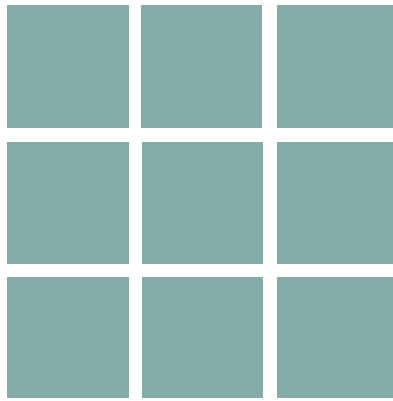


# **IRON-CORE REACTORS FOR DETUNING POWER CAPACITORS IN MEDIUM AND LOW VOLTAGE NETWORKS**

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HANS VON MANGOLDT AACHEN





## Harmonic network distortion and its effects

(background)

Electrical power supply to industrial networks is nowadays polluted to the same degree as the air we breathe in the major conurbations and large cities of our planet. This is due to increasing application of non-linear loads, such as variable speed drives, frequency converters and rectifiers, but also the astronomically high number of electrical energy consumers. The outcome is unusually high levels of harmonic distortion, not only resulting in unnecessary losses from transmission lines, but also in non-calculable resonances between network inductances and power factor correction capacitors.

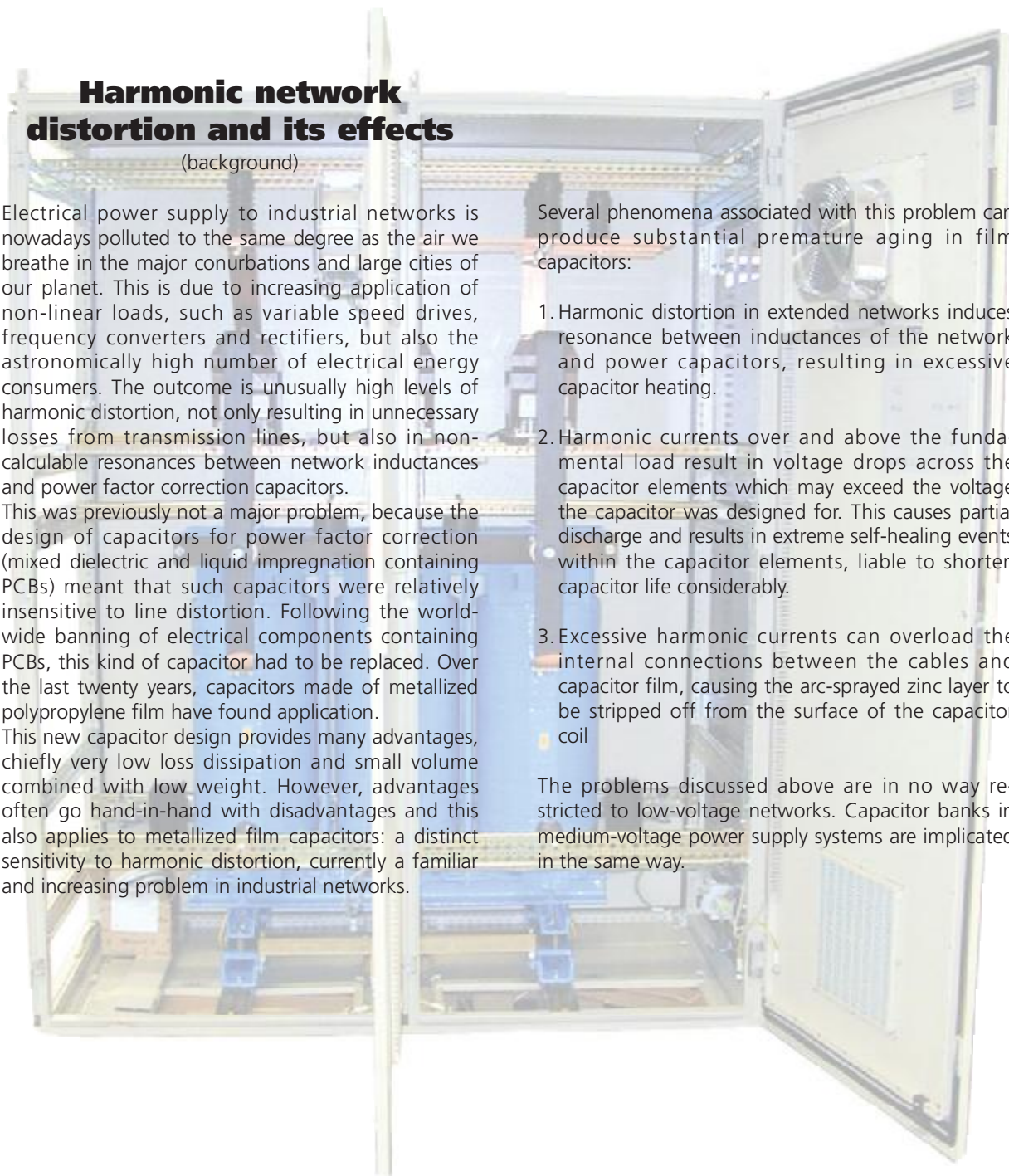
This was previously not a major problem, because the design of capacitors for power factor correction (mixed dielectric and liquid impregnation containing PCBs) meant that such capacitors were relatively insensitive to line distortion. Following the world-wide banning of electrical components containing PCBs, this kind of capacitor had to be replaced. Over the last twenty years, capacitors made of metallized polypropylene film have found application.

