

An On-Line Grain Size Measuring System for Grain-Oriented Steels

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It is important to monitor grain-oriented steel during production so that regions of small, loss-inducing grains can be detected. These are a rare occurrence, but need to be eliminated to prevent a stripe of small grains from passing unnoticed. On-line full-strip-width power loss measurements may overlook stripes of small grains. A system for detecting small grains is described.

1 Introduction

GRAIN-ORIENTED electrotechnical steel is used for the cores of transformers, primarily those used in the electricity supply industry. Such steels are graded in terms of power loss, usually at 50 or 60 Hz and 1.5 or 1.7 Tesla peak induction. Samples are taken for grading, and these are cut up and graded by the Epstein frame method. Additionally, an on-line power loss tester is used to monitor power loss during the final processing of strip. The combination of spot Epstein tests at the end of coils and an along-the-length impression of loss provides good protection against any high-loss material escaping attention.

However, because the on-line test magnetizes the entire strip width (on the order of 1 m) and bases attained induction and power loss on an average value for the complete sheet width, any defect that gives rise to a high-loss area in a narrow region of the strip can be overlooked when included in an average value.

Frequently, the full width strip is slit into narrow subcoils, maybe as small as 100 mm wide, and if a linear high-loss region occurs within such a slit, it can have a much bigger impact than it would on the average performance of wide strip. Figure 1 shows an undesirable stripe of small grains.

The chemical and metallurgical reasons for streaks of high-loss metal are well known and are guarded against. However, in the interest of quality protection, it has been commonplace to cut out across-the-strip-width samples and etch these so that the grain pattern is easily visible. This process is time consuming and expensive and does not, of course, examine the whole length of a coil of steel.

The means for automating the assessment of steel for small grain streaks will be described in this article.

2 Domain Viewers

Domain viewers developed by British Steel at Orb Works Newport[1] have enabled the domain structure of steel to be observed without removing the tensile insulative coating on the steel. This is particularly important because removal of the coating so that magneto-optic viewing is possible destroys the magnetic integrity of the substrate steel when the coating tension is released. The image seen in such a viewer is shown in Fig. 2. The action of the particles of magnetic material that move within the viewer is shown in Fig. 3.

Magnetic particles raining out of a suspension medium gather at the leakage fields that arise at domain walls so that the wall sites are delineated. The application of a weak magnetic field normal to the sheet surface interacts with that component of the in-sheet-plane magnetization that tilts out of the surface. Such a component always exists, because the orientation of any grain is not completely perfect. The normal field thus enhances

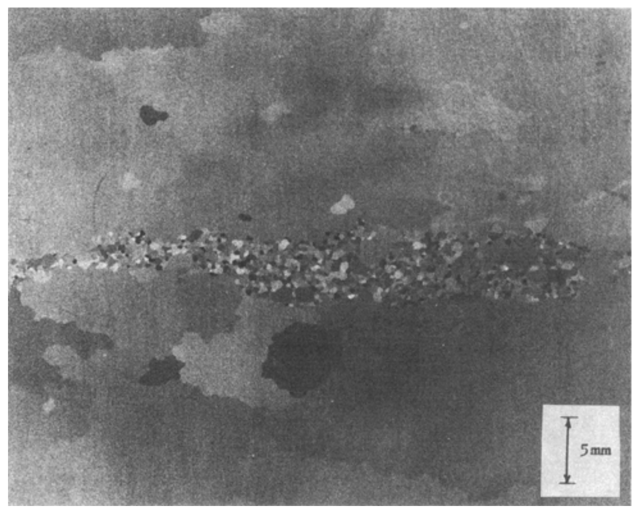

Fig. 1 Streak of fine grains in grain-oriented steel.

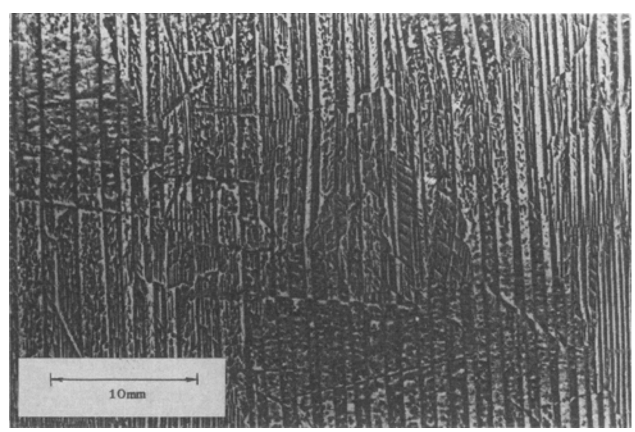

Fig. 2 Typical domain pattern revealed by domain viewer.

