17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

Application of Portable Non-Destructive Testing (NDT) Instruments to Enhance Performance of Hot Strip Mill Rolls

Rama S VERMA [1], Krishna K SINGH [1], Damodar CHOUDHARY [2], Subrat KUMAR [2], GMD MURTY [1]

[1] R&D Centre for Iron & Steel, Steel Authority of India Ltd. < rsv49@rediffmail.com>

[2] Bokaro Steel Plant , Steel Authority of India Ltd

Abstract

Roll inspection in roll grinding shops is necessary to ensure that rolls being returned to the hot strip mill after grinding are free from surface breaking cracks and internal defects that may cause roll failure during service. Hot strip mills in finishing stands normally utilize cast duplex type work rolls in alloy indefinite chill double poured (ICDP) or high chrome iron grades and back up rolls of alloy cast or forged heat treated steels. Back up rolls (BUR) suffer from mechanical pressure cracks in contact stress zones due to excess work hardening. These cracks move downwards through cyclic loading, if not detected and removed by grinding, and cause roll spalls or catastrophic failures. Work rolls in hot mills are subjected to severe thermal fatigue causing fire cracks on the surface and other mill operational deviations and accidents inducing surface and sub surface damage in roll body.

Surface cracks with a depth more than 0.2 mm have to be detected and removed by grinding. Apart from detection of surface cracks with eddy current, other sub surface flaws, shell depth measurement, internal flaws in shell and evaluation of disbonded conditions at shell/core interface are done with ultrasonic. Back up rolls are tested with eddy current and ultrasonic testing instruments both for complete surface and internal evaluations. Manual testing of rolls using portable Eddy Current and Ultrasonic Flaw Detector has been introduced since last one year in hot strip mill of Bokaro Steel Plant for optimizing roll grinding. There is decreasing trend in back up roll consumption by 10-15 % excluding material related failures with complete rejection are heavy stock removals. Further, work roll spall cases has reduced by almost 50% and overall mill delay due to roll changes has come down by more than 40 % after implementation of NDT assisted grinding. The total cost of NDT including man power and that of the

instruments in simple way is less than 20 % of only work roll saving which can justify the project.

INTRODUCTION

To have a complete picture of roll conditions, it is imperative on roll grinding shop managers to detect all surface cracks more than about 0.20 mm depth to repair or remove by grinding. Roll life can be improved by efficient location and removal of cracks during grinding. The hot rolled strips in steel mills are produced normally with four high mills consisting of two work rolls and two back up rolls. The work rolls used in hot strip mills are usually of cast variety and vary in quality ranging from alloy indefinite chill cast iron, Hi-Cr irons and more recently, the high speed steel. Mostly these rolls are composite in nature consisting of hard and wear resistant outer shell and softer steel or iron core.

The back up rolls in the mills are used for applying rolling load and are subjected to heavy mechanical stresses during rolling. They are not driven and rotate under friction with rotating work rolls. Both cast and forged steel back up rolls are in use at different mills but forged steel rolls are preferred due to their superior fatigue strength and fracture toughness. The hot strip mill at Bokaro Steel Plant uses Indefinite Chill Double Poured (ICDP) work rolls with alloy cast iron shell and iron core in finishing stands and Hi-Cr work rolls in few intermediate stands. Back up rolls made of forged high carbon alloy steel (0.9 %C-1.5 Cr-V) were historically used which have been replaced now with 3-5 % Cr-Mo-V forged and heat treated steel rolls. The work rolls used have barrel of 810 mm X 2000 mm with 60 mm shell thickness when new and are scrapped at 750 mm diameter. The backup rolls are of 1610 mm diameter with 2000 mm length when new and are scrapped at 1460 mm diameter. Some typical composition and hardness levels of HSM rolls used in the plant are given in Table –I.

