Paper 117

Proceedings of the Second International Conference on Railway Technology: Research, Development and Maintenance, J. Pombo, (Editor), Civil-Comp Press, Stirlingshire, Scotland.

Restoration of Switch Manganese Steels Crossings by Electric Arc Welding in a Robotized Plant

A. Bracciali[1] and M. Salciccia[2]
[1]Dipartimento di Ingegneria Industriale, Università di Firenze, Italy
[2]SAGA s.r.l., Scurcola Marsicana, L'Aquila, Italy

Abstract

Worn austenitic manganese steel crossings can be repaired in service up to a certain limit by means of electric welding. The welding process can be either fully manual or automatic with programmable portable welding machines. When wear is greater restoration is still possible but the crossing must be removed from the line and fixed in a workshop. The paper describes a patented flexible high-productivity fully automated robotized plant, named Rail Switch Welding RSW®, where crossings are milled, welded and finished according to railway administration regulations. Special attention is deserved to the problems that were encountered and solved in milling a hard material with a slender and flexible structure such as a robot.

Keywords: railway, turnout, crossing, austenitic manganese steel, welding, milling, restoration, robot.

1 Introduction

Restoration of rails by electric arc welding is standardized by EN 15594 [1]. A similar standard does not exist yet for manganese steel crossings that are nevertheless subject to distortions and wear due to the interaction with wheels resulting in impacts and friction much greater than those acting on rails. A draft European standard that covers crossings restoration was recently (29 August 2013) submitted by WG4 "Rails" to Sub Committee 1 of CEN/TC-256 Railway Applications [2].

The high mechanical strength of austenitic manganese steel (AMS) used in crossing castings is not sufficient to totally avoid wear and distortion of the nose and the wing rails. When wear reaches a predefined threshold, the infrastructure owner (from now on defined as "Railway Administration" or RA for short) needs to take some actions to prevent further damages and possible derailments.

RAs have developed their own procedures to repair crossings in service, an operation that is always economically favourable as crossing replacement is expensive and time consuming, being the crossing casting heavy, bulk and needing at least 4 aluminothermic welds to be inserted it in the turnout.

Two wear thresholds are defined (see for example [3]) and affect the handling of a worn crossing:

- in-service repair is possible when defects remain below a first set of limit values, in the order of 5 mm of wear of the nose;
- repair is still possible in a workshop when the first set of limit values is passed but wear is below a second set of limit values, in the order of 8 to 10 mm of wear of the nose;
- if for any reason also the second set of limit values is passed then the crossing cannot be repaired and must be scraped.

In-service restoration follows a set of operations defined in the welding procedure specifications (WPS) according to RA and international standards on welding. It basically consists of the following basic steps:

- the crossing in visually inspected and measured with proper gauges to check if the in-service operation is possible;
- in case wear is below the first set of limits, clearly damaged portions of the crossing are removed by manual grinding until maiden steel is found;
- a PT (non-destructive inspection with dye penetrant liquid) procedure is applied to verify the absence of any cracks;
- multi-layer welding process is then started by means of manual metal arc or cored wire metal deposit repair welding applied with automated portable welding machines (see below);
- surface polishing and finishing by grinding removes the excess material resulting from welding giving the final correct geometry of the crossing;
- a final PT is done to check the absence of cracks on the surface of the restored crossing.

Italian RA (RFI – Rete Ferroviaria Italiana) allows the restoration of cast manganese steel crossings by means of automated portable welding machines by either RFI approved personnel or by qualified contractors with approved personnel. This is due to the acknowledged intrinsic difficulty of the manual operation of multi-layer welding which requires the best skills from the welders, and RFI wants to have the highest confidence on the restoring operations. If the process is strictly followed, there are no restrictions on the use of restored crossing in full speed line.

During the technical life of a turnout several crossings can be restored and/or replaced due to excessive wear. At the end of the useful life of the turnout, and if wear is still tolerable, the crossing is normally saved from scraping and restored. That’s why out-of-service (or workshop) crossing restoration has *anyway* its importance. It follows basically the same operations of in-service restoration, the main difference being that the tolerable wear is greater. Workshop repairs can be done in all-weather conditions and guarantee the best quality of the restored crossing.

SAGA s.r.l. is an RFI approved supplier for crossing welding restoration since 2009. The company owns welding units installed on fully equipped lorries and street-rail vehicles which can do the automated in-service crossing restoration according to WPS released by RFI.

Following a market analysis, the company decided to invest in the development of a new fixed plant consisting of two robots, one specialised for welding and the other for machining a worn crossing before and after welding. The paper describes the plant in terms of architecture, performances and quality achievable with the fully automated process, including the critical situations that were solved.

