Noncontacting displacement transducers locate and quantify defects on magnets

by Wolfgang Jentner and Werner W. Eißler

During their manufacture, ferrite magnets are subject to thermal and mechanical loads which sometimes cause surface chipping or breakage. In order to single out defective magnets, a thorough visual examination is generally carried out in connection with the packaging process. In the case presented, automation of the packaging process made it necessary to search for a technique for automatic defect detection and quantification which would match the necessary criteria for speed and reliability. This article introduces a technique for automatic examination of dish-shaped permanent magnets using noncontacting displacement transducers. Advantages of the system include easy construction and uncomplicated signal processing.

The production of permanent magnets has increased considerably in recent years both in traditional application areas (i.e. the construction of electric motors, loud speakers, etc.) as well as in industrial and consumer areas (brakes and clutches of small motors and all-purpose magnets of many different shapes and forms). During manufacture, ferrite magnets are subject to thermal and mechanical loads which sometimes lead to formal defects, cracks, chips, or even breakages. **Fig. 1** shows typical flaws for dish-shaped raw magnets. Because these types of flaws are unavoidable, visual examination is usually carried out before packaging so that defective magnets can be singled out and recycled. In the case studied, the examination procedure obstructed automation of the packing process, making it necessary to automate examination as well.

The following article introduces a general procedure for the automatic examination of dish-shaped, ferrite magnets. The technique is easily transferrable to other magnet shapes because of its easy construction, uncomplicated signal processing, and low cost, which allows an extraordinarily short amortization period. Manufacturing defects can reduce the operational safety of the final product, hinder installation, or detract from aesthetic appearance. Cracks, for example, represent a safety risk in applications with high dynamic loading, such as fast-running motors. The extensive breakage or chipping shown in **Fig. 1** may not only negatively influence magnetization, it may also cause difficulty in mounting. Local chipping is less a practical than an aesthetic problem which nevertheless bears directly on the magnet's saleability.

Defect identification and quantification

To develop an automatic examination system replacing the older visual method, a well-known manufacturer of permanent magnets contracted the Fraunhofer

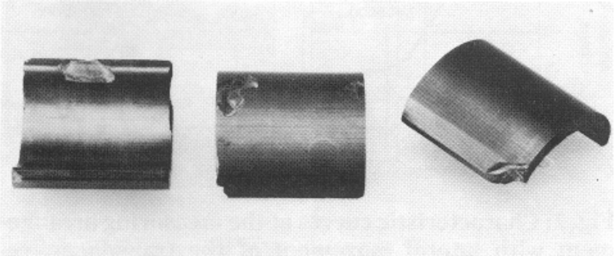

Fig. 1: Typical damage to dish-shaped permanent magnets caused by mechanical and thermal overloading

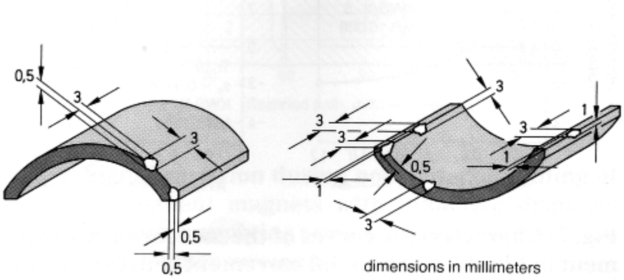

Fig. 2: Permissible defect dimensions for dish-shaped magnets with an average length of 45 mm (1.77 in.)

Institute for Production Technology, Stuttgart, West Germany, to carry out an experimental study to determine a suitable measuring method for defect detection. Two important criteria were system marketability quantification of defect dimensions.

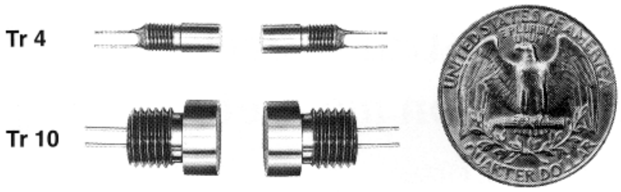

Fig. 3: Noncontacting inductive displacement transducers Tr 4 and Tr 10, which were applied in the detection of manufacturing defects on permanent magnets

For the study, defects were defined as chips and breaks, whose dimensions exceeded the quantities illustrated in **Fig. 2**. These dimensions apply to dishshaped magnets with an outside radius of 28 mm (1.1 in.) and a length of 45 mm (1.8 in.). For smaller dimensions, the critical defect quantities generally decrease. The results of the following study are based on these dimensions.