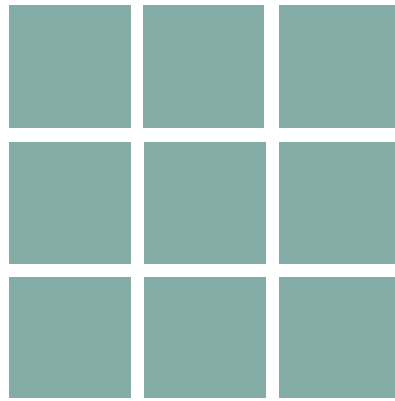
This new capacitor design provides many advantages, chiefly very low loss dissipation and small volume combined with low weight. However, advantages often go hand-in-hand with disadvantages and this also applies to metallized film capacitors: a distinct sensitivity to harmonic distortion, currently a familiar and increasing problem in industrial networks.

Several phenomena associated with this problem can produce substantial premature aging in film capacitors:

1. Harmonic distortion in extended networks induces resonance between inductances of the network and power capacitors, resulting in excessive capacitor heating.
2. Harmonic currents over and above the fundamental load result in voltage drops across the capacitor elements which may exceed the voltage the capacitor was designed for. This causes partial discharge and results in extreme self-healing events within the capacitor elements, liable to shorten capacitor life considerably.
3. Excessive harmonic currents can overload the internal connections between the cables and capacitor film, causing the arc-sprayed zinc layer to be stripped off from the surface of the capacitor coil

The problems discussed above are in no way restricted to low-voltage networks. Capacitor banks in medium-voltage power supply systems are implicated in the same way.





## Remedial measures and what they can achieve

When film capacitors first started to be manufactured, the only way of avoiding premature capacitor failure was over-dimensioning the thickness of the capacitor film. This dealt with the excessive overvoltages due to harmonic currents in a better way. However, this method proved to be rather expensive and not very appropriate to withstanding resonance conditions, which in extended networks are difficult to plan for.

This called for an effective and simple solution for extending the life-time of power factor correction equipment, while at the same time eliminating resonance amplification.

Over the last couple of years, the use of detuned filter circuits has proved to be a very reliable and safe way of avoiding premature failure or excessive aging

in power factor correction equipment.

In configurations of this kind, serial reactors are connected to the capacitors. The serial reactors detune the circuit to a frequency below the 5th (or 3rd) harmonic, which is the most significant in a harmonic-rich environment. In Europe, detuning by a factor of 3.78 times the line frequency is most common, whereas in other parts of the world, in particular in Asia, a factor of 4.08 is standard (Fig. 1).

The thinking behind this solution is quite simple: the impedance of L/C resonance circuits is capacitive below the resonance frequency, and becomes inductive above this value. At line frequency the capacitive load of the capacitor is thus dominant, enabling it to achieve a perfect power factor

