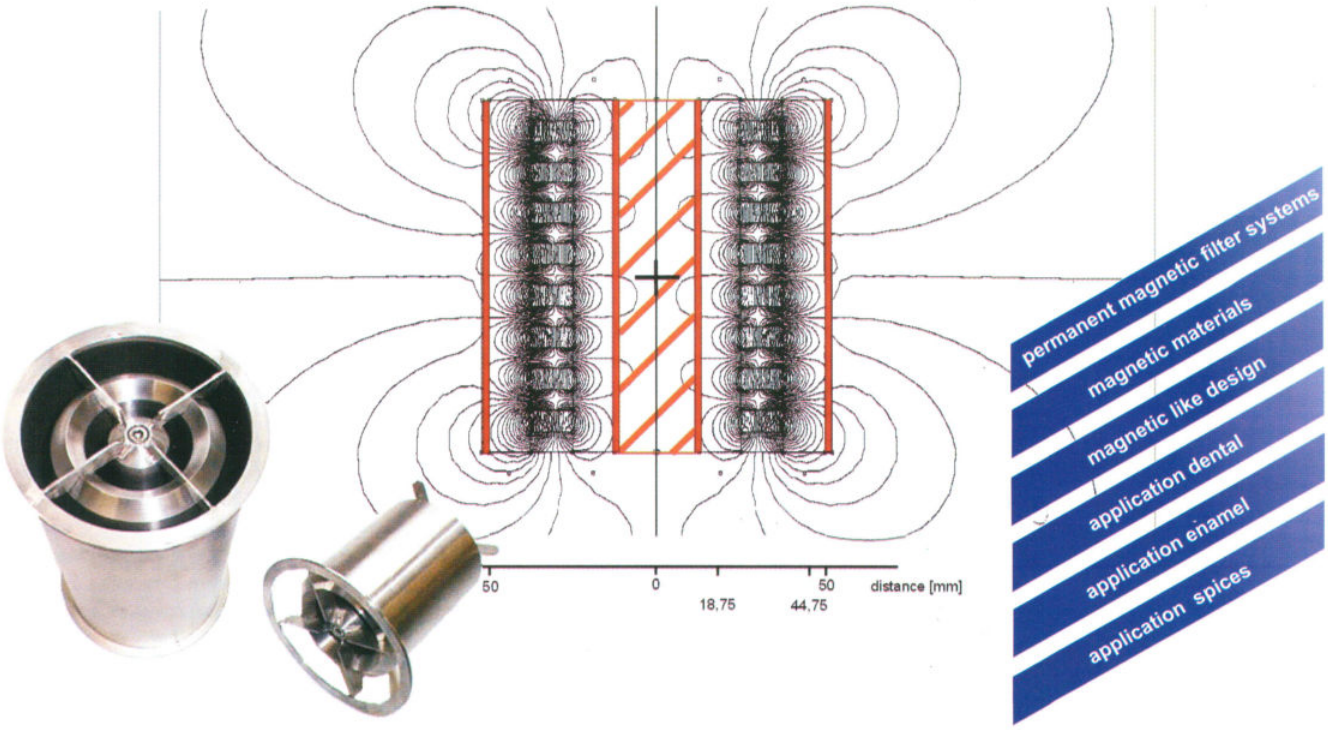
Interceram
International Ceramic Review

Sonderdruck aus Vol. 52 Nr. 3 (2003) 146-156

Development of High-performance Nd-Fe-B Magnetic-Filter for Separation of Metallic Impurities

[1]H.U. Benz, [2]M. Bommert, [1,3]J.S. Kim, [4]D.J. Vigueras and [1,4]H. Zoz

[1]Zoz GmbH, D-57482 Wenden, Germany
[2]Ivoclar Vivadent AG, FL-9494 Schaan, Liechtenstein
[3]ReMM, University of Ulsan, Ulsan 680-192, Korea
[4]ESIQIE, National Polytechnic Institute, Mexico City, DF 07300, Mexico



Zoz GmbH
Maltoz®-Strasse
D-57482 Wenden
Tel. +49 (0) 2762 - 9756 - 0
Fax +49 (0) 2762 - 9756 - 7
e-mail: info@zoz.de
http://www.zoz.de

Development of High-Performance Nd-Fe-B Magnetic-Filter for Separation of Metallic Impurities

H. U. Benz, M. Bommert, J. S. Kim, D. J. Vigueras, H. Zoz

Hans Ulrich Benz joined Zoz GmbH Germany in 1997 and is responsible for powder production as well as lab-/application technology.

Dipl.-Ing (FH) Martin Bommert is Head of the Ceramic Production Division at Ivoclar Vivadent AG in Schaan (Liechtenstein).

Prof. Dr. Ji-Soon Kim is Professor at Ulsan University (Korea).

David Jaramillo Vigueras is the Director of the Project Investigation Department and the Chairman of the Research Programs at the National Polytechnic Institute of Mexico.

Henning Zoz is the President of Zoz GmbH.

Interceram 52 (2003) [3]

Abstract

Most mechanical processes such as grinding and milling are accompanied by unexceptional contamination impurities which have a significant influence on subsequent processes and product properties. In particular, metal impurities in ceramics are fatal. Therefore, many attempts have been made to reduce contamination by choosing ceramic milling tools and using magnetic filters.

High-strength rare-earth magnets (Sm-Co, Nd-Fe-B) are used for magnetic-metal impurity separation. This contamination is mostly caused by Fe, Ni, or Co as well as moving parts of milling facility and transfer systems, drives etc. A permanent-magnet based filter system is favoured because of easy adaptation, handling and maintenance.

In this study, a new magnetic filter is described which has been developed by advanced magnet-flux design. A multi-component magnetic core is constructed by means of several magnet-rings that initiate magnetic fields with high magnetic flow densities in the intermediate Fe-rings. An important aspect is the performing and concentrating area with highest field gradient inside 2 ring-gaps where the product passes without hindrance at high throughput.

For testing, several products were contaminated with pre-determined Fe-powder particles, then filtered and investigated by means of chemical analysis, laser diffraction, scanning electron and optical microscopy. This system has been rapidly introduced in the ceramics industry in Europe. Applications and improvements at Ivoclar Vivadent AG, one of the largest dental-ceramic producers world-wide, are reported here.

Keywords: rare-earth magnets, permanent-magnet based filter system, high-field magnetic separation, powder technology

1 Introduction

The present paper describes the design, testing, and commercial application of a new permanent magnetic filter system. The inventor, Zoz GmbH (Germany), was originally a producer of conventional grinding equipment for crushing / particle size reduction of solid materials (ball mills) [1]. At the same time, the firm pursued specialization in High Kinetic Processing (MA, HEM, RM) [2] which also describes the basis of today's almost 50 % share of the R&D-volume in the field of materials design and development in the company. Since 1998, powders have been produced using the above-mentioned techniques of HKP-routes [2, 3] and since early 2000 PM parts as well [4].

In effect, the company had never designed or produced any kind of magnetic filter system before and this has certainly been of advantage, which will become obvious below. For decades, Zoz GmbH has used magnetic filters and adapted them to conventional sieving and mixing/milling operations, mostly supplying the ceramics industry [5]. However, the authors were not fully satisfied with the properties of these units. Either it was pretty hard to clean them, or the adaptation was difficult; the throughput too small; the magnetic field-gradient in particular was too low due to the non magnetic-like design; the achieved magnetic field-strength was too low according to what by today's standards are antiquated magnetic-materials; or all of the above. Furthermore, these products were not at all cheap.

Fig. 1 *New magnetic filter system MF-DN100x110, complete and single components*

Today the company's main business field is research related to Powder Metallurgy. The decision to design a new magnetic filter (Fig. 1) with the aim of improving all of the properties mentioned above was taken at a relatively late stage.