The requirement that magnets be examined within the flow of normal production represents an important criterion that each examination technique had to satisfy. Assuming a station time of about 1 s, the raw magnets had to pass through the defect-detection device with a speed of about 50 mm/s (2 in./s). Flow is usually uniform, however it is possible that the magnets are placed discontinuously into the defectdetection device by special manipulation instruments, so that examination can be performed intermittently.

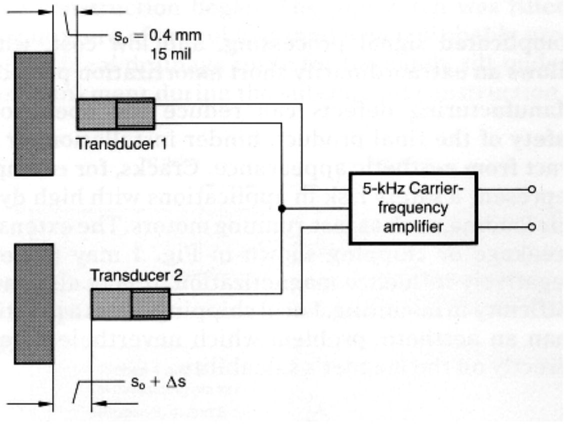

Fig. 4: Determination of the longitudinal sensitivity of the measuring arrangement with respect to the axial displacement of the transducer

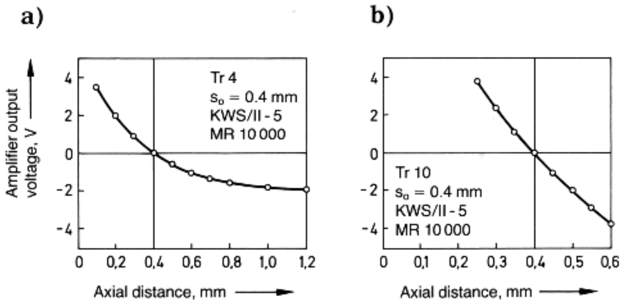

Fig. 5: Characteristic curves of the measuring arrangement in Fig. 4 with the axial movement of a transducer, recorded for sintered ferrite material

a) with transducer Tr4
b) with transducer Tr 10

Feasibility of noncontacting pickups

Theoretically, noncontacting displacement transducers operating on the inductive principle of measurement are ideally suited to the highly sensitive measurements necessary in quantifying defects in the ferrite material of raw magnets. This fact was also confirmed experimentally.

Fig. 3 shows the noncontacting displacement transducers (HBM Type Tr 4 and Tr 10) used in the study. These transducers are energized by a 5-kHz carrierfrequency measuring amplifier (HBM Type KWS/2-5) which supplies the voltage necessary for inductive measurement, completes the transducer half bridge internally to a full bridge, and amplifies the signal.

The sensitivity of the measuring system made up of transducer pair and measuring amplifier can be determined very easily with the aid of the setup shown in **Fig. 4**. This is done by maintaining a constant air gap s_O on transducer 1, changing the air gap of transducer 2 by a defined amount Δs, and plotting the relationship between the output voltage of the measuring amplifier and the air gap at transducer 2. The sensitivity is dependent on the size of the constant air gap s_o and

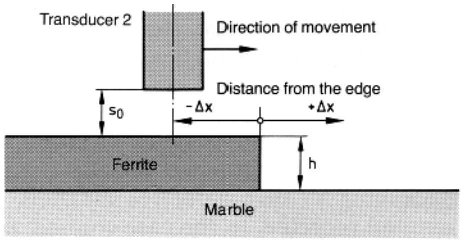

Fig. 6: Determination of the measuring sensitivity perpendicular to the axial direction with lateral transducer movement