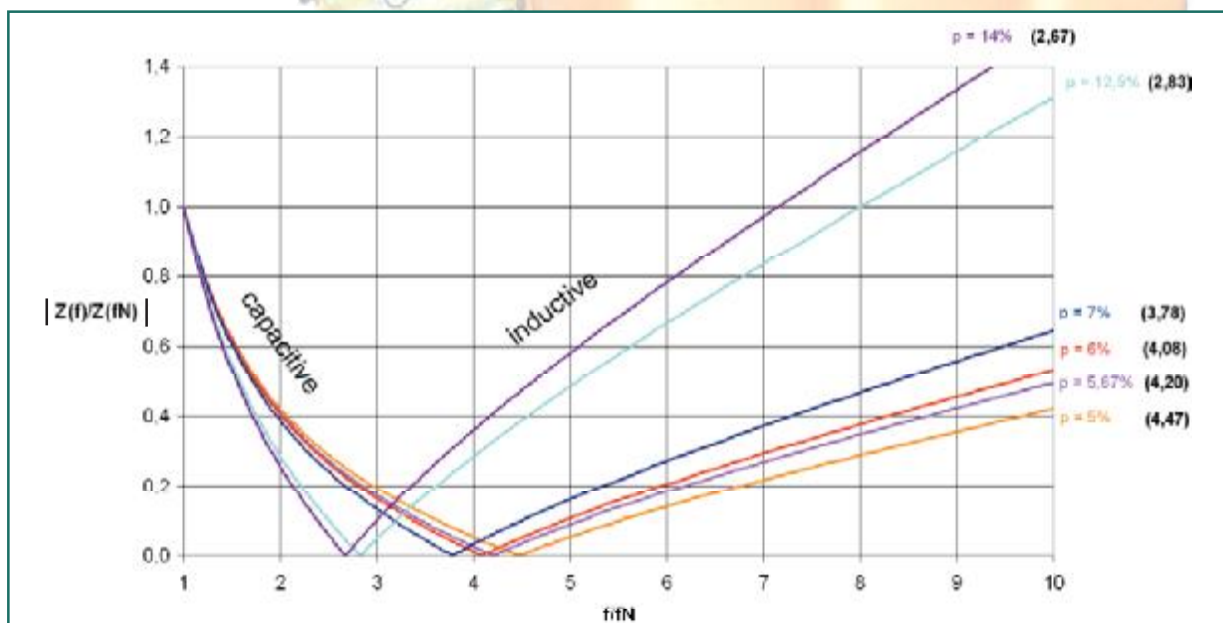
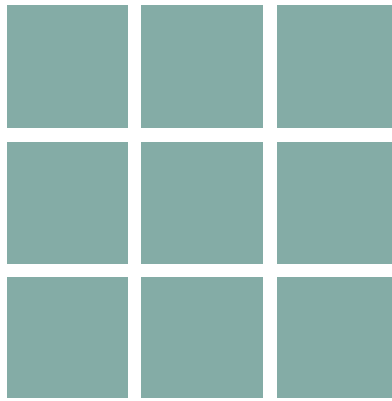


Fig. 1: Common detuning factors and ordinal of resonance



correction (see Fig. 1). The fact that the L/C filter is inductive above its resonance frequency eliminates the occurrence of any resonance between cable inductances and power factor correction equipment. In particular, all harmonic currents above the tuning frequency of the filter are limited to values which depend only on the voltage distortion in the relevant network. Sensitive capacitors are thus spared any unpredictable situations. Apart from this obvious advantage, there are two other effects related to detuning power capacitors which should be remembered. As Graph shows in Fig. 1, the impedance of an L/C filter relative to the fundamental impedance of the capacitor versus frequency variation starts at 1 and reaches its minimum at resonance frequency. Beyond this, impedance does not increase sharply, but steadily rises to infinity. The result of this is a harmonic filtering effect beyond the resonance frequency, which does however decrease with the order of the harmonic frequency. Thus, capacitor detuning usually cleans the network of harmonic distortion.

A second advantageous effect is based on the laws of physics: the vector of the voltage across the reactor corresponds to network voltage. This means that this voltage is added to line voltage, and the sum of the two is present at the capacitor terminals. Again, the laws of physics tell us that the reactive power of a capacitor increases in proportion to the square of the voltage increase. However, we have to remember that this increase is partly compensated for by the reactive power of the reactor. As a result, the gain of reactive power due to the reactor is

$$\frac{1}{1 - \frac{p}{100}} - 1 (\%),$$

which means that capacitance can be reduced by p(%) to arrive at 100 % NC in respect of the serial reactor. At the same time, care must be taken in dealing with the extra voltage (Fig. 2).

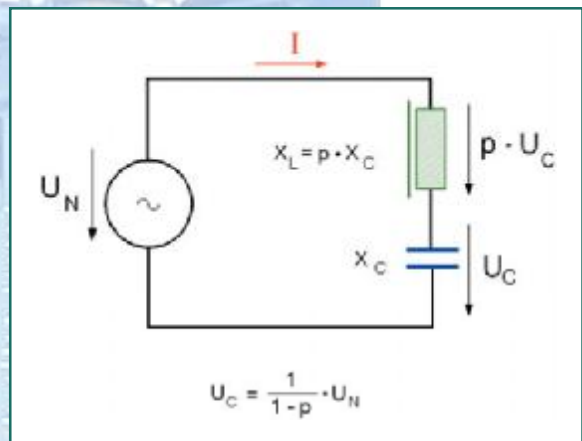
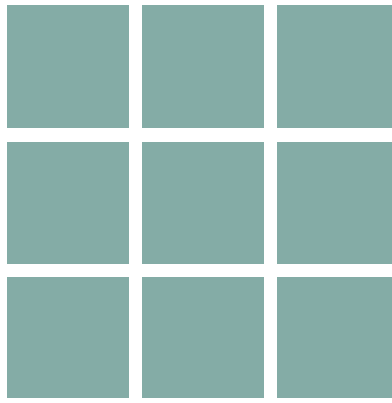


Fig. 2: Gain of reactive power due to the detuning reactor

## Reactor design and technology

High demands are placed on reactors. Reactors are connected in series with capacitors and thus need to be able to withstand losses resulting from both fundamental and other harmonic currents without the temperature range of the insulation material being exceeded under actual environmental conditions. Moreover, inductance accuracy must be to within close tolerances, and sufficient core linearity must obtain to withstand switching of capacitor steps without causing saturation problems in networks of high harmonic distortion.



