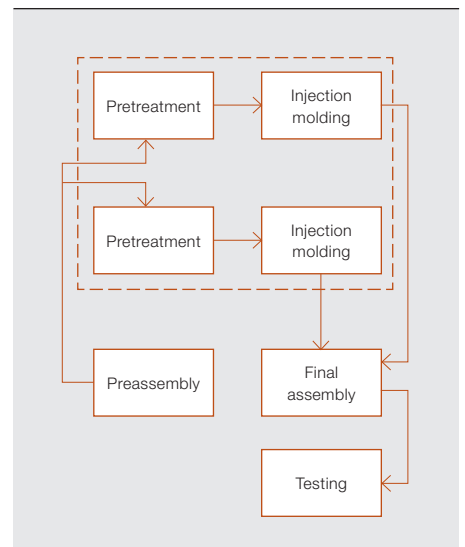
The use of a fully automated modern injection molding machine with integrated sensors in the production of the thermoplastic VI improves on the already high process reliability of the epoxy pole.

The PT1 pole

The two available variants of the PT1 pole are shown in → 6.

The PT1 pole → 6a is capable of handling short-circuit currents up to 31.5 kA, nominal currents up to 1,250 A and voltages up to 17.5 kV. These values are similar to the ones of the corresponding epoxy pole type P1. The detailed characteristics are shown in → 7.

5 General flow of production: thermoplastic vs. epoxy resin poles



6 Variations of the PT1 pole – version for 31.5 kA (6a) and 25 kA (6b)



As the PT1 is used in medium-voltage systems, the general requirements are laid out in IEC 62271-100. These are all fulfilled or exceeded by the PT1. The pole fulfills the highest qualifications known by the standard, namely M2 (mechanical endurance), E2 (electrical endurance) and C2 (capacitive switching for back-to-back and cable switching operations).

Although this classification indicates that the PT1 fulfills the standard, it does not indicate the limit of performance. For example, concerning mechanical endurance, the standard requires 10,000 mechanical switching operations, whereas the PT1 is easily able to handle more than 50,000 operations without any maintenance.

7 Characteristics of the PT1 pole

Electrical Characteristics		1206-25 1706-25	1212-25 1712-25	1206-31 1706-31	1212-31 1712-31
Rated voltage	kV	12 / 17.5	12 / 17.5	12 / 17.5	12 / 17.5
Rated frequency	Hz	50 / 60			
Rated power-frequency withstand voltage (ms)	kV	... 42			
Rated lightning impulse withstand voltage	kV	... 95			
Rated normal current (ms)	A	630	1250	630	1250
Rated short-circuit breaking current (ms)	kA	25	25	31.5	31.5
Rated short-circuit making current (peak)	kA	63	63	80	80
Pole weight	kg	4.8	4.8	5.6	5.6
Contact force	N	2400	2400	3200	3200
Mechanical life CO-ops.		30,000			
Service life	yrs.	30			
CO-ops. at rated short-circuit breaking current		50			
Operating temperature	°C	-30 ... +40			

Generally, it can be stated that the PT1 pole exceeds all requirements from standard point of view and is superior or

test for capacitive switching (back-to-back and cable charging) and electrical endurance have been carried out in this

The use of a fully automated modern injection molding machine with integrated sensors in the production of the thermoplastic VI improves on the already high process reliability of the epoxy pole.

equal in performance to existing embedded poles based on epoxy resin composites.

Tests performed

As already mentioned, the PT1 pole fulfills the requirements of IEC 62271-100 and passed all mandatory type tests. These tests were performed on PT1 fitted with the standard ABB vacuum circuit breakers type VD4 and VM1. Moreover, to render the demonstration fully functional, these tests were not carried out on standalone breakers but on breakers inside ABB switchgear type UniGear and enclosures type PowerCube.