Since the first two prototypes were launched, the system has been widely accepted in the industry in Europe. One of the users, Ivoclar Vivadent AG in Schaan (Liechtenstein), who currently utilizes a total of 12 of the new systems and is one of the world-wide largest dental-ceramic producers, agreed to co-operate with Zoz GmbH for the further development of, and to provide significant support for, this work. What is remarkable is the fact that the time from idea to development and the first two prototypes took no longer than 6 months. Since then the new system has been applied all over Europe.

2 Common Application of Permanent Magnetic Filter Systems

Most technical commercial products depend on components where at least some of the materials are fabricated by mechanical processing techniques. Here the control of impurities/contamination is always important since mechanical processing without impurities is generally impossible. There is only a variation in the extent and quantity of the contamination which means that suitable tools for its control must be found. For example, in the case of ceramic materials, it is very important to lim-

Fig. 2
Magnetic trap formerly used at a major boiler producer (Source: Buderus)

Fig. 3
Typical magnet-grating built up by several magnet-bars

it the contamination of metals to an acceptable amount. It is often not possible to properly control contamination just by choosing all product-touching parts from suitable ceramic material since the process is either too complicated or the use of ceramics in production plants, e.g. as wearing parts in transfer and drive systems is too expensive, not possible, or not available.

Since Fe-alloys, being the most common metal, belong to the ferromagnetic materials (Fe, Co, Ni and Lanthanides like Gd, Er, Dy etc.), magnetic filters offer a good possibility to control and clean ceramic materials and to separate impurity fractions accordingly. In this case, various kinds of systems are applied where in general a compromise between maximum contamination ratio that can be accepted and required throughput (and cost of course) must be accepted or found. As adaptation, handling and maintenance/cleaning play an important role, filter systems based on permanent magnets are frequently used as they are easy to handle, are low cost, and are of a small unit size.

3 State-of-the-Art of Permanent Magnetic Filter Systems

State-of-the-art permanent magnetic filter systems can be more or less described in that a magnet is placed into a mass-flow and an attempt is made to use modern magnetic materials. The principle is probably 100 years old [6] and has not changed in recent decades. In the industry, two main application routes can be observed.

The first is when a strong magnet is placed in the same container where some suspension or slurry is being stored in the hope that magnetisable particles will be attracted and pulled to the surface of this type of magnetic trap and remain there until a cleaning cycle of the same can be performed (Fig. 2).

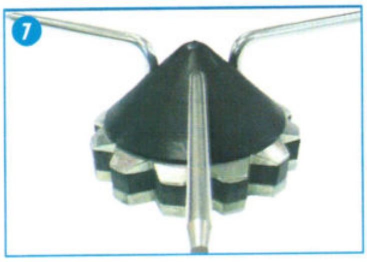
Secondly, a somewhat more sophisticated technical route is to build up a barrier for a volume flow of a product in order to force it to pass close to the magnet surface. However, the main problem is already defined by the word barrier itself. In order to have an acceptable barrier, its design usually leads to a non-barrier. Fig. 3 shows a typical magnet-grating that is built up by several magnet-bars. The gaps between the bars are relatively big so that the product can pass through. However, the desired effect is not achieved since this arrangement does not guarantee that the major fraction of the product passes extremely close to the magnet surface which in turn does not lead to a significant separation of magnetisable particles, which will be discussed below (application at Gewürzmühle Nesse).

Fig. 4 shows a device with a block-like arrangement of magnet bars where the distance between them is much shorter. Therefore it can only be used for liquid products with low viscosity. The separation effect versus throughput is regarded to be higher.

The device shown in Fig. 5 has a very similar design in that the bar-block is assembled in a kind of pump-casing. Surprisingly, the magnet-bars are fixed inside a complex non-magnetic metal chamber which is obviously a better option for cleaning the unit. This is also surprising because, in this design, the magnets also have a free play of several millimetres to the chamber. By comparing the outer surface of the chamber and the magnetic bars itself, this air gap leads to a tremendous loss of the magnetic flux density (due to air-induction) the effect of which is boosted by the wall thickness of the chamber as well. Other vari-

Fig. 4
Magnet bars in block-like arrangement

Fig. 5
Magnet bars in a block-like arrangement in a kind of pump-casing



ations for these types of solutions will be presented by means of the application of a major bath tub producer later in this paper.

Fig. 6 again shows a block-like design of magnet bars but this time with a curious kind of skin of corrugated iron – obviously in order to enlarge the surface where a magnetic field is induced – which is again surprising as the magnetic core has, on average, a number of millimetres free play to the curved metal skin. Furthermore, it seems that this device is very hard to clean.

Finally, Fig. 7 shows a simple arrangement of several horseshoe magnets on the outside circle of a flat cylinder. This particular unit is designed to be fitted on top of a funnel and is expected to fulfil more or less an alibi-function for the user. In conclusion, it seems that the devices mentioned above have not undergone any significant improvements recently, except that more modern magnetic materials are used. The authors believe that this is because magnetism is a rather difficult subject and therefore a brief survey of related correlations is given below.

Fig. 6
Magnet-bars in block-like arrangement with corrugated iron skin

Fig. 7
Arrangement of several horseshoe magnets on the outside circle of a flat cylinder

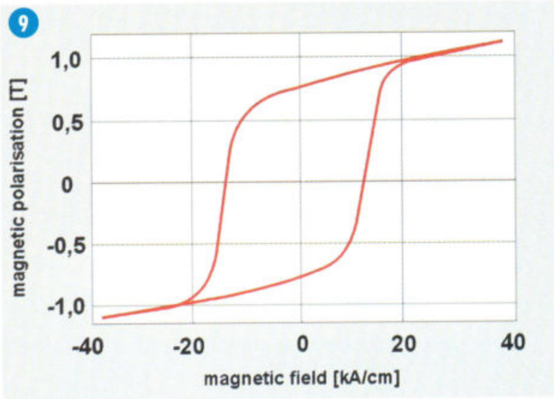
Fig. 8
Schema of electron orbit and spin with magnetic moment

Fig. 9
A typical hysteresis of ferromagnetic material (produced by Simoloyer CM01)

4 A Brief Overview of Magnetic Materials

Generally it is distinguished between diamagnetic, para- and ferromagnetic materials [7–11]. The term ferro refers to iron and has a historical basis as the first magnetic materials were observed (magnetite) and/or identified due to its attraction to other naturally occurring iron-based materials, probably first by the Greeks and the Chinese a thousand years ago [12].

Every known material in nature shows diamagnetic behaviour which is caused by atomic diamagnetism and is not related to a permanent magnetic moment. In Bohr's atomic model, negative loaded electrons orbit around the positive nucleons in the centre where the electrons additionally rotate around their own axis, i.e. spin. Any orbitally moving electrical load describes an orbital current and is known to cause a magnetic dipole. However, in any atom, the orbit magnetic dipoles from orbit and spin are opposite directed in pairs which means



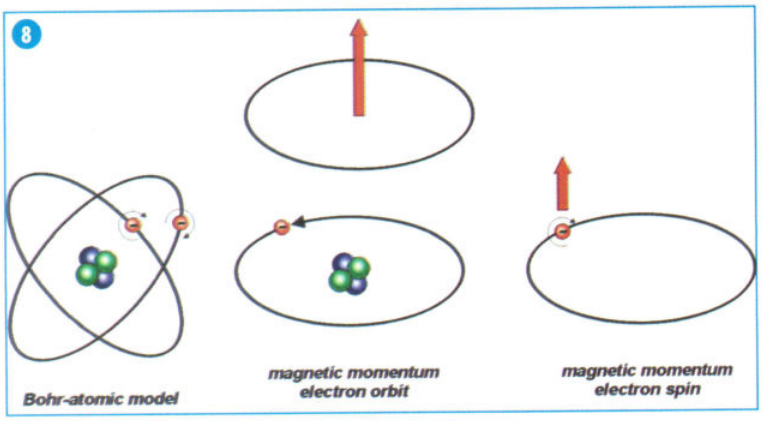
that, in the case of saturated electron shells, the magnetic moments compensate each other. To explain the reason why these materials interact with an external magnetic field, the quantum theory is required [13–16]. Fig. 8 shows a schema of the electro-movement and the resulting magnetic moments.