## Expertise unique to Mangoldt

In the case of medium-voltage reactors, other requirements, such as the capacity to withstand induced overvoltage, fault level and BIL, have to be considered.

Our company, Hans von **Mangoldt**, is able to look back on more than 20 years' experience in successfully handling such tasks. Starting with transformer production only, **Mangoldt** decided in the seventies to focus their future energies on this growing filter market. Time has proved this decision a sound one. Today, there are few countries around the world where **Mangoldt** reactors are not in operation. Typical industrial applications are cement and steel mills, furnace compensation, the chemical, petrochemical and rubber industries, car assembly plants and public transportation systems, while other applications include high-rise buildings, hospitals, public water supply systems, flicker compensators, active filters, wind generators, motor starting devices and dynamic compensation systems. **Mangoldt** reactors function in an unobtrusive and efficient way. The main downside of iron-core reactors is their limited linearity and the high cost in outdoor installations. Yet iron-core reactors are finding increasing acceptance among expert consultants in situations where air-core reactors were previously used. This is because space available for reactor installation is limited and also because linearity is not a major concern. In applications like these, **Mangoldt** reactors, with a design which prevents magnetic leakage and ensures low losses and noise level, provide the best solution. **Mangoldt** reactors can be mounted within metal enclosures or in switch rooms, correctly observing clearances so as to obtain the BIL level required and making sure that ventilation is sufficient for dissipation of reactor losses (specified in the quotation we give ahead of the customer's purchase order).

The success that **Mangoldt** reactors have enjoyed is no miracle. Our achievement is the result of sound and detailed engineering (1), imaginative manufacturing (2), uniquely innovative measuring equipment (3) and excellent support from our sales force (4)

- (1) The software we have developed enables our design engineers to optimize reactor design to provide customers with a tailor-made product, in which their requirements with regard to losses, dimensions and environmental conditions are given our full attention. To facilitate reactor installation in a given configuration, customers can obtain CAD drawings as pdf files by e-mail (Fig. 3).

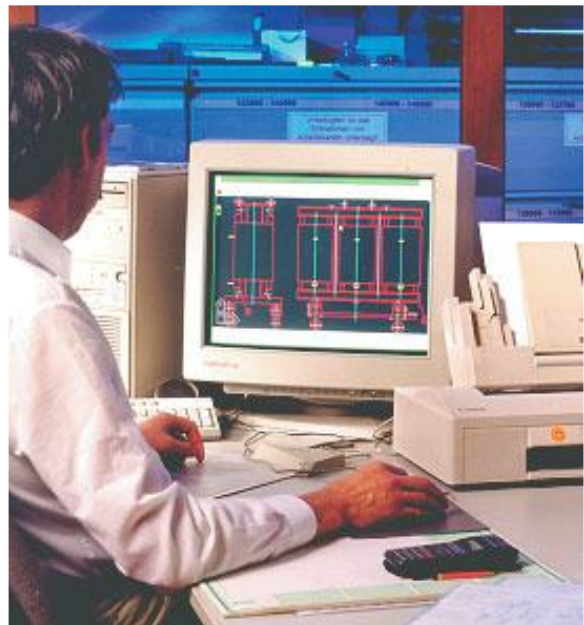
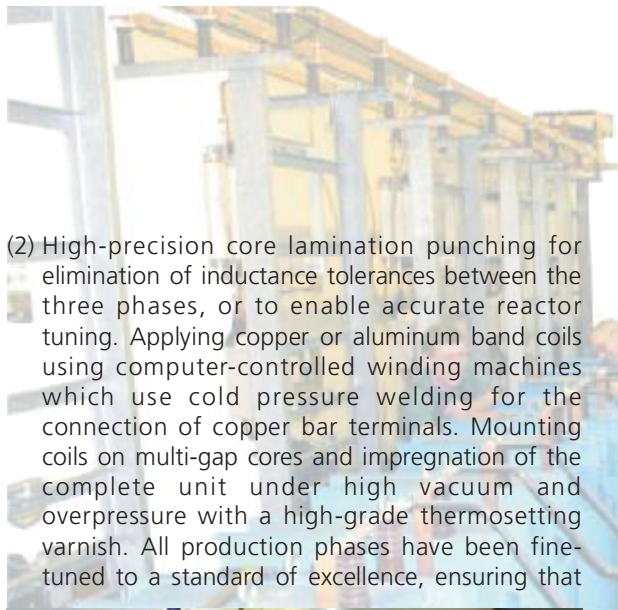
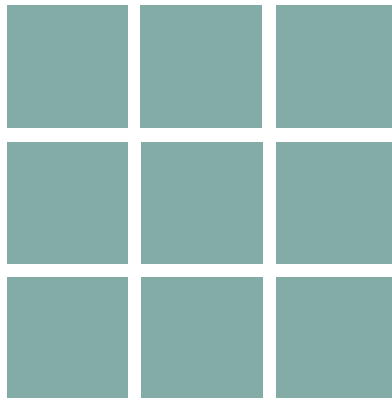