This setup was used for all mandatory IEC type tests, ie, mechanical endurance, temperature rise, making and breaking, short-circuit testing (STC), as well as dielectric tests. Furthermore, the

test for capacitive switching (back-to-back and cable charging) and electrical endurance have been carried out in this way. As the pole is intended for worldwide use, the requirements of these tests were adapted to cover the values required by most standards, eg, the power frequency test voltage was set to 42 kV, the BIL test voltage to 95 kV and 4 s have been applied for the STC. All these tests were carried out under the rules of the internationally recognized STL organization (Short-circuit Testing Liaison) and were therefore witnessed by an independent third party.

In addition to these, a large number of additional tests were performed, eg, an internal arc test according to IEC 62271-200. This was passed by the circuit breaker without any ignition of the pole. Furthermore, partial discharge (PD) measurements were carried out on a large number of poles. These tests have shown no PD on any of the investigated poles and thus confirm the well-known superior behavior of ABB embedded poles in the field.

Applications of the new pole type PT1

As a member of the ABB embedded pole family, the PT1 will be used on the current versions of both the VD4 and the VM1 → 8. It will be used to break short circuits, loaded and unloaded cables, transformers, motors, generators as well as capacitor banks. Furthermore, the pole will be sold as a components to OEM customers and as a replacement part for retrofit projects. Examples of application areas are shown in → 9.

From a customer point of view, the transition from the current embedded pole to the PT pole is extremely smooth and requires little effort. The PT1 is fully compatible to the existing P1 pole and has identical functional dimensions. To allow a smooth transition for OEM customers, ABB will not only provide support through the sharing of test reports, but also be issuing advice and declarations to help minimize the number of tests that need to be repeated in combination with an IEC-based test matrix. Once the circuit breaker is fitted within the customer's switchgear, the dielectric test is usually the only test that needs repeating

Advantages of the PT1 pole

Thermoplastic poles offer the same advantages as all other ABB embedded poles and fulfill highest quality requirements, eg, optimized dielectric insulation, protection of the VI and maintenance-free operation. In addition, they have several advantages compared to the current embedded poles and are therefore equal or superior in all aspects compared to the epoxy ones.

From an environmental point of view, PT poles present significant improvements over their epoxy predecessors, in terms of both their environmental-friendly production and recyclability³. To quantify this statement, a calculation was performed of the carbon footprint needed for the production of the poles. The analysis did not only consider the production of the poles themselves but also the pro-

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³ See also "For a better environment: Recycling opportunities for insulating components" on pages 10–16 of ABB Review 2/2009.



9 Examples of application areas of PT1 embedded poles

- Power plants
- Transformer substations
- Chemicals industry
- Steel industry
- Automobile industry
- Airport power supply
- Shipbuilding (Marine applications)
- Power supply to buildings

The production of PT-type thermoplastic poles reduces CO₂ emissions by more than 50 percent with respect to their predecessors.

duction of the base material⁴. This calculation shows that the production of PT-type thermoplastic poles reduces CO₂ emissions by more than 50 percent with respect to their predecessors, corresponding to a reduction of approximately 3,000 tons of CO₂ per year considering the ABB production numbers.

Another advantage of thermoplastic materials is that the production process itself can be controlled very accurately, reducing variation of the properties of the material as well as the pole itself. Due to the mature technology of injection molding machines, a fully automatic production process is possible for PT poles, allowing detailed recording and full control of all relevant process parameters. This leads not only to increased traceability but also an improved quality control by statistic process control (SPC), improving the already well-known high quality of the present embedded poles.

Concerning technical parameters, the performance of the PT1 pole could be increased with regard to the P1 epoxy pole. The mechanical strength and the low temperature performance of the PT could be significantly increased, extending its operating limits. Furthermore, the fire load of the PT poles is significantly lower, presenting a further safety advantage for the end-customer. Additionally, the weight of the pole was reduced by 35 percent simplifying handling and transportation.

The PT pole, as the newest member of the successful embedded pole family of ABB, is the latest step in the development of this successful technology. They match or surpass all performance aspects of their predecessors while being totally compatible and making an important contribution toward climate protection.

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Footnote

- ⁴ Using original data that was either published or directly provided by the manufacturer of the material.