Table 1- Typical Chemistry and Barrel Sizes of Hot Strip Mill Rolls

Roll Type	Grade	Barrel Diameter (mm)		Typical Chemistry						Hardnes (HSC)
		New	Scrap	C	Mn	Si	Cr	Ni	Mo	
Work Rolls	ICDP	810	750	3.2	0.60	0.80	1.50	3.50	0.50	70-85 (Shell)
Back Up Rolls	Forged Steel	1610	1460	0.50	0.50	0.45	3--5	-x-	0.80	55-60

In present days most of the roll shops include some method of inspection to determine roll integrity during and after roll dressing operations are performed on used rolls and before they are sent back to mill for service. These inspection techniques have evolved from visual, to liquid penetrant , to magnetic particle, to eddy current and/or ultrasonic based non destructive testing system. Although the initial testing with eddy current and ultrasonic started manually with portable instruments , gradually this method is being replaced with modern automatic on line testing systems operating on one of these principle and also using both eddy current and ultrasonic sensors in form of a Combi Roll Inspection System. A typical combi roll inspection system (Fig. 1) can scan complete roll surface simultaneously with ;

- Eddy current testing up to 3 mm in depth for surface defects (cracks, pinches, bruises)
- A 5 MHz ultrasonic sensor applied for inspection in the range of 5-125 mm (inclusions, blow holes, core/shell bonding zone defects.)
- A 10 MHz ultrasonic sensor utilized for inspection in the range of 2 -20 mm (near surface cracks, inclusions)

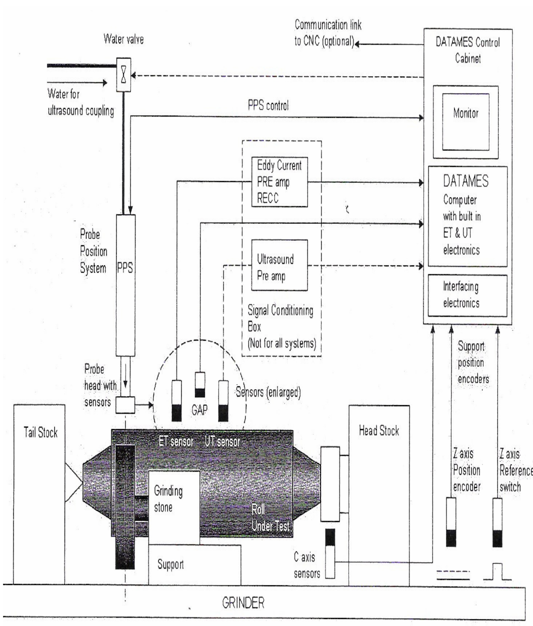

Fig.1- Schematic view of on line surface inspection system with eddy current and ultrasonic sensors

Fig. 2- ICDP work roll being tested manually with hand held eddy current testing instrument

Manual testing of rolls with portable instruments is not preferred because of high man power cost in developed countries and limitations with respect to 100 % surface coverage in shortest time. However, use of portable hand held NDT instruments have their own benefits and present work is based on manual testing (Fig. 2) of hot strip mill forged steel back up rolls and alloy cast iron work rolls. The use of hand held portable instruments has been thought to be a low cost solution to start with surface inspection. It has greater flexibility and one instrument can be used for testing on different grinding machines and even for rolls on floor after grinding. The instrument costs are also much lesser than cost of automatic on line systems.

SURFACE INSPECTION WITH NDT INSTRUMENTS

Eddy current inspection is performed when an eddy current field is generated on roll surface by applying AC current in copper wire coil probe. The eddy current field on roll surface induces secondary field. The primary and secondary fields remain opposite and resultant difference in their strength changes the current flowing and thus providing signals (Fig. 3) for monitoring. A phase change is created when there is increase in path of current travel due to surface cracks and thus detecting spalls, cracks and fire cracks on roll surface. Pinch/bruise are detected due to change in material conductivity. Eddy current testing primarily focuses on surface defects because penetration of EC is less than 2-3 mm and decreases with higher frequency, higher electrical conductivity and magnetic permeability of roll material. The portable instrument in the plant is a dual frequency hybrid (Uniwest-US-454 Model) instrument that enables selection between eddy current, video or strip chart. The frequency range of the instrument is from 10 Hz to 10 MHz and at present 10 KHz and 100 KHz probes are being used for inspection of last three stands work rolls and all backup rolls. Ultrasonic Instrument used in the roll shop is Krautkramer, USM-35-DAC model with a set of 1 MHz normal probe, 30, 45, 70 and 90 degree angle probes with 2 & 4 MHZ and a 4 MHz TR probe.