Fig. 3: CAD work station



(2) High-precision core lamination punching for elimination of inductance tolerances between the three phases, or to enable accurate reactor tuning. Applying copper or aluminum band coils using computer-controlled winding machines which use cold pressure welding for the connection of copper bar terminals. Mounting coils on multi-gap cores and impregnation of the complete unit under high vacuum and overpressure with a high-grade thermosetting varnish. All production phases have been fine-tuned to a standard of excellence, ensuring that

quality standards are maintained as demanded by the DIN EN ISO 9001 specification (Fig. 4).

(3) Database-controlled test equipment is used for routinely completed reactor testing at nominal current. For type-testing **Mangoldt** has a unique three-phase harmonic generator rated at approx. 0.9 MVA<sub>r</sub>, enabling to test reactors in a realistic environment, i.e. simultaneously loaded with fundamental and specified harmonic currents (which can also be modified in respect of amplitude and angle of shift). Thus heat-run and noise dissipation tests are available, as well as induced overvoltage tests for product reliability testing (Fig. 5).

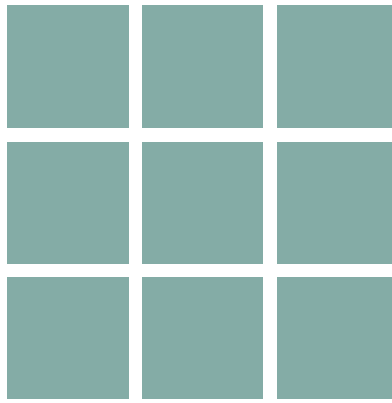


Fig. 4: Assembly of a three phase iron cored reactor



Fig. 5: Harmonic generator for real load tests

(4) As required, **Mangoldt** is able to supply clients with high-grade measurement equipment, plus the analytical expertise of a team experienced in finding solutions to low-voltage network tasks.



## Design Criteria

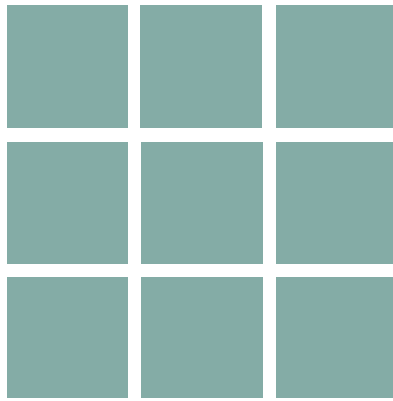
Since it is impossible to predict conditions prevailing in the network where the reactor will do its job, all reactors have to be designed for a defined worst-case scenario, meeting all tolerances laid down by the international standard IEC 60289. In the absence of an appropriate standard relating to network quality, this worst-case scenario had to be agreed between leading power factor capacitor suppliers and **Mangoldt**. These are the design criteria of proven reliability over a period of many years:

<b>Tolerance for inductance:</b>	<b>- 2 % ... + 3 % of <math>L_N</math></b>
<b>Fundamental current <math>I_1</math>:</b>	<b><math>1.06 \cdot I_{CN}</math> or <math>1.10 \cdot I_{CN}</math> (for 6% or 10 % overvoltage respectively)</b>
<b>Assumed harmonic voltage distortion:</b>	<b><math>U_{H3} = 0,5 \%</math>; <math>U_{H5} = U_{H7} = 5,0 \%</math>; basing on <math>U_N</math></b>
<b>Thermal current <math>I_{th}</math>:</b>	<b><math>1.05 \cdot I_{rms}</math> (relative to worst-case tolerances and capacitor aging)</b>
<b>Limit of core linearity <math>I_{Lin}</math>:</b>	<b><math>1.20 \cdot I_{1...7}</math> (relative to switching procedures at full harmonic load)</b>
<b>Assumed ambient temperature:</b>	<b>40 °C</b>

These design parameters remain unchanged for medium-voltage reactors

Against a background of deteriorating network quality, standards have now been launched, making corresponding adjustments to the **Mangoldt** design for low voltage reactors necessary as follows:

<b>Tolerance of the inductance:</b>	<b><math>\pm 3 \%</math> of <math>L_N</math></b>
<b>Fundamental current <math>I_1</math>:</b>	<b><math>1.10 \cdot I_{CN}</math> (for 10 % overvoltage)</b>
<b>Assumed harmonic voltage distortion:</b>	<b><math>U_{H3} = 0.5 \%</math>, <math>U_{H5} = 6.0\%</math> <math>U_{H7} = 5.0 \%</math>, <math>U_{H11}</math> &amp; <math>U_{H13} = 3.5 \%</math> relative to <math>U_N</math></b>
<b>THD:</b>	<b>limited to 8 %</b>
<b>Thermal current <math>I_{th}</math>:</b>	<b><math>1.0 \cdot I_{rms}</math> (neglecting tolerances and capacitor aging)</b>
<b>Limit of core linearity <math>I_{Lin}</math>:</b>	<b><math>k \cdot I_{CN}</math> where <math>k = f(p)</math> (<math>p = 5.0 / 5.67 / 6.0 / 7.0 / 12.5 / 13.0 / 14\%</math>)</b>
<b>Assumed ambient temperature:</b>	<b>50 °C</b>



There is thus no question that reactors manufactured by **Mangoldt**...

- ...are designed and manufactured according to the above-mentioned specifications and under the conditions laid down by DIN EN ISO 9001 (Registration No. 09 100 6544), and, as necessary, to UL File No. 173 113

Proof of load capacity as specified can be provided in the form of a heat-run test report, available on request for a corresponding extra fee (Fig. 6).

- ...are multi-gap. The cores are punched out of cold-laminated steel to a standard of very high precision, thus ensuring low tuning tolerance (Fig. 7)

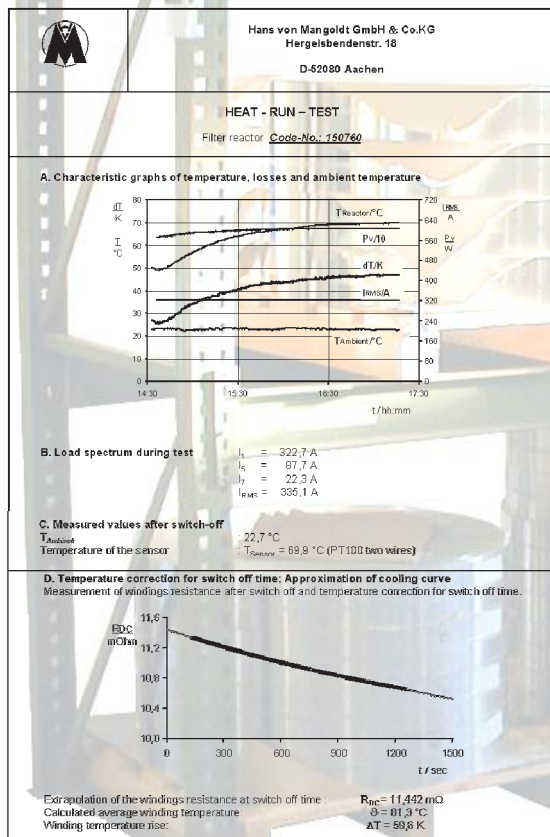
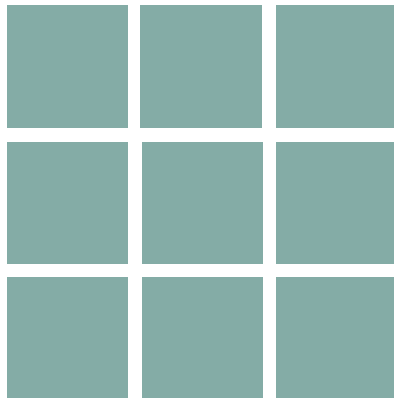


Fig. 6: Heat-run test report



Fig. 7: Production of core laminations





- ...have wire wound coils, or aluminum or copper band coils. With aluminum band, the copper bar terminals are welded to the aluminum by cold pressure welding (Fig. 8)



Fig. 8: Computer controlled winding machines



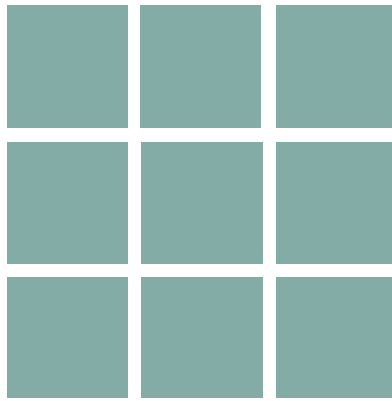
Fig. 9: Vacuum/overpressure impregnation equipment

- ...are impregnated as a complete unit under vacuum and overpressure using thermosetting impregnation varnish of temperature class H (Fig. 9)

- ...are measured at nominal current using data base test equipment. If the inductance is outside the specified tolerance, the equipment does not print the name plate and test report (Fig. 10)



Fig. 10: Data base test equipment for routine tests



## Temperature monitoring

All low-voltage reactors can be fitted with a temperature control device in the center coil (available for all coils, if requested).

Medium-voltage reactors are available with temperature monitoring in the core only. The sensors can be microswitches (normally closed or normally open), thermistors or PTC sensors.