In the case of non-saturated electron shells, the left and right turn oriented currents as well as negative and positive spins do not fully compensate each other which means that the individual atoms behave like magnetic dipoles. This effect is very soft and in strong interaction with the thermodynamic. The higher the temperature, the lower the paramagnetic behaviour. A full alignment of all magnetic moments is achieved at no temperature [7–11].

This does happen in the case of ferromagnetic materials [7–11, 17]. Here the interaction of neighbouring atoms leads to an alignment of spins on neighbouring lattice places, even without the presence of an external magnetic field. This occurs only in crystalline structure and leads to regions of numerous but each aligned atomic dipoles. These domains are not aligned among each other but will do so under the presence of an external magnetic field. If this magnetic field is strong enough, all domains can be aligned and the material is magnetised at saturation. After removing the external field, the domains will dominantly remain aligned, resulting in a permanent magnet. This relation between initial magnetisation and remaining (remanent) magnetisation at varying field strength describes the typical hysteresis for ferroelectrica [18–21]. Fig. 9 shows a typical hysteresis of Nd-Fe-B magnetic material produced by HKP with the Simoloyer [22].

A characteristic value, the magnetic field (strength) (H), is important and is expressed in the Oersted unit:

magnetic field (strength) $$1\,\mathrm{Oe} = \frac{1000}{4\pi} \cdot \frac{A}{m} \quad (1)$$



The magnetic flux density or magnetic induction (B) is expressed in terms of the Gauss [G] and Tesla [T] units:

magnetic flux density (magnetic induction)

$$B = \left[\frac{Vs}{m^2}\right] = \mathrm{Tesla\,[T]} \quad 1\,\mathrm{Tesla} = 10000\,\mathrm{Gauss\,[G]} \quad (2)$$

The magnetic flux density of the earth on the surface refers to about $1 \cdot 10^{-4}$ T which refers to 1 G.

In the case of a magnetic filter application where clearly, due to the needed throughput, not all material can be forced to directly touch the magnet surface, it is of major importance to accelerate particles passing close to the magnet surface to the same. For the force F on a charged particle q moving with velocity v, the vector (Eq. 3) is valid:

$$F = qv \cdot B \quad (3)$$

Commonly used to determine the quality of magnetic materials is:

$$BH_{maximum} \text{ energy product } BH_{max} = H \cdot B \, [\text{MGOe}] \quad (4)$$

Since in the case of a magnetic filter, the volume specification over the distance from the magnetic surface to the particle to be separated is unknown or consists of variable product in variable concentration in air or suspension the permeability, which describes the inverse resistance of a medium against the magnetic flux lines, the following is also essential:

absolute permeability:

$$B = \mu_0 \cdot H \qquad \mu_0 = 4\pi \cdot 10^{-7} \left[\frac{Vs}{Am} \right] \quad (5)$$

Examples are:

$$\text{vacuum} \quad 1 \frac{Vs}{Am} \quad (6)$$

$$\text{steel, approx} \quad 10 \frac{Vs}{Am} \quad (7)$$

The permeability at air-induction μ_{Luft} – which must be taken into account for magnetic filter operation of dry powders – can be determined to be close to 1 (vacuum).

Fig. 10 shows a survey of commercially used permanent magnetic materials in historical chronology.

This summary must start with the AlNiCo magnets (Al-Ni-Co) developed around the 1940's which are still in frequent use today [23]. In the 1960's, hard ferrite or ceramic magnets were developed. These magnets are made of strontium hexaferrite where the base material is strontium carbonate and iron oxide which are both widely available at relatively low costs. These materials represent probably about $^3/_4$ of the world magnet

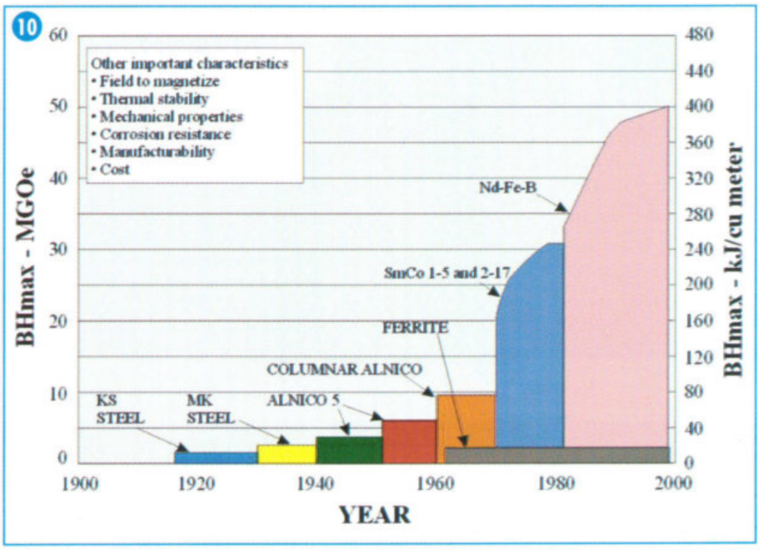


Fig. 10
Development of permanent magnets in the 1900s

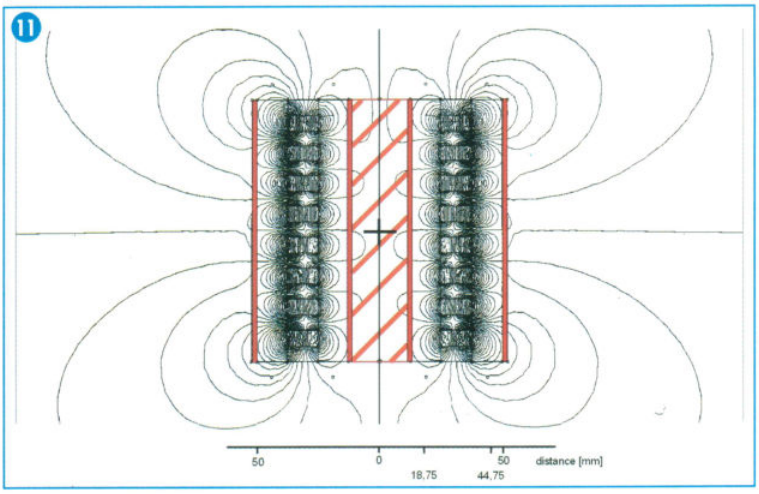
consumption and are used e.g. in motors, speakers, etc.[24]. Since around 1970, sintered samarium cobalt magnets have been available which supply very high magnetic properties at excellent corrosion resistance and thermal stability. The listed Sm_2Co_{17} composite e.g. supplies a maximum energy product of over 30 MGOe and can be used up to 350 °C (Curie temperature 700–800 °C).

The permanent magnet material with the highest available maximum energy product is the Nd-Fe-B magnet (usually $Nd_2Fe_{14}B$) which has been available since around the mid 1980's whereas today refined materials can almost go up to 50 MGOe. A disadvantage is the relatively lower Curie temperature at 310 °C that can be shifted by adding e.g. 5 % Co to about 370 °C which refers to a working temperature of 150–200 °C in maximum. Also the corrosion resistance is low, so usually these magnets must be protected by coatings or caging [23].