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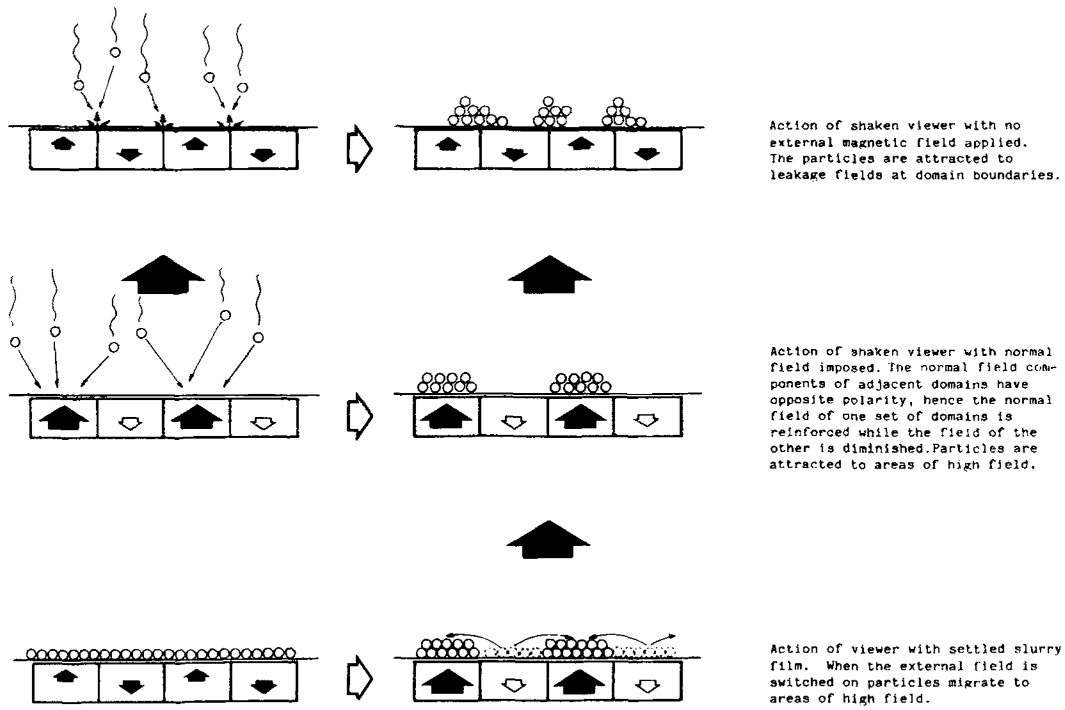

Fig. 3 Principle of domain viewer operation.

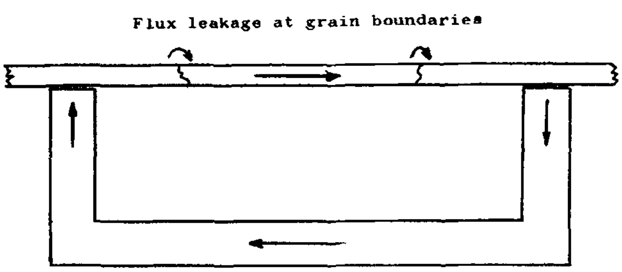

Fig. 4 Magnetization of sample.

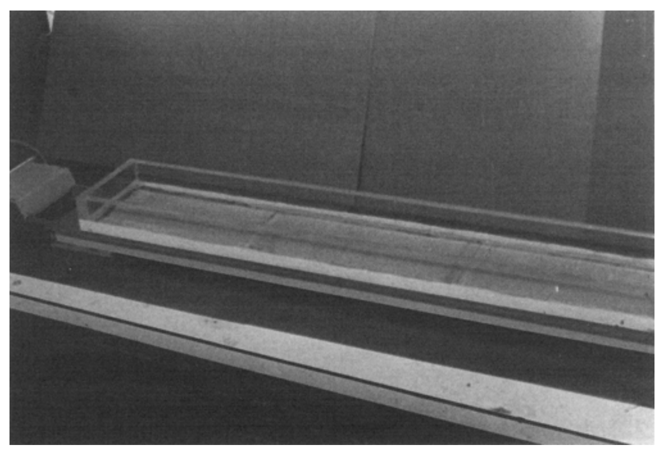

Fig. 5 Trough viewer (1 m long).

the attraction of falling particles toward one domain surface (rather than wall) and detracts from its antiparallel neighbor. In this way, the domains are visible in area contrast, which is much clearer than domain boundary contrast alone.

