An In-line Automatic Billet Magnetic Particle Inspection System

A Paper By

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Table of Contents

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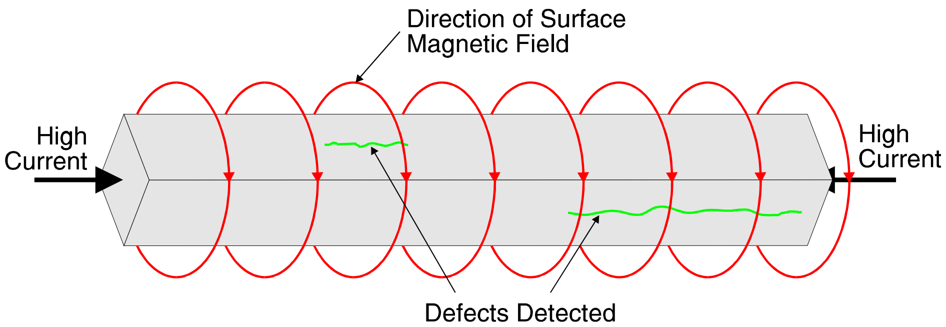
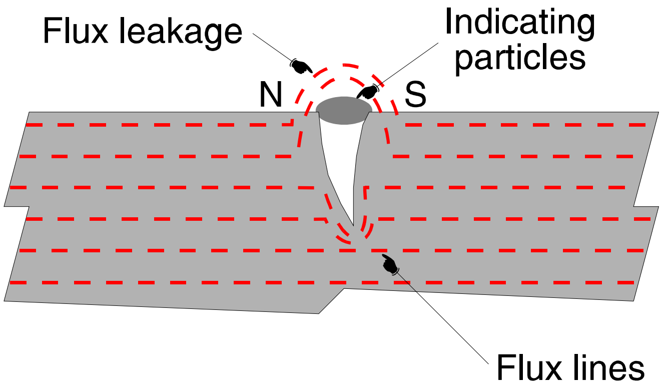
1 Background

Magnetic Particle Inspection (MPI) of Hot Rolled Billets is a long established technique for the detection of surface breaking longitudinal cracks as part of the mill production routine quality control process. MPI aids in the grading of steel products, and provides an indication of the severity of the defects detected, which are normally a result of the rolling process.

The common method of applying the MPI test is to pass high amperage current along the length of the billet in order to induce a circular magnetic flux into the billet. As these billets, typically up to 40” long, this becomes quite a chore. As high amperage current is being passed through the billet, fluorescent encapsulated ferro-magnetic particles in a treated water suspension is applied to the billet.



These magnetic particles will migrate through the liquid to the attractive magnetic fields (North and South) produced at the edges of any surface breaking cracks where the magnetic flux leaks into the air.



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The fluorescent encapsulation is used on the particles to create a higher contrast between the background of the billet and the cracks indications which are exposed by MPI. Ultraviolet lighting is used to excite the fluorescent dye on the particles, which further enhances the visual contrast of crack indication against the background. This increased contrast allows the inspector to visually identify any cracks present without very close examination of the billet surface. The inspection is carried out in a darkened viewing area, which in the case of Inland Steel, was a 50' long structure sealed to inhibit daylight. The inspectors would walk alongside the billet length, marking any indications of cracks which were located.

This system, which has been used in many steel mills for several decades, was considered to be state-of-the-art technology in its time. While this system has been effective in most cases, it suffers from several drawbacks, not the least of these being the maintenance costs necessary to keep it operational. It is estimated that the MPI area at Inland Steel required maintenance, on an annual base, which exceeded the cost of replacing the complete system. The maintenance cost was actually far more than this when mill downtime is factored into the equation. It was for this reason, the cost of maintenance, that Inland Steel investigated an improved modern method of inspecting their billets. In addition to these costs, there were several other drawbacks to the existing system. These include:

- For the range of lengths of billets normally tested, exceedingly high output currents from the power pack are necessary, typically 10,000 amps FWDC (Full Wave rectified Direct Current). The resistive load of the billet together with the long leads of cables that carry the current to the billet ends from the power pack would reduce the magnetising current to only 2,000 amps at the billet ends. The fact that FWDC was utilised also made demagnetisation impossible at the inspection area, since no demagnetisation circuit was integral to the system. Because FWDC was used to induce the magnetic field, an AC (Alternating Current) coil, because of the 'skin effect', would be ineffective in demagnetising below the surface of the billet.
- The high current is passed into the billet ends by means of copper contact pads connected to the power pack cables. It is essential that these contact pads be in very firm contact with the billet ends in order not to further decrease the current available. Billet ends are sheared, which presents very rough surfaces with which the pads had to make contact. It is necessary to clamp these pads to the billet ends using pneumatic cylinders or hydraulic cylinders to make this contact point as good as possible. This results in considerable wear on the pads, which require frequent replacement. Occasional complete lack of contact results in a invalid test, not necessarily always noticed by the operators.

