PRODUCTION OF THE FIELD OF A DEFECT BY MAGNETIZATION
BY THE MOVING FIELD OF A LOCALIZED SOURCE

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Results are given on the origin and structure of the field due to a transverse crack when the specimen is magnetized by the longitudinal moving field of a localized source. The causes of the field are deduced from oscillograms of the magnetization of parts near the faces of a natural crack in a rail at speeds up to 25 km/hr. The results may be used to evaluate proposed modifications to the probes of high-speed flaw detectors.

§1. INTRODUCTION

Detectability in high-speed magnetic flaw testing is governed by the production and structure of the field of a defect; the latter features determine the choice of parameters (magnetization, speed, pulse separation, etc.). Much attention has been given [1–5] to the detection of defects by the field of a moving electromagnet.

Highly conflicting interpretations have been given [1–3] for the mechanism of detection of cracks transverse to the field; the best interpretation appears to be that of [3], which is based on recordings of pulse shapes. It might at first sight seem easy to interpret the pulse shape if the defect field is represented as the superposition of the polarization field of the defect and the field that would be observed at the defect with currents flowing around it [2, 5]. This approach has been used to deduce that there is a critical velocity and that conditions must provide for strong unipolar currents to be induced in the rail. This description of the mechanism is open to doubt for the simple reason that the deduction as to a critical velocity is not supported by experience in high-speed flaw detection. Sometimes defects remain undetected even when the tester moves at speeds well above the critical value [2].

The induction near the defect was measured in order to determine the mechanism. The results show a definite time dependence for the production of the field around the crack, which is due to nonlinear magnetization reversal in the region of the defect.

§2. METHODS

The pulse shape indicates that the field of a transverse crack is unsymmetrical about the plane of the crack when the coil is moving. The distortion is particularly prominent for cracks near the surface scanned by the magnet. This asymmetry is related to unequal magnetization, and here it is useful to distinguish types of region near cracks in relation to the direction of motion. Region I is that reached before the crack by the magnet, while region II follows after the crack. The differential change in magnetization in these regions may be evaluated experimentally, provided that the conditions allow us to elucidate magnetic and current effects. For this reason the tests were conducted as follows.

Use was made of the laboratory system described in [6] with the magnet moving at up to 25 km/hr, the specimens being pieces of rail with square-cut ends of lengths 1.2 and 1 m taken from a single rail previously run in to form a rounded bearing surface. The 1.2 m piece had a natural defect, a transverse fatigue crack emerging on the side face and partly on the bearing surface.

The tests were begun with measurements on the gap formed by placing the two pieces end to end, since here no currents flow around the defect. The gap was gradually reduced until the ends were firmly in contact, which may be considered as a model for a transverse fracture. The induction was measured by the inductive coil method [7], which gives oscillograms of the magnetization change in the part of the specimen covered by the measuring coil. For this purpose two holes (diameter 1.5 mm) were drilled in the piece having the defect, to take the turns of the measuring coil. One hole was near the square-cut end, while the other was near the defect, these holes being parallel to the corresponding planes and separated from them by walls of 1 mm (Fig. 1). The hole near the defect had a depth of 20 mm, the length of the crack as seen on the bearing surface. This specimen allowed measurements to be made with the holes in regions I and II, in accordance with the direction of motion. The oscillograms from regions I and II of joint and defect made it easy to examine the mode of formation of the field.

§3. RESULTS AND DISCUSSION

This is best begun with the butt joints, since the curves for the defect regions are more readily interpreted. Figures 2–4 show magnetization curves for gaps of 12 mm, 3.5 mm, and nominally zero used at speeds of 3, 10, and 21 km/hr; curve I relates to the magnetization in region I, and curve II relates to region II, with appropriate sense of motion. The envelope of the sine wave characterizes the induction change near the coil [7]. These curves are best read as though the joint were moving in the direction of the arrow (Figs. 2–4) under a fixed electromagnet, whose position is indicated by the section of straight line.

Figures 2–4 show that the joint gives a rather com-
plicated pattern, which is determined by electric and magnetic effects. The zone of low magnetization (ZLM) occurs at end II as it emerges from under the first pole; this is a consequence of the differential spin reversal in the regions of spontaneous magnetization [8].

The behavior in the section between the front and rear poles is of interest. Curves I and II of Figs. 2–4 show that ends I and II are magnetized differently; end I is magnetized more strongly than end II at a given speed. This differential behavior in the field of a horseshoe magnet is due mainly to magnetic processes as is easily understood in terms of the production of a permanent magnet by induction from a moving magnet pole. The magnetization of end I (where the probe coil lies) as it leaves the first pole does not involve a change of polarity, whereas such a change is involved when end II leaves this pole. This polarity change for end II involves magnetization reversal along the hysteresis loop in the region of the coil. Curves II of Figs. 2–4 the instant of polarity reversal by an appreciable reduction in the magnetization (part PR); they show that this reversal starts after end II has left the first pole, with a slow rise in magnetization as end II approaches the second pole. The ends as they emerge from under the first pole are magnetized as single poles and produce a divergent flux, which from magnetization reversal of end II is transformed to a longitudinal flux (leakage flux).

Curves I and II of Figs. 2–4 also show that the magnetization of ends I and II on moving from the first pole to the second is dependent on the velocity; the magnetization of end I increases with the speed, whereas that of II is reduced. This difference is larger when the gap is small and when the speed is high. The reason is that the effective magnetic conductance of the gap varies with the speed, the tendency of the poles to act separately [8] also increasing with the speed. Increase in the magnetization of end I as it approaches the second pole facilitates the conforming polarization of end I produced by the first pole, while the reduction in magnetization of end II is related to the kinetics of magnetization reversal, this being dependent on interaction between the faces of the gap and the poles of the electromagnet.

Figure 5 shows oscillograms recorded for the defect of Fig. 1 at speeds of 3–4, 9, and 20 km/hr; here again I refers to region I and II to region II. Here the trends are also fairly clear. Motion of the crack from the first pole to the second causes the magnetization in the two regions to behave as for the gap; hence the field is produced by conversion of the initial divergent flux to a longitudinal leakage flux, on account of reversal in the region behind the defect (region II). The difference in magnetization between regions I and II increases with the speed, as for the gap; the structure and strength of the field are related to the speed, but the increase in the field with the speed is restricted.

The above concerns the field of a transverse crack emerging on the head, but it would seem that a similar effect from reversal at end II should occur for a crack at a certain depth below the surface. Even cracks lying comparatively far from the poles may be observed in the longitudinal leakage flux due to polarization of the crack walls. Hence the formation and structure of