In addition, **Mangoldt** can provide low-voltage reactors including a retrofit device, i.e. the center coil includes an insertion slot for later installation of a temperature sensor. This sensor can be supplied by **Mangoldt** soldered to a screw terminal and is easy to fit.

Important: Please specify the reactor temperature class when ordering the retrofit set. Please also remember that when monitoring all coils, normally open switches must be connected in parallel, whereas normally closed switches are connected in series.

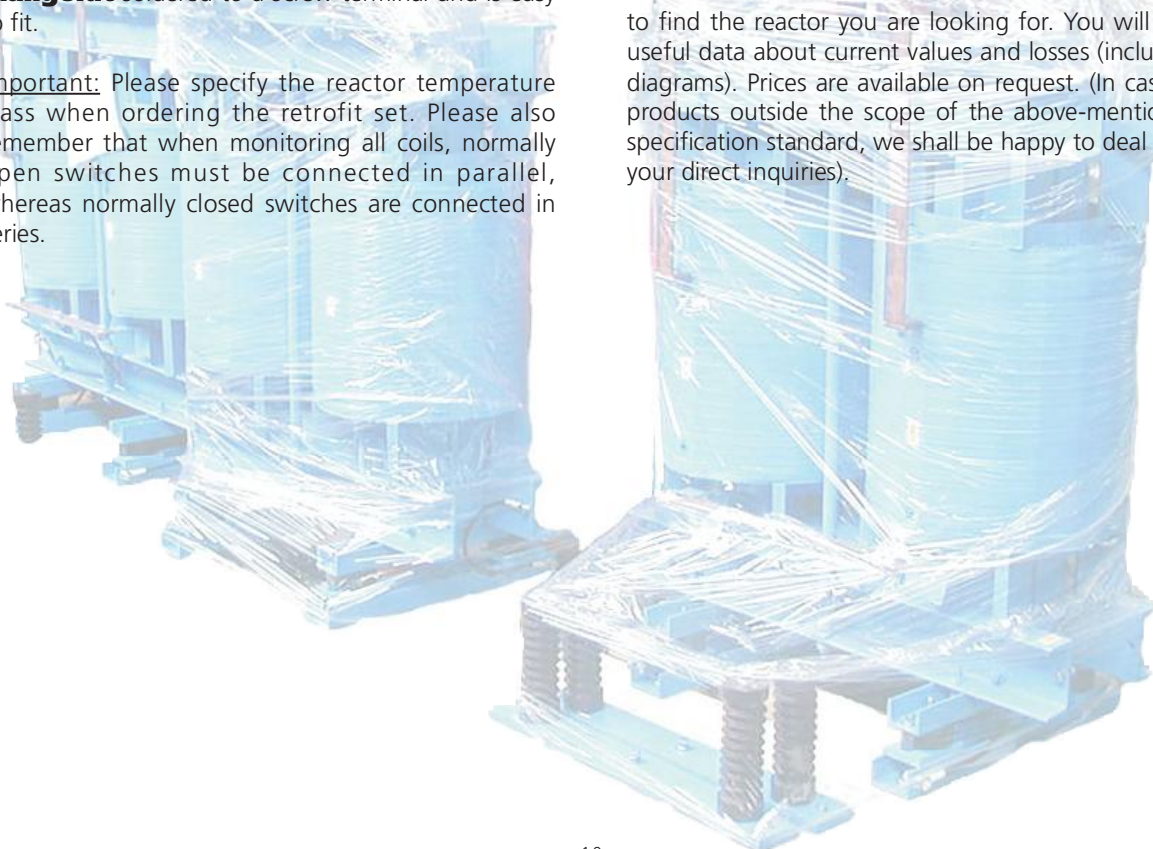
## How to get the reactor you need

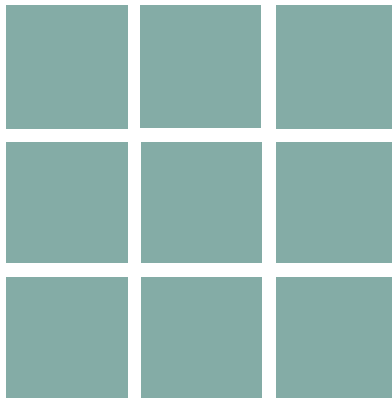
Since **Mangoldt** reactors are currently exported to more than 30 countries around the world, the potential range of different networks is extensive.