5 Advanced Magnetic-Like Design

In the case of a magnetic filter application, high magnetic properties of the material are of major importance. Taking into account that the insofar best commercially available materials (Nd-Fe-B) are limited to a maximum energy product of about 50 MGOe where the theoretical maximum value is at about 64 MGOe [23], a promising improvement in magnetic filter systems must use these materials but improve the application which can actually mean designing the magnetic field as well as the technical / mechanical unit where the product is sent through.

One area where significant improvements can be expected is the design of the gaps where the product passes since this is where the magnetic field loses almost all of its performance due to the low permeability of air and/or non-magnetisable base-product. This particular relation between distance and magnetic property is obviously not at all obeyed in the case of most conventional systems described above; even the effect can easily be imagined if one tries to take a piece of steel, bring it close to a permanent magnet, and then see what happens in very close proximity to it and at the same time observes what happens just a few millimeters away from the magnet surface [25]. However, this approach is limited with respect to direct interaction with the existing throughput of any kind of gap or dis-



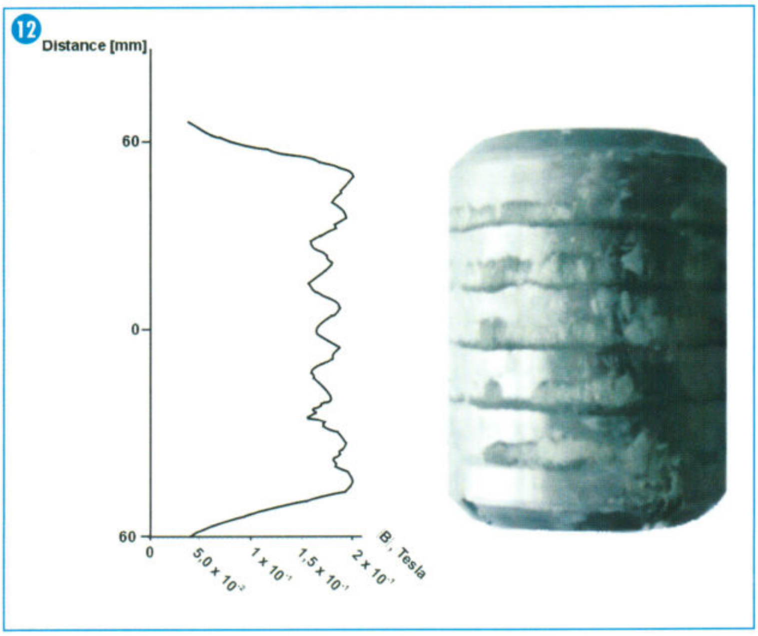


Fig. 11
Chart of magnetic flux lines of magnetic filter MF-DN100x110

Fig. 12
Magnetic flux density at air induction at res. of magnetic unit MK-078105

tance since a filter that would block the mass flow of product would not be suitable. Furthermore, simply from an economic point of view, it cannot be imagined that all (solid) particles of the product can directly touch the surface of the magnet which may be described as a flat container or pipeline lined with a huge number of magnets. Such a device would be extremely large, on the one hand, and even more expensive on the other. If this is acceptable, the main objective then must be to accelerate the magnetisable particles towards the magnet surface and collect or fix them thereon [26, 27]. If it is further taken into account that, for the acceleration of a magnetisable particle in the magnetic field, the magnetic field gradient – which is described by the variation of the magnetic flux density over the distance to the magnetic source – is a determining factor, then the product of field gradient and flux density must be of major importance for a magnetic filter system [7].

Since the magnetic flux density can be imagined as being similar to the density of magnetic flux lines, the main idea was to increase the density of these flux lines by arranging thin, anti-polar ring-magnets around each iron core and to press the single rings together in order to condense the magnetic field in the same way. Since this happens right at the surface of magnets and ring-cores initially, a significant increase of the field gradient can also be expected.

Fig. 11 shows the chart of magnetic flux lines of the developed magnetic unit MK-078105 with a number of 10 anti-polar arranged ring-pairs which in the intermediate Fe-rings initiate magnetic fields with high magnetic flow densities (Fig. 12, left). The barriers inside and outside represent the inner and the outer circle limit formed by an inner tube called the center unit as well as by the outer tube which is defined as the standard pipe DN100 (Fig. 1).

The chart in Fig. 12 shows the magnetic flux density determined on the gap-middle-axis of each circle-gap which illustrates what is meant by the statement regarding extremely reduced magnetic properties at air induction just some millimeters (here 4.25 mm) away from the magnet surface. It should also be considered that the design introduced here is strongly expected to achieve a significantly higher standard than any other design.

Additionally, this technical solution allows concentrating areas with the highest field gradient inside two determined ring-gaps where the product can pass without any barrier at high throughput. Since the entire magnetic filter system only contains a low number (3) of single units which are only assembled by one single screw, it can easily be disassembled, cleaned, and adapted to pipe-lines carrying multi-phase flows and slurries.

For a better removal of separated particles from the magnetic unit, the peaks of the relevant unit are non-magnetic which means that the waste can be pushed towards or from these peaks and are easier to remove from there. The main dimensions of the unit are given in Table 1.

6 Simple In-House Testing

By far, the easiest and most suitable way of testing a magnetic filter systems is a comparative quantitative test under real conditions which means that the new filter system be applied for products/materials where standard systems have already been applied.

The authors followed this procedure exactly with the two prototypes it produced and sent these units to some large industrial applicators. A quantitative statement is, however, not possible as the authors have not seen the prototypes yet as they have only been sold recently. Since this is a non-defined yet very satisfying result, another 10 were produced, sent out and the same thing happened again. Production was subsequently increased to 25 and currently the production batch is 50.

Meanwhile, it was decided that some testing needed to be done, at least in-house where it has in effect not been easy to reserve at least one of the systems for own use. Therefore it was decided to conduct some very simple

Table 1
Main dimensions of the magnetic filter MF-DN 100 x 110

Inner diameter of the outer tube	99 mm
Outer diameter of the magnetic unit	78 mm
Inner diameter of the magnetic unit	48 mm
Outer diameter of the center unit	27 mm
Free gateway of the outer circle-gap	2897 mm^2
Free gateway of the inner circle-gap	1215 mm^2
Nominal gateway dia	NW 71.6 mm

Fig. 13 *Experimental set up for Fe-powder and water, simulation of full water flow, water drained*

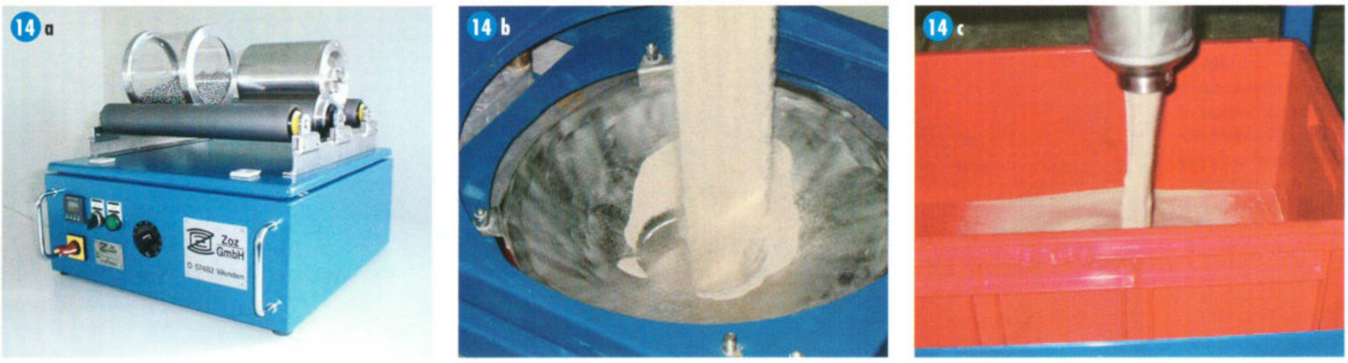


Fig. 14 *Mixing of Fe-powder in sand in a Zoz Rollermill RM1, simulation of full powder flow, sand drained*

testing, choosing 3 different type of media (water, sand and enamel-slurry), loading each with a determined amount of Fe-powder, partly mixing it and then separating it again by means of the new filter system.