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- Since the billets are not of identical lengths, it is necessary that both the pads are moved longitudinally to meet the billet ends. The billets are loaded transversely onto the magnetising station, an action that requires additional material handling equipment to raise the billet to the level of the contact pads. With billet weight of several tons, this material handling equipment is also very costly to maintain.
- The inspection area must be as long as the longest billet. This makes it necessary for two inspectors to view the billet by walking the length of the billet marking any cracks located. The inspectors also need to rotate the billet to view the three other billet surfaces. The rotating of the billet not only creates much wear on the system, but it also creates the potential to obliterate indications which are formed on the underside – initially - of the billet. Yet another drawback is that the system, because of its length required 30-35 400 watt UV lamps to illuminate the entire billet length. The number of lamps is not only a capital expense, but the simple replacement of bulbs becomes costly and time-consuming effort.
- The floor space required in the mill for this system is significant; the old MPI system and its necessary material handling equipment occupy approximately ½ of the bay width. It also is a “bottleneck” in the mill as the billet is loaded transversely into the machine, raised, magnetised, raised, inspected, rotated through 90^0 three times, marked, then lowered, ejected and driven away on “vee” rolls, the opposite direction to which it was fed.

2 The Yoke Method

An alternative method was introduced by Insight NDT in 1994. This method was installed in Inland Steel mill in summer 1998 following the technical report issued in 1995 explaining the yoke method for the MPI of steel billets:

In the yoke system only a short length of billet is magnetised circumferentially and inked progressively whilst the billet moves axially through the system. With the special viewing arrangements adjacent to the magnetising station, it is thus not necessary to stop the billet for inspection purposes. The yoke induces transverse flux in square billets, two yokes, in the format shown below, are necessary.

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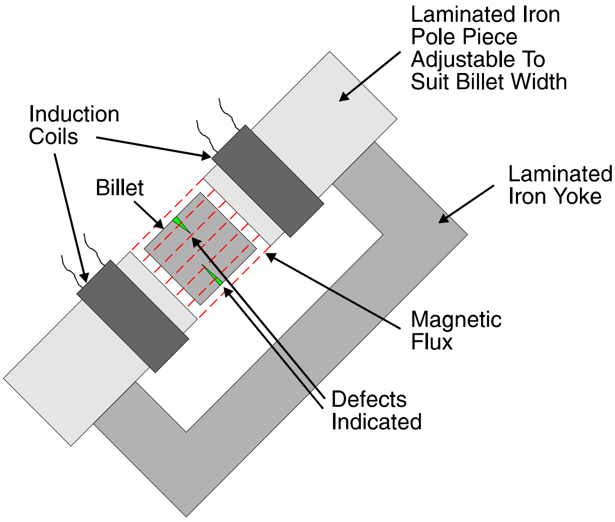
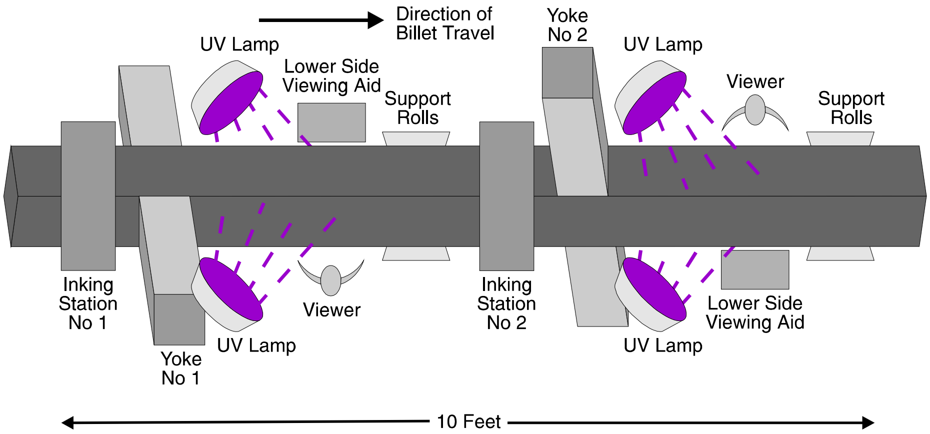


Each yoke magnetises two opposite faces by generating AC flux between the pole piece ends. AC flux with its attendant skin effect will traverse the two opposite sides creating a transverse magnetic field in the required direction. Indicating fluid applied immediately before each yoke will allow particles to move through the fluid layer to the defect edges during the magnetising phase.



Manual Viewing

Immediately after each magnetising position is a viewing station. The viewing can take either of two forms. Each of the two viewing stations can have a man to view the upper surface and, with the aid of a specially designed mirror system, the lower surface.