It has long been evident from the domain pictures formed by such viewers that the area of whole grains can be inferred by examination of changes in the angles of domain walls as a grain boundary is crossed.

3 Grain Boundary Viewers

It was thought that a grain boundary, being a major metallurgical and magnetic discontinuity, should have associated with it a sizable leakage field when the metal was magnetized. Such has proved to be the case, but only when the magnetizing field is applied parallel to the easy direction of magnetization of strip (rolling direction). When magnetized in this way, the leakage that occurs due to the increased reluctance at a grain boundary attracts the magnetic particles in a viewer very strongly. Figure 4 shows the scheme of magnetizing, and Fig. 5 shows a tank viewer that is long enough to examine the full width of 1-m

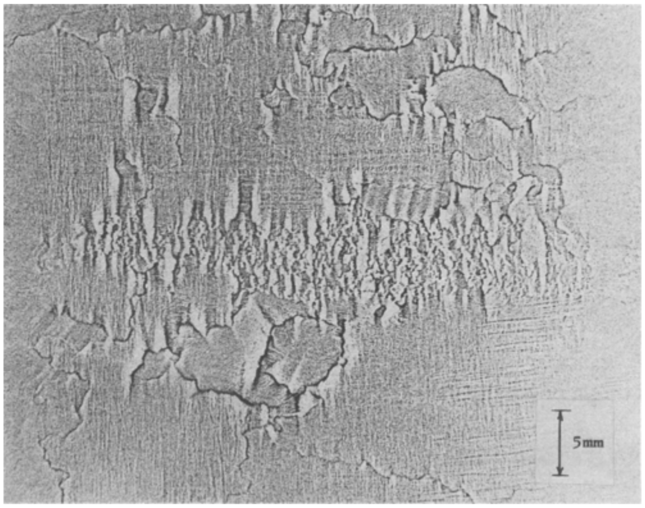

Fig. 6 Small grains revealed by grain size viewer.

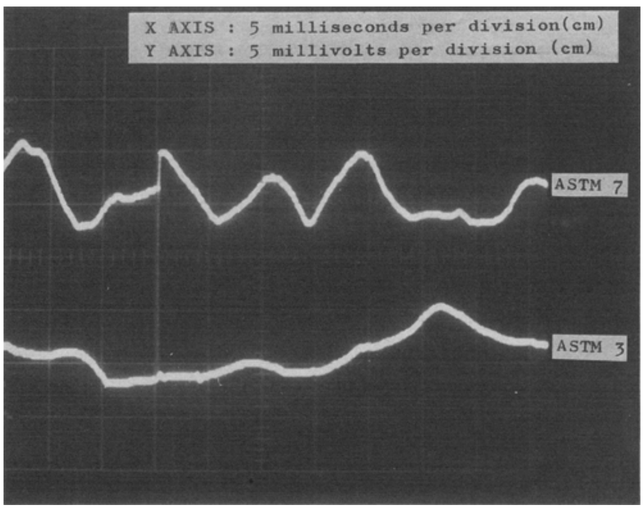

Fig. 8 Oscillograph traces of grain-oriented samples.

wide strip when placed on it. The magnetization system lies below the strip.

Such viewers enable stripes of small grains to be readily observed without the removal of the insulative coating. Figure 6 shows the same grains as that of Fig. 1, but the grains are revealed in terms of grain boundary leakage field. The difference is that no sample preparation has been required so that the process of decoating, etching, drying, and direct observation is avoided.

However, although such a system speeds up the examination of full-width samples taken from coils, it again only views discrete regions.