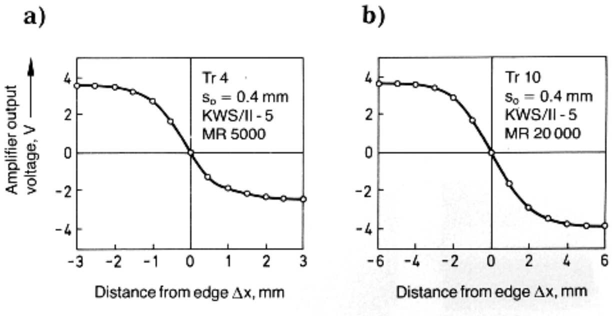

Fig. 7: Characteristic curves of the measuring arrangement with lateral movement of the transducer, recorded for sintered ferrite material

a) with transducer Tr 4
b) with transducer Tr 10

measuring range selected on the measuring amplifier. **Fig. 5** shows sensitivity curves for both transducers using a constant air gap s_O = 0.4 mm (15 mil) and a measuring range of 10,000. From the curves, one can infer an average sensitivity of 7 V/mm for transducer Tr 4 and 22 V/mm for transducer Tr10. In addition to greater sensitivity, the latter also shows better linearity and a more favorable measuring range.

To enable detection of small chips at the edges of a magnet, the transducer must also exhibit adequate sensitivity perpendicular to its axial direction. This ability was determined by observing variation in the output signal as the transducer passes over an edge, as illustrated in **Fig**. **6**. The results for both of the transducer pairs investigated are plotted in **Fig. 7**. The expected drop in signal strength takes place with the Tr 4 over a span of about 2 mm (78 mil), with the Tr 10 over a span of 4 mm (0.16 in.). The smaller transducer Tr 4 portrays the edge better than the larger Tr 10. From this, one must conclude that the Tr 4 is the more suitable transducer for detection of local chips or small surface breaks.

A number of considerations go into selecting the proper carrier frequency for inductive measurements of this type. This frequency should be chosen high enough to meet the minimum travelling speed of 50 mm/s (2 in./s) stipulated by the manufacturing process, yet no higher than necessary. A relatively simple calculation was used to determine whether a carrier frequency of 5 kHz was sufficient for the proposed system. **Fig. 7** shows that the transducer Tr 4 tends to distort the edge as it passes by, making it appear almost 2 mm (78 mil) wide. This distortion is a result of the 4-mm (0.16-in.) diameter of the transducer. At a lateral speed of 50 mm/s (2 in./s), the edge requires 80 ms to pass under the transducer. This corresponds to 400 cycles when applying a carrier frequency of 5 kHz. Thus, the edge moves about 10 um per cycle and the signal voltage drops about 15 mV. Since the signal change per cycle amounts to 0.25 % of the total change, it can be concluded that 5-kHz carrier frequency is in this case sufficient.

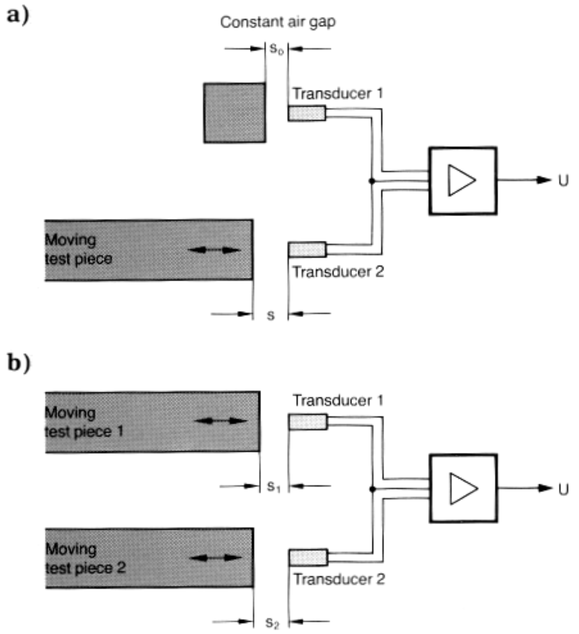

Fig. 8: Illustration of possible measuring techniques

a) Absolute measurement with fixed reference value
b) Differential measurement of both signals

Differential measurement proves best

Inductive displacement transducers are usually wired in pairs to form a half bridge, and completed to a full bridge in the amplifier where they can be balanced according to magnitude and phase. The amplifier also serves in supplying excitation voltage to the transducers as well as demodulating the amplified signal for output.