Fig. 13 shows the experimental set-up for Fe-powder in water. Since this composition can hardly be mixed, 2 g Fe-powder was placed on the inner border of the funnel in a standard Zoz-sieve SW50 where the magnetic filter was adapted to the end of the funnel. In order to simulate a full water flow, a large plastic container was used to guide the water and another one to supply more water than can pass by gravity at once. The figure on the right also shows the lower end of the funnel where the magnetic filter is assembled.

For the composition Fe-powder in sand, the same procedure was followed, only that sand and Fe-powder were mixed to a ratio of 1250:1 by mass-% in a Zoz-Rollermill RM1 (again to 2 g of Fe-powder). The procedure is shown in Fig. 14 a–c.

For the composition Fe-powder in enamel-slurry, the same procedure as in the case of Fe-powder and water was applied and the slurry was contaminated with 2 g of Fe-powder placed on the inner border of the funnel. This procedure is shown in Fig. 15 a–c.

In the case of the water flow, where flow parameters were calculated and measured to be 18 l/s and 4.4 m/s, 1.5 g was separated; in the case of the sand flow of 0.83 l/s and 0.2 m/s separated at 1.5 g and in case of the enamel-slurry flow 0.9 l/s and 0.2 m/s, approximately 2 g was separated.

As expected, these simple results show that the quantitative separation strongly depends on the flow velocity which is at fixed magnet unit lengths a number for the remaining time of the multiphase flow in the magnetic field and of the viscosity of the same which refers again to the flow velocity. The remaining time can be influenced by extending the length of the magnetic unit which has in fact been simulated in the case of the water flow by adapting not one, but two magnetic filter units. Fig. 16 displays these two magnetic units.

7 Applications

7.1 Application Report and Testing at Ivoclar Vivadent AG

As mentioned above, the by far easiest and most suitable way of testing a magnetic filter system is a comparatively quantitative test under real conditions as reported here.

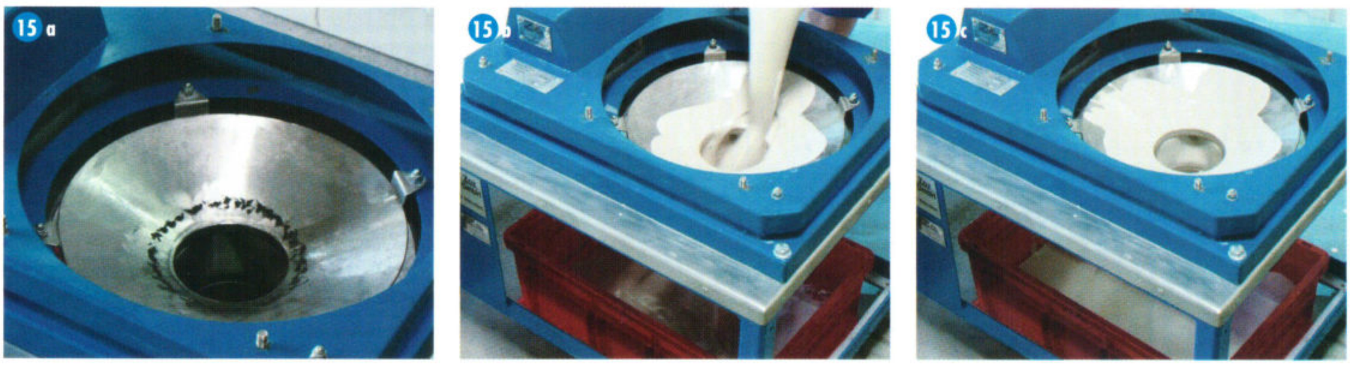


Fig. 15 *Experimental set up for Fe-powder and enamel slurry, simulation of full slurry flow, enamel slurry drained*

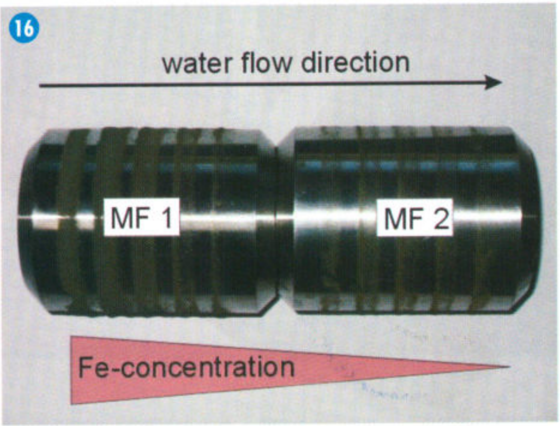


Fig. 16
The 2 magnetic units as dismantled after the test of Fe-powder and water

Fig. 17
3 of 6 sieving operations carried out at Ivoclar Vivadent AG with both adapted magnetic filters MF-DN100x110

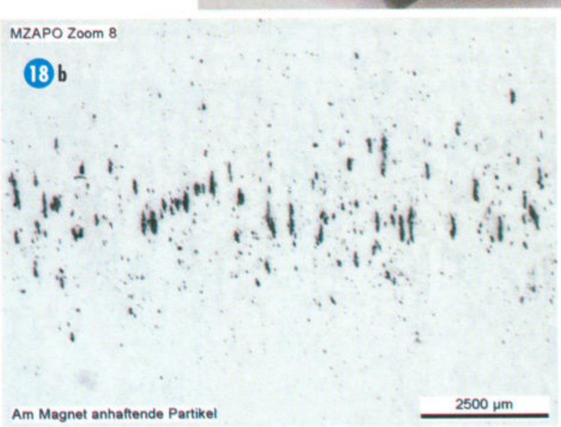
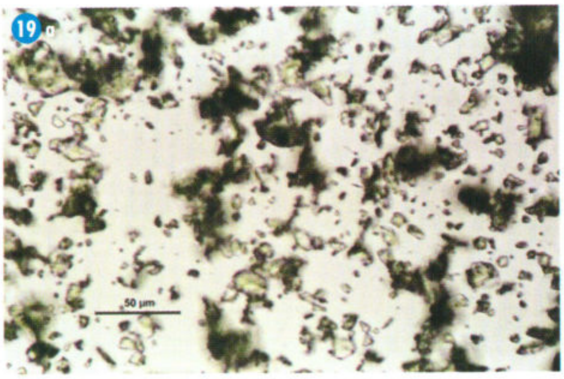


Fig. 18 a–b
Separated waste on the outer surface of the magnetic unit, enlarged



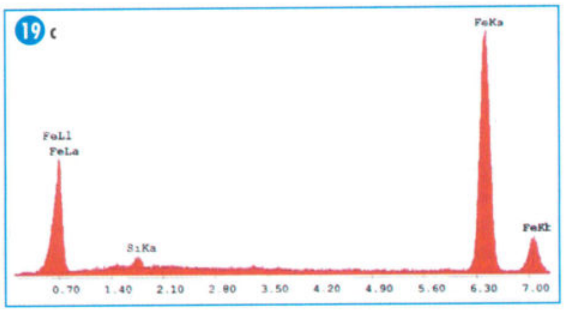


Fig. 19
Optical microscopy, SEM and EDX analysis of separated particles, very high Fe-content

Ivoclar Vivadent, as one of the largest dental ceramic producers in the world, must and do pay particular attention to clean and in particular Fe-free dental ceramics. As such, this offered perfect conditions for intensive testing of the newly developed system.