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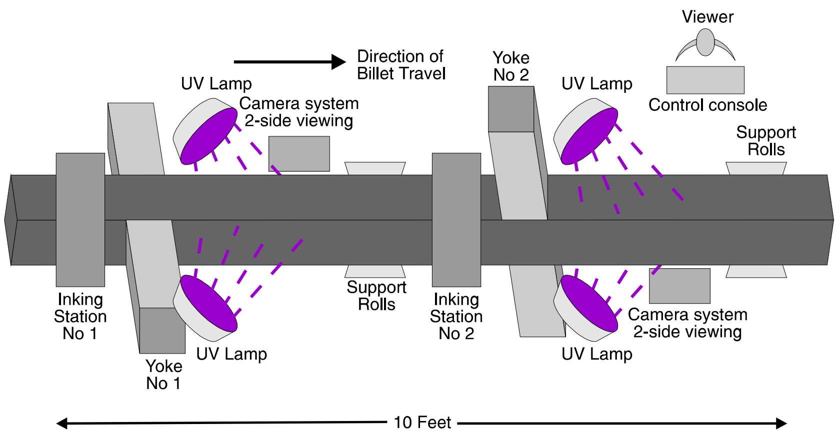

Camera Aided Viewing

A much more simple and reliable viewing system is the use of low light level, spectrum filtered CCTV cameras, one for each surface with outputs to a single four-way split screen monitor to be viewed in an operator's booth. The operator would be provided with a remote operated marking device to mark defects appropriately.

Since the yokes are operating continuously with AC, as the billet moves from the yokes it is subjected to a reducing AC reversing polarity field and therefore is automatically demagnetised.

The advantages of the yoke system are:

- Non contact and therefore no wearing parts.
- Billet length not significant.
- Lower capital and running costs through lower electrical current requirements.
- Lower manpower requirement.
- Faster throughput with continuous operation, approximately 1 second per foot for the complete test.
- Economical on floor space requirement.
- Complete control from booth for better operator working conditions.
- High sensitivity with programmable magnetising values for different billet widths.
- MPI is an in-line operation which does not slow mill production.
- Maintenance costs virtually eliminated.

3 Inland Steel Installation

The final installation at Inland Steel Bar Company was completed in June of 1998. The actual system installed comprised of the following stations and equipments:

- Pre-wetting station to completely wet billet for ease of particle migration and to remove loose scale and shot dust from billet. Under pre-wetting station is a recirculating water tank with filter and dragout conveyor system to remove large scale and debris.

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- Ultrasonic inspection station. The ultrasonic inspection station will be utilised to detect transverse, corner breaking defects. The benefit will be a higher confidence in detecting these defects and further, doing so without the operator needing to mark such cracks as well as the longitudinal cracks on the faces of the billet. The ultrasonic system will be computer controlled and will comprise an integral defect marking system to mark corners with cracks for their removal in the grinding process.
- Magnetic particle inking station. This station applies the magnetic particle suspension to the wetted billet. The placement of this station is immediately before the magnetising yokes to allow the particles to migrate to the crack edges while in the magnetising field. The inking station uses two recirculating ink tanks with similar filtration to the pre-wetting station. The recirculating station also includes tank heaters in winter conditions to prevent freezing of the inking fluid in winter.
- Yoke magnetising stations. Two yokes were used for opposite faces of the billet. Because of billet camber and shear drag conditions which may be present, a system of sensors is used to prevent the billet from damaging the yokes. The yokes provide up to 10,000 ampere turns of magnetising current. The actual level of magnetising is adjustable via the Insight NDT microprocessor control system. This magnetising level is based on billet cross section dimension.
- The final station is the operator cabin inspection area. This station uses eight ultra-violet flood lamps (UVA) to illuminate the billet as it moves through the inspection station. The two operators are seated on either side of the billet. Operators are responsible for viewing two billet faces, the corner facing them, and either the top or the bottom corner with the assistance of viewing mirrors. The cracks seen by the inspector are marked with paint markers for removal in the grinding process later. The inspectors have control over the line speed, magnetising amperage level and the choice of white light or black light inspection.
- The inspection area is suited for a yet developed automatic, machine vision system that will be fitted later. The vision system envisioned will replace inspectors and, together with the ultrasonic system, will yield a 100% inspection of all billets for internal and external defects without human involvement.

4 Conclusions

The system as described above has been in operation since June 1998. The results, concerning inspection quality, probability or detection, maintenance costs and production times have been all positive. Figures pertaining to volumes, tonnage, etc., are proprietary and therefore not a part of this paper.

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- It is estimated that the quality of the MPI inspection is approximately four times better that the old system. This figure is based on the use of AC current to detect longitudinal defects very close to the corners, which were potentially missed with the use of FWDC current where the magnetic field tends to “cut around” these corners.
- The billet being presented on the diamond on vee roll assemblies allows the operator to view the billet for defects without the need to roll the billet over several times. This decrease in handling the billet results in an increased probability of detection, as defects will not be wiped off the billet since it is not necessary to rotate it.
- Operator comfort has been improved tremendously, which results in a more alert inspector.
- Maintenance costs have been virtually eliminated. This is a saving of several hundred thousand dollars per year.
- Production figures are improved. The improved inspection quality, the increased probability of detection, and the confidence in the quality of the billets after inspection have resulted in a 35% increase in inspection ability. The maintenance improvement further increases this figure.
- The MPI procedure is in-line with the production line. This has eliminated the need for crane operators to load the MPI and has increased the inspection speed to line speed.

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