The paired method of inductive displacement measurement allows two measuring techniques: differential and absolute. In differential measurement, both transducers are applied actively and signals are subtracted to obtain a relative measurement. Absolute measurement is performed by holding the measured variable of one transducer constant while measuring with the other. **Fig. 8** illustrates absolute measurement and differential measurement.

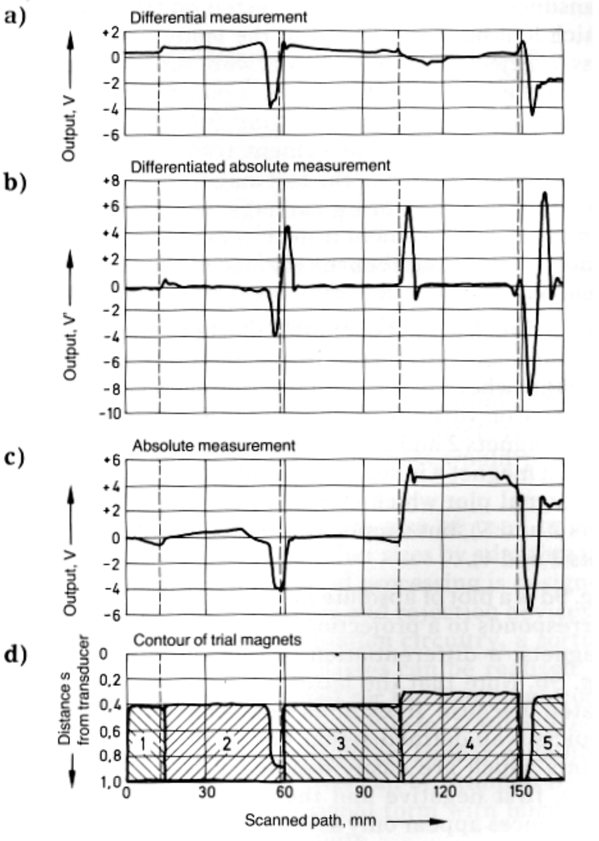

Fig. 9: Signal variation during noncontact scanning of ferrite permanent magnets with inductive displacement transducer applying various evaluation methods:

a) Differential measurement
b) Differentiated absolute measurement
c) Absolute measurement
d) Contour of the trial magnets

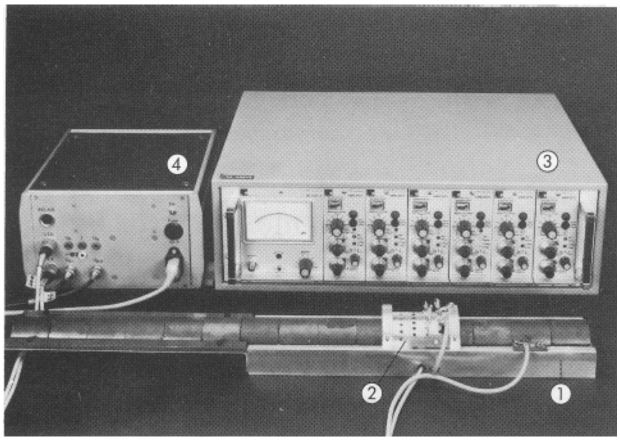

Fig. 10: Laboratory version of defect-detection device

① Prism-shaped guide rail for the trial magnets
② Testing head with noncontacting transducer
③ Six-channel carrier-frequency measuring amplifier
④ Evaluation electronics

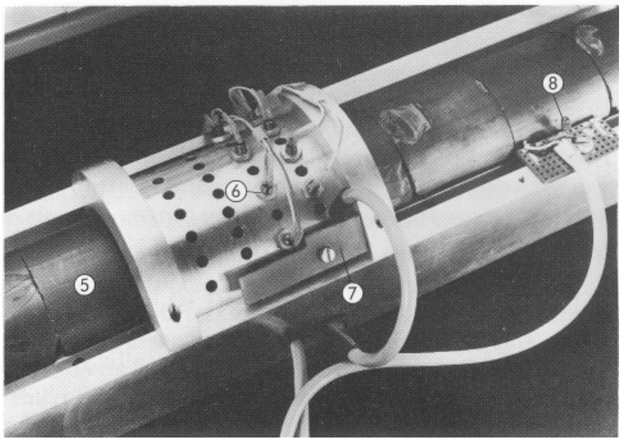

Fig. 11: Testing head with displacement transducers

⑤ Trial magnet
⑥ Inductive displacement transducer
⑦ Light barrier for electronic separation of magnets
⑧ Luminous diode for defect indication