Fig. 17 shows 3 of 6 sieving operations carried out for ceramic base and finished products where both of the magnetic filters MF-DN100x110 are used.

Fig. 18 a–b show an example of separated waste on the outer surface of the disassembled magnetic unit (left) and enlarged by optical microscopy after removal on a bond-strip. Fig. 19 shows a consolidated ceramic sheet under optical microscopy in conventional processing route (left) and including additional application of the new magnetic filter system (right). In contrast to the left sample, the one on the right-hand side does not exhibit any inclusions such as black oxide spots, which is the best possible result for the new device.

In order to try and determine the source of the separated magnetisable particles, 1.3 g of waste were collected after sieving 400 kg of powder with an apparent density of 1.2 kg/dm^3 at a sieving rate of 50 kg/h followed by optical, scanning electron microscopy (SEM) and X-ray diffraction (EDX). Fig. 19 shows an optical microscopy, a SEM-micrograph, as well as the EDX-analy-

Fig. 20
Pressure capsule D-MF1011 with assembled magnetic filter in a pump-line at a Zoz screen-cart*

sis referring to the marked spot on the SEM-image, thereby identifying extremely high Fe-content of 91 at.-% which allows the conclusion that an Fe-particle has been separated, thus preserving the product.

7.2 Application Report and Testing at Major Enamel Applicators

In the case of the following reports by two major enamel application processors, the magnetic filter MF-DN100x110 was assembled in a pressure capsule D-MF1011* as shown in Fig. 20. The product was then pumped through the filter.

In the case of the first example, about 7 t of enamel slurry with a density of 1.7–1.75 kg/dm^2 was pumped through a pipeline system within 1 h where the new magnetic filter was adapted. 69.7 g of waste was separated and partly characterized.

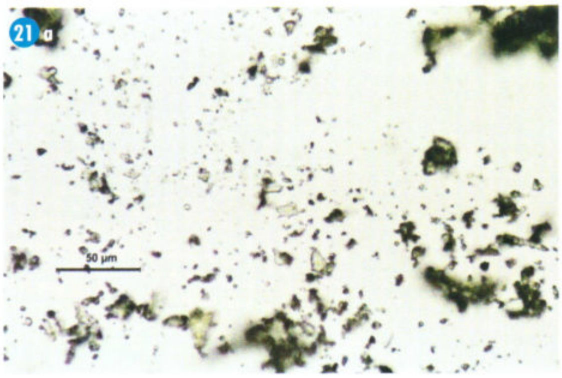
Fig. 21 shows an optical microscopy, a SEM-micrograph, as well as the EDX-analysis referring to the marked spot on the SEM-image, thus identifying high Fe-content of 41 at.-% which may allow the conclusion that an Fe-particle has been separated.

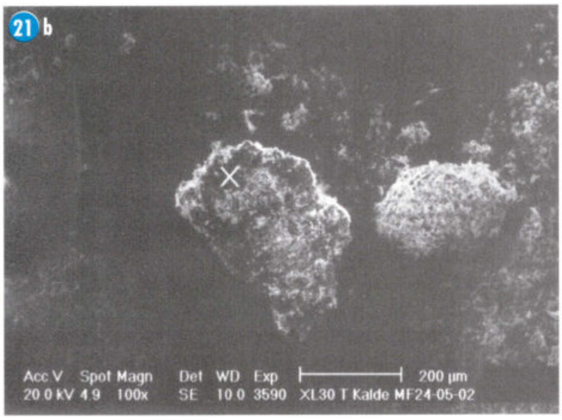
In the case of the second example, 1.5 t of enamel slurry with a density of 1.4–1.75 kg/dm^2 was pumped through a pipeline system where the new magnetic filter was adapted after a Zoz-screen-car sieving rate of 1200 kg/h. The separated waste was cleaned where 7.85 g remained.

Fig. 22 shows an optical microscopy, a SEM-micrograph, as well as the EDX-analysis referring to the 2 marked spots on the SEM-image, identifying high Fe-content of 74 at.-%, respectively high Ni-content of 80 % where the first can be expected to be a contaminating Fe-particle and the second caused by some remain in the tested base-slurry that contents Co- and Ni-rich oxides for bonding of the slurry.

7.3 Application at Gewürzmühle Nesse GmbH

The application report concludes with an example for the application of the same magnetic unit MK-078105 (2 each) but assembled in a tube-capsule RF-DN140x250 at Gewürzmühle Nesse GmbH, a major spices, herbs and condiments producer in Germany.





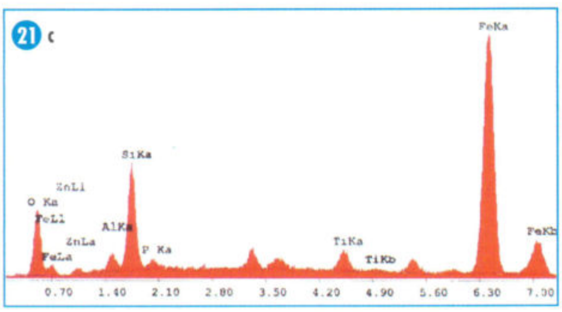


Fig. 21
Optical microscopy, SEM and EDX analysis of separated particles, high Fe-content

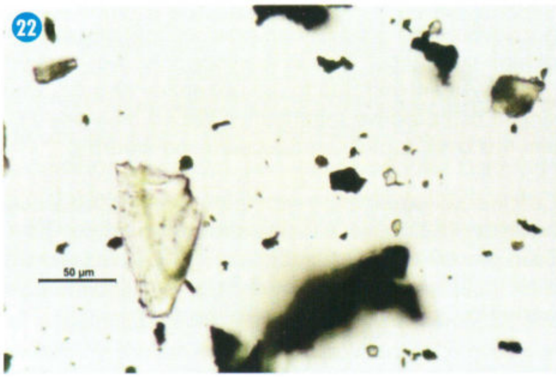


Fig. 22
Optical microscopy, SEM and EDX analysis of separated particles, high Fe-, respectively Ni-content

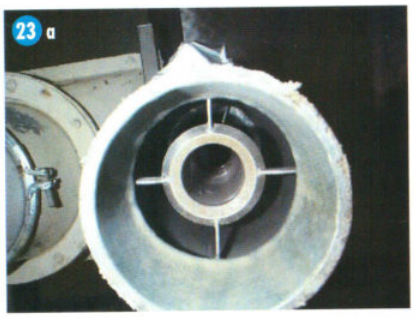


Fig. 23
Tube capsule RF-DN140x250 at Nesse and disassembled magnetic units

Fig. 23 shows the assembly of the unit in the plant (left) as well as separated waste on the surface of the magnetic units (right). Here 100 kg of pepper was filtered in 15 min where 3 g of waste was separated.

8 Conclusion

A new magnetic filter has been developed by means of advanced magnetic-flux design using modern permanent magnetic material. A multi-component magnetic core is built up by several magnet-rings that initiate magnetic fields with high magnetic flow-densities in the intermediate Fe-rings. The most important outcome is a technical solution for performing and concentrating areas with the highest field gradient being inside 2 ring-gaps where the product can pass without any barrier at high throughput. Due to its superiority over conventional systems and due to the possibility of quick and simple comparative quantitative testing, this new system has been rapidly introduced in the industry.