BACK UP ROLL INSPECTION

Back up roll life can be improved by efficient location and removal of cracks during grinding. Removing cracks which are even less than 0.20 mm deep, can prevent the propagation of spalls which can cause even a new roll to be scrapped. Back up rolls are redressed with an objective of removing all mechanical cracks and thermal cracks. Although NDT inspection can detect the surface/sub surface flaws to be removed with safe limit for mills usage, nevertheless mill practice must be clearly known to the NDT personnel to pay more attention to crack prone areas in manual testing. For example, the back up roll surfaces are plastically deformed under high rolling contact stresses. This zone of high contact stress goes on shifting with progress of non uniform roll wear and back up rolls are subjected to heavy mechanical contact stresses under rolling loads once the barrel contact with work rolls get reduced due to uneven wear of rolls. In later stage of campaigns, approx 300 mm length on both ends of rolls, the contact stresses reach maximum limit causing severe work hardening .

Work hardening makes surface layers highly brittle and prone to crack initiation under localized contact stresses. This zone needs to be carefully scanned with both eddy current and

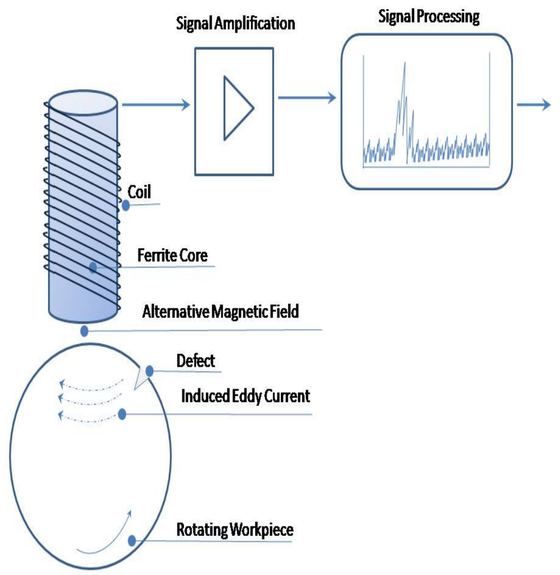

Fig.3 Schematic view of operating principle of an eddy current testing system

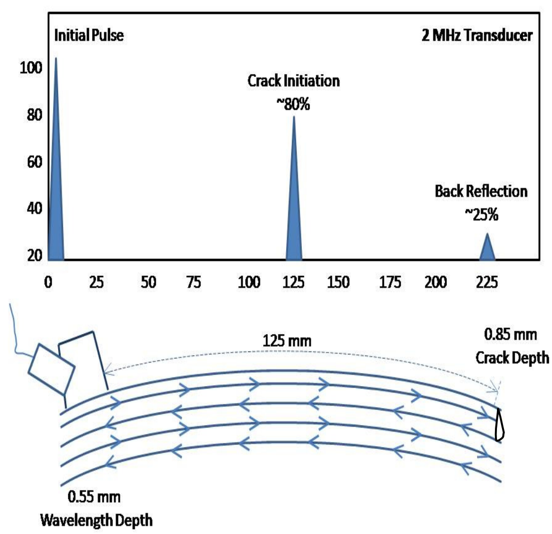

Fig.4 A typical reflection from a surface flaw with back reflection tested with surface wave transducer

ultrasonic instruments. Any sign of spall in this region is evaluated with angle probes for assessment of depth for local or full barrel grinding. The spalling due to surface/sub surface cracks in work hardened zones at both barrel ends is very frequent. Eddy current testing is capable of locating and roughly classify the defect depth on surfaces as well as locate soft spots (pinch/bruises), surface wave ultrasonic testing offers several other advantages with its ability to locate and even classify the surface cracks on the basis of depth.