To determine which technique was best suited for this task as well as how measuring signals should best be processed and evaluated to avoid unambiguous results, several pairs of commercial-size displacement transducer of type Tr 4 were tested on trial magnets, which had been sorted out of the manufacturing process as rejects. The transducers were then permanently installed, once both parts of a pair for differential measurement, and another time for absolute measurement only one displacement transducer opposite from the convex side of the test magnets. Resting on an airsuspended measuring carriage, the magnets were run by the displacement transducers so that a scanning zone parallel to the convex surface of the magnet was created.

Fig. 9 illustrates the results of these experiments. Measurements are taken in the axial direction of the magnets whereby the ordinate is greatly expanded in comparison with the abscissa. In the observed profile, only magnets 2 and 5 are flawed, the additional height of trial magnet 4 is not considered defective. Desirable is a signal plot which clearly identifies defects (magnets 2 and 5), but suppresses height differences (magnets 3 and 4).

Fig. 9d is a plot of absolute displacement and therefore corresponds to a projection of the contour of the trial magnets; a differentiation of this curve is shown in Fig. 9b. Note that the latter can be more easily evaluated because it exhibits constant zero level and depicts well-defined signal deflections at the defect points which are easily distinguishable from deflections, first negative and then positive, while height differences appear only as a single deflection. The one disadvantage of this otherwise amazingly effective technique lies in the fact that the dimensions of the defect are not quantifiable. The signal plot only allows testimony as to the "roughness" of the chips or breaks, but no information about their depth.

A signal plot taken during differential measurement is shown in Fig. 9a. Although it identifies defects distinctly and suppresses height differences, this technique is only reliable if the transducer pair sits rigidly tangentially beside each other, i.e. on the same axial coordinate. The advantage of this technique is that the amplitude of the measuring signals is an approximate measure of the vertical dimension of the defect. For this reason, differential measurement with inductive displacement transducers of type Tr 4 was chosen for the prototype defect-detection device.

Construction of defect-detection device

Fig. 10 shows the laboratory model of the defectdetection device. It consists of a prism-shaped guide rail ①, a dish-shaped testing head ② corresponding to the convex magnet with the inductive transducers which belong to it, a six-channel carrier-frequency amplifier ③, and an electronic evaluation circuit ④. In an actual manufacturing process, the test magnets are pushed under the testing head; for the laboratory trials, a simple auxiliary motor was enough for movement of the trial magnet. In order to keep the expenditure of time and money within reason, the system was designed only to examine the convex upper side of the magnets.

The trial magnets glide on their concave side along the two lines on the prism-shaped guide rail. In this way, only the comparably confined tolerance thickness affects the measuring signal, but not the strongly varying height of the trial magnets. As **Fig. 11** shows, all of the transducers are oriented perpendicular to the magnet surface at a distance of 6 mm (0.24 in.) from each other in two rows 30 mm (1.18 in.) apart. The transducers of both rows are staggered so that their scanning surfaces overlap as each magnet run under the testing head.

Orientation of the transducers is illustrated in **Fig. 12. Fig. 12a** shows the overlapping of the scanning surfaces and **Fig. 12b** shows how transducers inside a row are connected.

In the interest of increased operating reliability, the two rows are separated: Transducers inside of each row are connected serially, however the resulting branches are connected parallely. Because of the symmetry of this arrangement, opposing influences of the transducers are eliminated. Thus, side and height differences between the magnets cause only small signal changes.

Evaluation electronics and results

Between the absolute and differential measuring technique, the latter was favored because of its higher defect sensitivity and the suppression of undesirable geometrical influences. **Fig. 13** clearly highlights the differences between both circuit types.

Since the transducers are arranged in two rows, operating reliability is increased by providing autonomous signal processing for each channel. Only for the defect display or marking are both channels tied together. By staggering transducer ros, the possibility that simultaneously occurring single defects compensate each other in their amplitude is largely prevented.