4 Dynamic Systems

It was found that the leakage fields associated with the grain boundary reluctance that are used in a grain size viewer can be

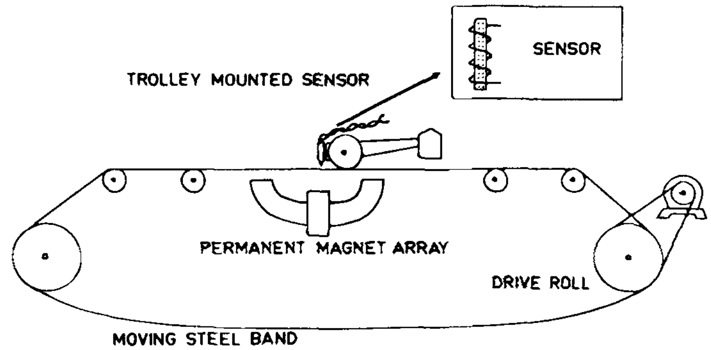

Fig. 7 Principle of small grain detector.

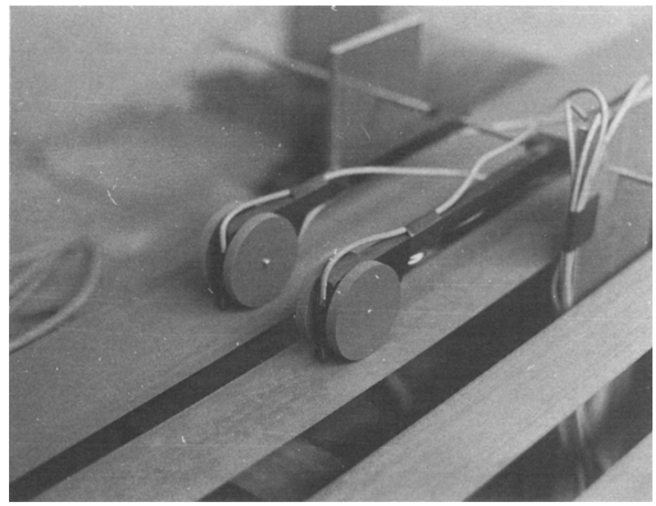

Fig. 9 Pair of grain size detectors on trolleys.

detected dynamically on moving strip in a production line. To do this, a pick-up is placed above the strip approximately 1 mm from the surface. The choice of 1 mm is a useful compromise between the reduced sensitivity that arises from a wider spacing and the engineering difficulty of maintaining a probe in good order at very close spacings.

Much experimentation was applied to probe design so that sensitivity and robustness could be optimized. Eventually, a suitable combination proved to consist of a whisker of silicon steel some 20 mm long and of a section size of 0.3 by 1 mm. Such a whisker surrounded by a coil of several thousand turns made a satisfactory sensor. Figure 7 shows the arrangement of a laboratory model.

An endless band of steel is used for test purposes. The strip is magnetized by passing it over a permanent magnet, and the leakage fields are detected by the sensor, which is carried on a hinged trolley. The trolley is hinged so that it is simply pushed upward out of the way without damage if a steel defect or weld should appear.

By use of numerous sensors across a strip width, a continuous, complete assessment of the material passing through a production line can be obtained. Although a permanent magnet is satisfactory for magnetization if desired, a one-sided electric magnetizer located below the strip can be used, based on the current sheet technique used by Beckley and Lodge in some varieties of on-line steel defect detectors.[2]

Assuming that the production line runs at an approximately constant speed, the sensor is cut by leakage fields from small grains at a higher frequency than by leakage fields for larger grains. In this way, spectral analysis of the signals from the array of sensors will give continuous protection against the presence of small grains. Figure 8 compares oscilloscopic traces from small grained steel (top) with normal grains (bottom). Figure 9 shows a pair of laboratory test trolleys, comparing strip of different properties.

At normal line speeds on the order of 50 to 100 m/min, the signals of interest lie in the 50-1000 Hz band. It might be supposed that, because this region could be readily monitored by the human ear, it would be sufficient to relay an amplified signal via a loudspeaker to line operators. However, when several detectors are in use simultaneously across a strip width, it is better to rely on computer spectral analysis and matching with standard patterns (which can also be related to line speed). Operator fatigue is thus not a consideration.

5 Conclusion

By applying some of the principles used in portable domain viewers, and by application of a longitudinal rather than a vertical enhancing field, the grain size passing through a production line can be monitored and warning given of any adverse deviation from a desired pattern. By suitable adaptation, a grain size monitor can be incorporated into the physical structure and computer control system of an on-line loss-measuring device.

References

1. R. Taylor, "A Large Area Domain Viewer," Proceedings of SMM9 Conference, El Escorial, Spain, Sep (1989).
2. P. Beckley and J. Lodge, A Magnetization System for a Thin Steel Flaw Detector, *B.R.J. NDT*, 19-20, Jan (1977).