Commercial application examples at major producers in the dental ceramic, enamel, and spices industry have been presented. The immediate and significant success is certainly accompanied by deficiencies elsewhere, in particular in applying magnetic-like designs.

H. U. Benz, J. S. Kim, H. Zoz
Zoz GmbH, D-57482 Wenden, Germany

M. Bommert
Ivoclar Vivadent AG, FL-9494 Schaan, Liechtenstein

J. S. Kim
ReMM, University of Ulsan, Ulsan 680-192, Korea

H. Zoz, D. J. Vigueras
ESIQIE, National Polytechnic Institute,
Mexico City, DF 07300, Mexico
e-mail: zoz@zoz.de

Received: 09.10.2002

References

[1] H. Zoz, R. Reichardt, J. S. Kim: Anwendung und Auslegung von Trommelmühlen. Keram. Z. **53** (2001) [5] 384–392
[2] A. Bose, K. Ameyama, S. Diaz de la Torre, D. J. Vigueras, D. Madang, H. Zoz): Review of Applications and Materials Processed by Rotating Horizontal High Energy Milling. Proc. PM2TEC'2002 - 2002 World Congress on Powder Metallurgy & Particulate Materials, 16–21 June 2002, Orlando, FL (USA)
[3] H. Zoz, H. U. Benz, G. Schäfer, M. Dannehl, J. Krüll, F. Kaup, H. Ren, R. Reichardt: High Kinetic Processing of Enamel, Part I. Cooperative Project 09-8-4413, Zoz GmbH, Pfaudler Werke GmbH, Degussa-Hüls AG, Wendel GmbH, Miele & Cie. GmbH & Co. Internat. Symp. on Metastable, Mechanically Alloyed and Nanocrystalline Materials, Ann Arbor, Michigan, 2001
[4] H. Zoz, H. U. Benz, K. Hüttebräucker, L. Furken, H. Ren, R. Reichardt: Stellite Bearings for Liquid Zn-/Al-Systems with Advanced Chemical and Physical Properties by Mechanical Alloying and Standard-PM-Route, Part I. Metall **54** (2000) [11] 650–659
[5] H. Zoz: Trommelmühlen – allgemeine Betrachtungen. Keram. Z. **47** (1995) 190–192
[6] H. W. Meyer: A History of Electricity and Magnetism. Cambridge/MA, MIT Pr, 1971
[7] Authors' discussion with F. J. Börgemann, Hanau (Germany), November 2000, August 2001
[8] A. Guinier, R. Jullien: Die physikalischen Eigenschaften von Festkörpern. München: Hanser-Verlag, 1992
[9] L. Bergmann, C. Schaefer, H. Gobrecht: Lehrbuch der Experimentalphysik, Bd. 2 Elektrizität und Magnetismus. Berlin, New York: de Gruyter, 1987
[10] C. Kittel: Introduction to Solid State Physics, Vol. 7. New York: Wiley, 1996
[11] D. C. Mattis: The Theory of Magnetism, Vol. I. Berlin: Springer-Verlag, 1981; Vol. II. Berlin: Springer-Verlag, 1985
[12] A. Kloss: Geschichte des Magnetismus. Berlin-Offenbach: vde-Verlag, 1994
[13] W. Nolting: Quantentheorie des Magnetismus. Teil 1: Grundlagen und Teil 2: Modelle. Stuttgart: Teubner, 1986
[14] H. Schroth, K. Laßmann, C. Borgmann und H. Bracht: Electric-Dipole Spin Resonance of Be-Doped Silicon. Materials Science Forum **417** (1997) 258–263
[15] S. W. Tjablikow: Quantentheorie des Magnetismus. Leipzig: B. G. Teubner Verlagsgesellschaft, 1968
[16] C. Kittel, C. Y. Fong: Quantentheorie der Festkörper. Munich, Vienna: R. Oldenbourg Verlag, 1989
[17] E. Kneller: Ferromagnetismus. Berlin: Springer Verlag, 1962
[18] A. Hubert, R. Schäfer: Magnetic Domains. Berlin, Heidelberg: Springer Verlag, 1998
[19] A. Magni: Magnetisation Dynamics and Hysteresis in the Framework of the Domain Theory. Diss. Politecnico di Torino, 1997
[20] G. Aguilar-Sahagun, P. Quintana, E. Amano, J.T.S. Irvine, R. Valenzuela: Equation of Motion of Domain Walls and Equivalent Circuits in Soft Ferromagnetic Materials. J. Appl. Phys. **75** (1994) [10] 7000–7002
[21] U. Enz: Die Dynamik der BLOCHschen Wand. Helv. Phys. Acta **37** (1964)
[22] K. Schnitzke, C. Kuhrt, L. Schultz: Siemens Zentralabtlg. F&E, Erlangen,1993
[23] Group Arnold, Company Profile,2001
[24] Authors discussion with S. Manoach, R. Muhamad, E. Brook-Levinson at Kibbutz Gesher, Israel, September 2001
[25] Ozaki-Yukiko, Fujinaga-Masashi: Magnetic Properties of High Permeability Iron Powder 'KIP MG270H' for Line Filter Cores. Kawasaki Steel Technical Report **42** (2000) 30–35, 13 Refs.
[26] J.H.P. Watson: Permanently Magnetised High Gradient Magnetic Air Filters for the Nuclear Industry. INTERMAG '95 – 1995 IEEE Internat. Magnetics Conf., 18-21 April 1995, San Antonio, TX, USA, IEEE Trans. on Magnetics **31** (1995) 6, PT.2, 4181–4183
[27] A. C. Lua, R. F. Boucher: Magnetic Filtration of Fine particles from Gas Streams. Proc. Inst. Mech. Engineers, Part E (J. of Process Mech. Engng.) **207** (1993) E2, 109–122

Entwicklung eines Nd-Fe-B-Hochleistungsmagnetfilters zur Abscheidung metallischer Verunreinigungen

Die meisten mechanischen Prozesse, wie Zerkleinern und Mahlen, sind begleitet von einer außerordentlichen Kontamination mit Verunreinigungen, die signifikanten Einfluss auf die nachfolgenden Verfahrensschritte und Produkteigenschaften haben. Insbesondere sind metallische Verunreinigungen in Keramik fatal. Deshalb sind viele Versuche unternommen worden, die Kontamination durch die Auswahl keramischer Mahlwerkzeuge und den Einsatz magnetischer Filter zu reduzieren.

Seltene-Erden-Hochleistungsmagnete (Sm–Co, Nd–Fe–B) werden für die Abtrennung magnetischer Metallverunreinigungen eingesetzt. Diese Kontamination wird meist durch Fe, Ni oder Co aus beweglichen Teilen der Mahleinrichtung und des Fördersystems, der Antriebe usw. verursacht. Dabei wird ein permanent-magnetisches Filtersystem wegen der leichten Anpassbarkeit, Bedienung und Wartung bevorzugt.

In dieser Arbeit wird ein neues Magnetfilter beschrieben, welches für den magnetischen Fluss ausgelegt wurde. Ein mehrteiliger magnetischer Kern wurde mit Hilfe mehrerer Magnetringe konstruiert, die magnetische Felder mit hohen magnetischen Flussdichten in den dazwischen liegenden Eisenringen initiieren. Ein wichtiger Aspekt dabei ist der Wirkungs- und Konzentrierungsbereich mit höchsten Feldgradienten innerhalb von 2 Ringspalten, durch welche das Produkt ohne Behinderung mit hohem Durchsatz hindurchgeht.