The testing of work hardened layers in BUR for internal flaws is done with ultrasonic testing using different ultrasound beams at varying frequencies. It is well known that surface or Raleigh waves do not propagate well in fluids especially oil, a low viscosity oil is used as couplant. Raleigh waves are called surface wave as their depth of penetration along the surface direction of travel is normally not more than one wave length (λ) of the beam. Generated by using a critical angle transducer, the sound beam travels on roll surface and are sensitive enough to pick up even a finger pressed on roll surface in beam's path. Surface wave ultrasonic testing is relatively inexpensive and easy to use with proper training. Once the cracks are detected, angle beam transducers are used to assess the crack depth " accurately " which also requires much more skill and experience to perform. Manual testing of hundred percent back up roll surface with ultrasonic instrument is time taking (30 to 60 minutes) and is only performed on rolls with visible or eddy current detected flaws at more than one locations

In manual testing with surface wave, screen displays are used to indicate the distances on roll surface. A physical anomaly at 180^0 can be used to generate a false back reflection without severe attenuation of the wave to assess the distance on roll surface. Defects perpendicular to the surface wave's path are reflected back to the transducer and show up on the screen display as back reflection (Fig. 4) between initial pulse and reference back reflection. Most roll body cracks occur longitudinally, rather than circumferentially and inspection is performed to place the expected cracks perpendicular to surface wave. If the transducer chosen, for example is 2 MHz with 1.2 mm wavelength in steel, the cracks of normal orientation as shallow as 0.10 mm are detected which is quite satisfactory. A crack depth class can be prepared with testing the rolls with 1, 2, 5 MHz transducers for direct assessment of crack depth during daily testing. For example, a 20 mm long crack located with 2 MHz transducer showing 100 % indication without reference back reflection can be tested with 1 MHz transducer and if the results are same, the crack depth will be more than 2.5 mm. If some reference back reflections are observed, the crack will be less than 2.5 mm depth. Once the crack is assessed, roll shop authority decide whether the roll will be ground, localized plunge cut to remove the crack or massive lathe cutting will be given with grinding separately.

Surface inspection with Raleigh wave is also useful to evaluate the roll surface integrity while grinding. A sound roll with minimum grinding and smooth surface condition facilitate travel of surface wave without undue attenuation and roll shop managers could decide that roll is perfectly ground and suitable for sending to the mill.

INSPECTION OF WORK ROLLS

The aim of eddy current testing is to detect fire cracks (perpendicular to rolling direction) and bar cracks (parallel to rolling direction) on the surface of the rolls. Although sizing of defects depth with ECT is a problem but more than 0.3 to 0.5 mm surface cracks with 3 mm depth can be detected with ECT. Work rolls of hot mills are tested with eddy current for surface fire cracks mainly and also for pinch/bruises (soft spots) if occurred during rolling. The rolls are ground to remove fire cracks up to a threshold according to stand they will be used in. Earlier stands have higher threshold and latter stands have increasingly lower thresholds. All mechanical cracks are completely removed up to noise level of NDT equipment. Ultrasonic penetration is much more difficult with hot mill ICDP grade work rolls and they present more diverse inspection challenge due to their cast and coarse three phase (carbides, graphite and matrix of martensite gradually changing to bainite and pearlite) structure. The use of surface wave testing is also equally restricted because of heavy attenuation with mixed coarse material structure. However, a skilled and trained operator still can evaluate with ultrasonic testing the indications found by eddy current, using suitable couplant and short testing distances. With a hand held ultrasonic machine surface screening with surface waves, crack depth assessment with shear wave transducer and shell/core bond line inspection with normal or TR probes is possible.

Pinch and bruises are often confusing with eddy current testing as they may be very often cluster of pinholes or remnant of fire cracks. Such defects are completely innocuous and removing such benign indications by additional grinding is not needed especially for work rolls of initial finishing stands. At present attempt is to test all ICDP rolls of last three finishing stands with hand held portable eddy current and ultrasonic instruments.