**Mangoldt** has therefore decided not to print a detailed catalog, but to make use of the Internet, thus enabling customers to identify the products they require by using the **Mangoldt** website. On our website there is a menu to guide you through the catalog pages on the site. Go to the website at

[www.mangoldt.com](http://www.mangoldt.com)

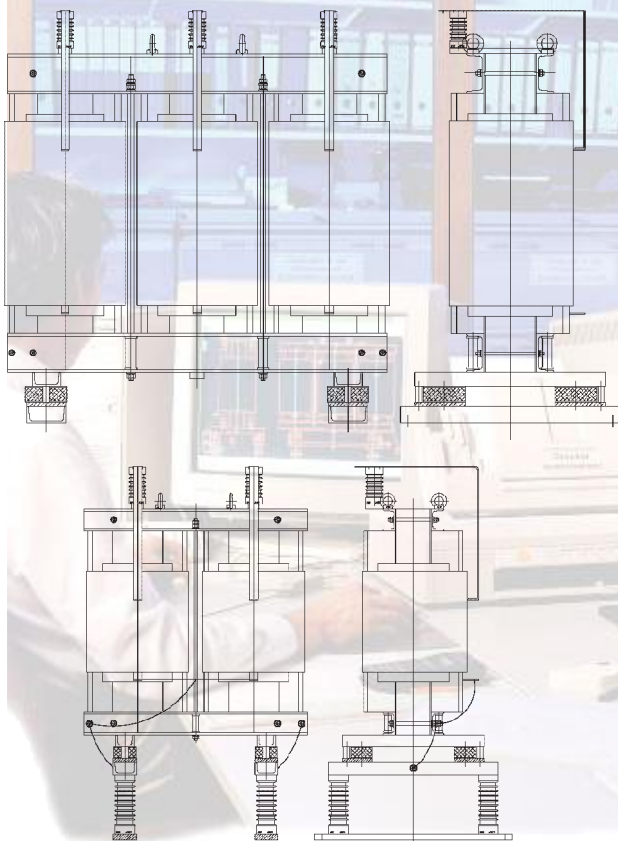
to find the reactor you are looking for. You will find useful data about current values and losses (including diagrams). Prices are available on request. (In case of products outside the scope of the above-mentioned specification standard, we shall be happy to deal with your direct inquiries).



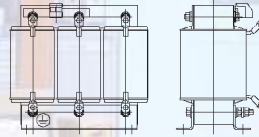


## Mechanical design features

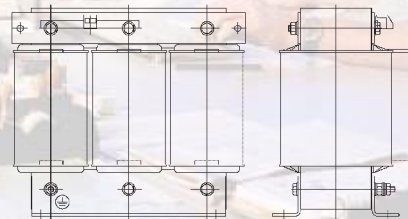
Low-voltage reactors come complete with mounting brackets (and lifting devices if weight exceeds 35 kg).



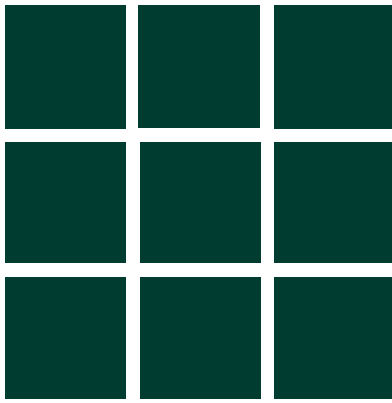
Medium-voltage reactors are fitted with lifting eyes and can be supplied with an optional bidirectional sub-assembly. All reactors of this type come mounted on mounting tracks including rubber/metal mounting fittings (standard feature). Terminals can be fitted on one or both sides of the reactor. If desired, support insulators at top of the reactor can be provided for fixing the copper bar terminals.



Where network voltages exceed 17.5 kV, single-phase reactors mounted on cast-resin insulators and rubber/metal mountings are the **Mangoldt** standard. With reactors of this type, the core is connected to the serial connection of the two coils.



All reactors can be supplied in a sheet-metal housing, as required.



Hans von Mangoldt GmbH & Co. KG is appropriately equipped to meet the requirements which activity in the international market place and the occupation of a position of increasing importance in that market implies. A highly-motivated and experienced workforce make a vital contribution to the success of the company. The use of state-of-the-art production systems, together with self-defined high demands for quality and reliability allow customers to have absolute confidence and trust in the products they order. The management of HvM looks to the future, firmly determined in maintaining its success in meeting this quality objective.

PRODUCTION RANGE:

Single phase dry type transformers up to 400 kVA  
Three-phase dry type transformers up to 800 kVA  
Transformer for special application  
Rectifier transformers  
Smoothing reactors  
Audio frequency blocking filters  
Filter reactors for low and medium voltage power capacitors  
Single phase magnetic voltage stabilizers up to 2 kVA  
Electronic voltage stabilizers up to 100 kVA  
Power electronics for special applications

# HANS VON MANGOLDT GmbH & Co. KG

Hergelsbendenstr.18  
D-52080 Aachen · Germany /Allemagne  
Telefon ++49 (0)241/1 66 07-0  
Telefax ++49 (0)241/1 6607-35  
[www.mangoldt.com](http://www.mangoldt.com)  
E-Mail: [info@mangoldt.com](mailto:info@mangoldt.com)  
Certified to DIN EN ISO 9001  
Registration No. 091006544