Zu Prüfzwecken wurden mehrere Produkte mit vorgegebenen Fe-Pulverteilchen kontaminiert, dann über die Filter geleitet und anschließend mittels chemischer Analyse, Laserbeugung, Rasterelektronenmikroskopie und Lichtmikroskopie untersucht. Dieses System wurde rasch in der keramischen Industrie in Europa eingeführt. Über Anwendungen und Verbesserungen bei der Ivoclar Vivadent AG, einem der größten Dentalkeramikhersteller weltweit, wird hier berichtet.

Développement d'un filtre magnétique à haute performance Nd-Fe-B pour la séparation d'impuretés métalliques

La plupart des procédés tels que broyage et mélangeage conduisent à une fréquente contamination en impuretés, ce qui a une influence marquée sur les processus ultérieurs et les propriétés des produits. En particulier, les impuretés métalliques sont fatales dans les céramiques. Par conséquent, de nombreux efforts ont été déployés pour réduire la contamination, en choisissant des outillages de broyage céramique et en employant des filtres magnétiques. Les aimants à haute magnétisation à base de terres rares (Sm-Co, Nd-Fe-B) sont employés pour la séparation d'impuretés de métaux magnétiques. La contamination est essentiellement due à Fe, Ni, ou Co, ainsi qu'aux éléments mobiles des équipements de broyage et des systèmes d'entraînement, des disques, etc. Un système à base d'aimants permanents est favorable car d'adaptation, d'emploi et de maintenance aisés.

Dans cette étude, on décrit un nouveau filtre magnétique qui a été développé à partir d'une conception d'aimant à haut flux. Le noyau magnétique multi-composant est construit au moyen de plusieurs anneaux magnétiques qui génèrent des champs magnétiques de haute intensité dans des anneaux intermédiaires en fer. Un aspect important est celui de la zone d'obtention et de concentration, où règne un gradient de champ le plus élevé possible, dans l'espace entre deux anneaux, là où circule le produit, sans faire obstacle aux hauts débits. Pour réaliser les essais, on a opéré avec différents produits qui avaient été contaminés avec des particules de fer bien définies, et ensuite filtrés puis étudiés par analyse chimique, diffraction laser, microscopie à balayage et microscopie optique. Ce système a rapidement été introduit dans l'industrie céramique européenne. On détaille ici les emplois et les améliorations observés chez Ivoclar Vivadent AG, qui est l'un des plus importants producteurs mondiaux de céramiques dentaires.

Desarrollo de un filtro magnético de Nd-Fe-B de alto rendimiento para la separación de impurezas metálicas

La mayoría de los procesos mecánicos como la molienda traen consigo una contaminación con impurezas que tienen una influencia significativa sobre los procesos subsiguientes y las propiedades del producto. En particular, las impurezas metálicas en materiales cerámicos son fatales. Por esta razón, se han realizado muchos intentos para reducir la contaminación, usando máquinas adecuadas y filtros magnéticos. Los imanes de tierras raras de alta intensidad (Sm-Co, Nd-Fe-B) son usados para la separación magnética. La contaminación es producida principalmente por Fe, Ni o Co provenientes de piezas móbiles de las instalaciones de molienda, los sistemas de transportes, las transmisiones, etc. Un sistema basado en imanes permanentes es preferible debido a la fácil adaptación, manipulación y mantenimiento. En este estudio, se describe un nuevo filtro magnético que ha sido desarrollado usando un novedoso diseño. Un núcleo magnético de varias componentes se construye usando varios anillos magnéticos que producen campos magnéticos con alta densidad de flujo en los anillos intermediarios de Fe. Un aspecto importante es la región de campo magnético de alta intensidad en los espacios entre dos anillos ,donde el producto pasa libremente a alto caudal. Para el ensayo, varios productos fueron contaminados con partículas de polvo de Fe definidas, filtrados e investigados por medio de análisis químico, difracción de laser, SEM y microscopía óptica. Este sistema ha sido introducido rápidamente en la industria cerámica en Europa. Se describen las aplicaciones y las mejoras obtenidas en la firma Ivoclar Vivadent AG, uno de los mayores productores de cerámica dental en el mundo.

Abstracts from our journals

Keramische Zeitschrift (in German)

Methodology and Procedures for the Planning and Construction of Production Plants in the Ceramics Industry, Part I
G. Zollfrank
Keramische Zeitschrift **55** (2003) [1] 4–8

In the present article and the subsequent papers, the author will present an integrated procedure of plant design according to the chronological planning process. Particular attention is paid to the numeric modelling of the industrial process in conjunction with a possible computer simulation. Another focus will be placed on logistic systems as the main cost-saving potential of the decade. The author will attempt to meet the data requirements of fixed employed project engineers as well as freelance/self-employed consultants in industrial engineering.

Direct Typing Process – A New Manufacturing Method for Cellular Components from SiC
J. Bauer
Keramische Zeitschrift **55** (2003) [1] 8–12

A new dimension has been added to the cellular structure of ceramic components from silicon carbide or other materials. Using the Direct-Typing-Process – a modified screen-printing method developed by the company Bauer RaD – it is possible to manufacture very thin wall thicknesses as well as new construction elements. Within a first prototype series of monolithic cellular honeycomb bodies from silicon carbide (SiC), a thin layer diaphragm of the same material is horizontally integrated in the middle of the monolithic body to achieve turbulent flow. The diameters of this diaphragm is 1/10 of the size of the channel diameter. By using this special production method, there arise no drying or sintering cracks although the material walls are combined at a right-angle orientation.

Flow Simulation of Plastic Ceramic Bodies, Part 2: Procedures and Processes for Numerical Simulation
W. Hoffmann
Keramische Zeitschrift **55** (2003) [1] 12–18

Most laws of nature and many engineering applications are formulated as partial differential equations. Most of these equations can only be solved by using numerical methods, therefore efficient numerical methods for solutions are required. A widespread and mostly for all purposes applicable tool is the so-called Finite Element Method (FEM). In this article, the basic principles of FEM are outlined based on a straightforward way of thinking and clear examples. In computational fluid dynamics, the Finite Volume Method (FVM) is used as an alternative to FEM. Both procedures are closely related and only a few features are different. As the principal construction of the two methods is identical, the principle is outlined in the context of the Finite Element Method. As it is not possible to discuss all the features of the method in detail within the scope of one article, the author therefore refers to the extensive technical literature and here illustrate the elegance and simplicity of the method.

A Concept for the Development of Piezoceramic Materials Based on Lead Zirconate Titanate (PZT), Part 2
G. Helke
Keramische Zeitschrift **54** (2002) [12] 1034–1037

Piezoelectric ceramics based on Lead Zirconate Titanate (PZT) show – within a relatively close Zr/Ti ratio range (close to the ratio 0.5/0.5) – extreme values for remanent polarization P_r and the dielectric coefficient $\epsilon_{33}{}^{T}/\epsilon_o$ as well as their corresponding piezoelectric coefficients. Remanent polarization P_r can be directly correlated to the structural parameter δ (spontaneous deformation) and the domain mobility η. PZT modification results from the substitution of isovalent or heterovalent ions under consideration. The substitution of specific ions is the process used to develop new piezoceramic materials which is mainly applied to determine the values of specific parameters corresponding to technical requirements.

Platiline® – Thermal-Sprayed Platinum Coating on Ceramic Components for Use in the Glass Industry
I. Rass, et al.
Keramische Zeitschrift **54** (2002) [12] 1042–1047

Ceramics coated with Platiline, show excellent thermo-chemical properties when immersed in molten glass. This coating prevents early corrosion and erosion of components subject to high temperatures in very aggressive environments. The service life of such coated ceramic components increase by a factor of 8–10. The paper presents the prerequisites for the production and some applications of these platinum coatings which are usually applied in the glass industry. Platiline, coatings prove to be a good economic and technical alternative to existing coating technologies, especially in the case of components with complex geometries.