The signals of the half-bridge wired row of transducers are amplified and compared with the positive threshold voltage U_p or the negative threshold voltage U_p. Here $|U_p|=|U_n|$ was set; in addition a hysteresis behavior was necessary. If during the examination process a signal is produced by a transducer row which exceeds threshold voltages U_p or U_n, the next "bad" storage is set. After the trial magnet passes by, the built-in light barrier supplies a timing signal whereby the stored information is transferred to a multistage recording device. Immediately after acceptance of the storage contents by the recording device, memory is erased by a delayed impulse and stands ready for information storage from the following trial magnet.

The signals of the second transducer row are processed in the second measuring channel. Depending on the position of a defect, it will be detected by either the first channel, second channel, or both channels one after the another. The outputs of the recording device are available as potential-free contacts depending on the switching amplifiers. The OR connection of both channels takes place via these contacts. In the laboratory version, a defective magnet was indicated by an alarm lamp, however the defect signals are provided for the control of marking devices or rejection stations. Applied here were integrated switching networks of the CMOS family as well as standard operational amplifiers.

During trial operation, a number of defective and non-defective magnets were led through the defect-detection device. During this trial, not a single defect above the critical range was left undiscovered. Even chips of smaller depth were occasionally detected. Reason for this occurrence was a safety range built into the defect boundary values to allow for variable dimensions in the unfinished magnets. Without this safety range, defective magnets of smaller thickness would possibly not be recongnized as defective.

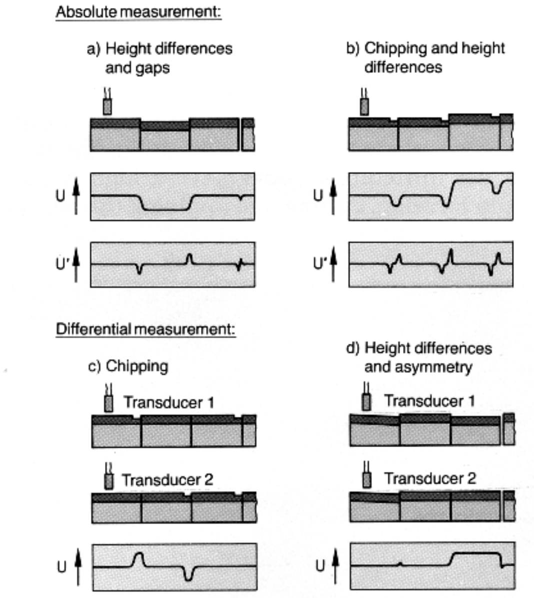

Fig. 13: Characteristic signal variation while passing over trial magnets with differently connected noncontacting inductive displacement transducers

The defect-detection device can also be used to examine ferrite components of other sizes by adapting the testing head. Electronic signal processing is designed so that connection of marking and rejection devices is possible. By modifying evaluation circuitry, a sorting device for several quality classes can be realized. In addition to the output signals for the handling procedure, defect information is available for statistical evaluation in an interfaced computer. Higher reliability or detection of smaller defects can be attained by additional evaluation of the signal form with microprocessor-based evaluation circuits.

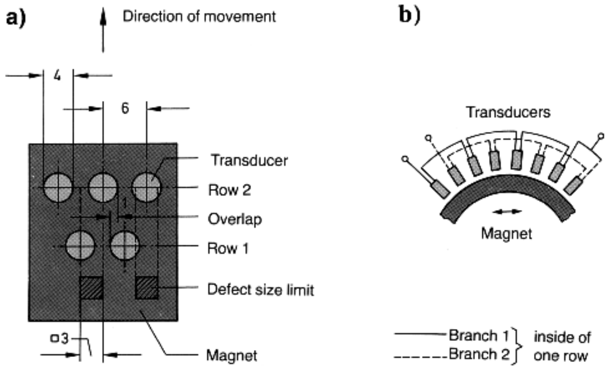

Fig. 12: Arrangement and connection of transducer

Dr.-Ing. Wolfgang Jentner and Werner E. Eißler carried out the described investigations at the Fraunhofer Institut, Stuttgart, West Germany.