Shell/Core Bonding and Shell Thickness Measurement

Monitoring of shell/ core interface is needed for assessing the bonding strength and that of shell depth thickness to ensure that preset minimum shell thickness limit is not crossed in service. The rolling stress penetration is estimated about 15 mm in hot rolling and the limit for shell thickness is maintained minimum 30 mm. The shell thickness is measured with 1 MHz longitudinal beam or 4 MHz TR probe with 60 or 120 mm range. The signal from interface is monitored with flaw gate. The consistency of the amplitude is measured and any sudden or cyclic off screen excursions of this signal is indication of bond line separation or formation of fatigue band. Multiple back reflections with complete loss of back wall reflection from opposite side of roll, is also sign of disbond situation. The length of disbond and loss of shell thickness below threshold level of 30 mm even locally is sign of alarm for the roll shop authority especially if roll diameter is reaching scrap limit. Such test is important if there has been mill wreck with rolls having visible surface damage like dents, welded strip with accompanied fire cracks or small half moon type spalls.

RESULTS

During last one year, surface inspection of about 300 numbers of inspection on rolls are being carried out every month using portable NDT instruments. The numbers consist of about 25 % scanning on back up rolls and 75 % on work rolls. Three trained personnel carry out surface inspection of ICDP work rolls and forged steel back up rolls during day time. At present the effort is to cover all work rolls of last three finishing stands and backup rolls of all finishing and one roughing stands. Earlier work rolls were ground with different amount preset for work and backup rolls. Now ICDP work rolls are ground ensuring complete removal of fire cracks above a threshold set for finishing stands and are detectable with eddy current with 100 KHz probe. Therefore the roll grinding amount has yet not significantly reduced. This needs to be fine tuned to derive benefit in terms of the roll grinding thickness. However, there is significant drop in roll spalling due to clean rolls reaching the mill and same has come down by 50 % during 2007-08. The reduction in diversion due to surface marks on strip quality due to deeper fire cracks on finishing work rolls earlier has come down.. The back up roll spalling due to residual cracks on surface has almost been eliminated. There is decreasing trend in back up roll consumption by

10-15 % excluding few cases of heavy material related failures. However, overall mill delay due to roll changes has significantly been reduced by more than 40 % after implementation of NDT assisted grinding. The total cost of NDT including man power and that of the instruments in simple way is less than 20 % of only work roll saving which can justify the project.

CONCLUSIONS

The hot strip mill roll inspection with NDT has been found to be highly benificial in today's quality and cost conscious mill operation. The manual NDT roll inspection with portable instruments is a low cost initial approach to assess its efficacy for future installation of on line system. The use of eddy current and ultrasonic instrument combination enables not only detection of surface/ subsurface harmful flaws in both work rolls and back up rolls, but also the evaluation of shell thickness and shell/core bond condition of composite type ICDP work rolls for reducing roll failures in the mill. The one year experience up till now with manual NDT testing in spite of less than hundred percent roll coverage has lead to, i) improved roll life due to less roll spalling, ii) reduced mill down time due to unschedule roll changes and iii) improved hot strip quality due to less fire cracks on finishing stand rolls. The pay back is significantly less and it is even less than 20 % of only work roll saving due to reduced roll spalls and breakages in mill. Back up roll consumption has also come down by 10-15 % due to improved detection and removal of surface cracks leading to undue spalls in the mill.

ACKNOWLEDGEMENT

The authors wish to thank RDCIS Management for encouragement and permitting this work for presentation in world conference. The support provided by Shri J.N. Singh, General Manager, Roll Grinding Shop, BSL-Bokaro to pursue this work is thankfully acknowledged.

REFERENCES

1. Paul Heckman, J. Ballani and R.Zorn , Surface crack depth classification through improved ultrasonic technique, 36th MWSP Conf. Proc. ISS-AIME, Vol. XXXII-1995-21
2. M. Stolzenberg and K. Berner, Trends in NDE Science & Technology, Proc.14 WCNDT, New Delhi, Dec-96, P-1691

3. Ron Webber, R&D Dofasco , Private Communication, Feb-2005
4. Jean Deniel Auzas, President, CMT System, France, Private Communication, April2006
5. Technical Brochure, Lismar Engg. B.V., The Netherlands
6. Paul A Kubakovic and Peter B. Nagy, Limitation and capabilities of UT of bimetallic work rolls and steel back up rolls, 43rd MWSP Conf. Proc. ISS-AIME, Vol. XXXIX-2001-719