2 Welding technology and repair of in-service crossings

The draft standard on restoration of turnout crossings is similar to the well established one on restoration of rails [1] and is based on the definition of a WPS which is, in synthesis, a “procedure approved to European standards and agreed by the RA for use on the railway infrastructure”. The approval of consumables and the related WPS for rails is broadly in line with the requirements of EN ISO 15613 [4], but owing to the special nature of the repair weld in terms of rail steel grade and use, e.g. rolling contact fatigue, the approval process follows EN 15594 [1].

SAGA s.r.l., as a contractor with RFI, uses only consumables approved by RFI. The company fulfils the EN ISO 3834-2 [5] quality requirements for welding according to EWF and IIW regulations for rails and crossings made of R260 EN 13674-1 [6] (former UIC 900) and GX120Mn12 EN 15689 (cast manganese) steels [7]. WPS approved by RFI according to the procedure [3] are available not only for manual metal arc but also for automatic arc welding process. SAGA uses approved Translarail WPS (for rails) and the Translamanga WPS (for crossings) with the equipment Translamatic 1252 manufactured by the J. Sauron S.A. company (Figure 1).

Figure 1: Translamatic 1252 equipment for automatic restoration of in-service crossings pictured during electrode path programming in the workshop.

3 Description of the robotized restoring plant

The plant layout is shown in Figure 2. It consists of two Yaskawa MOTOMAN robots (HP20D and ES165D) [8] installed in a dedicated area of a company-owned shed located in central Italy.

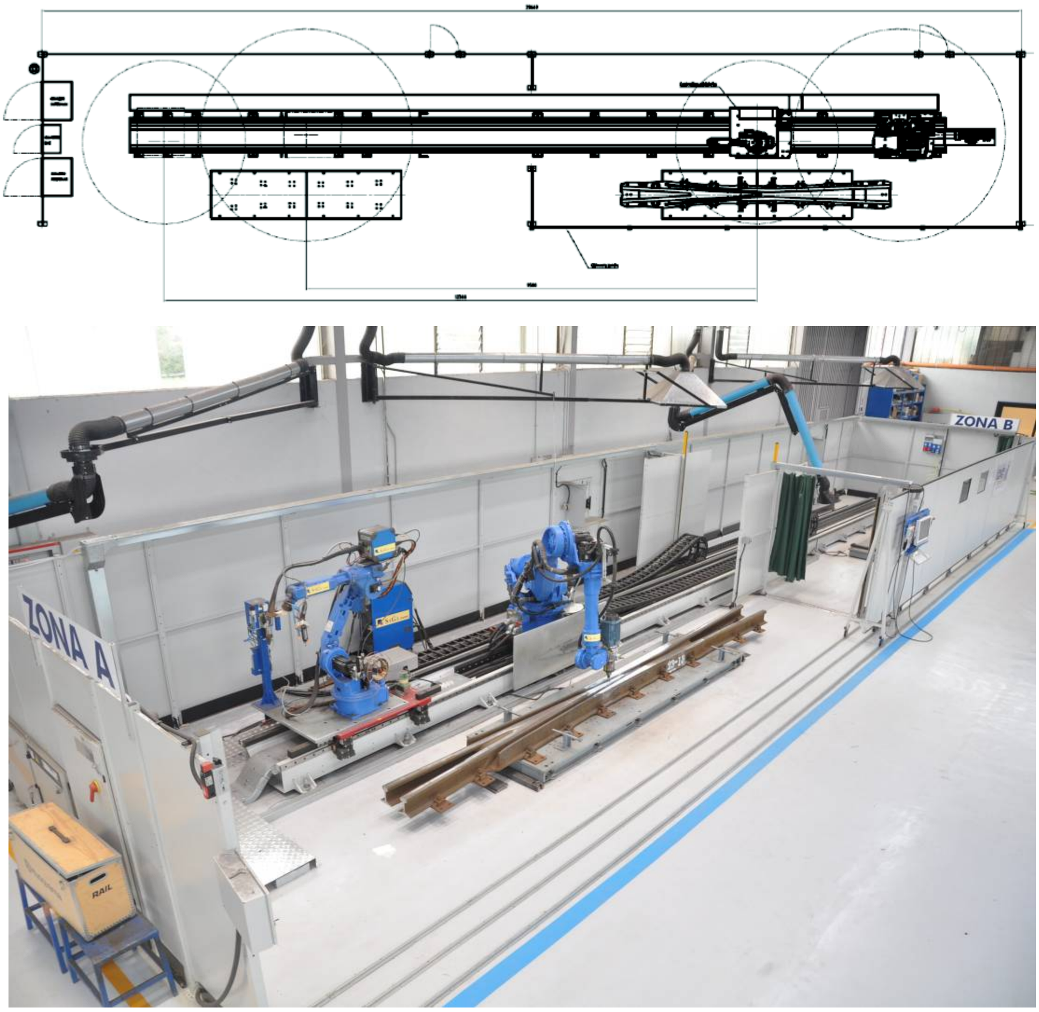

Figure 2: Layout and elevated view of the robotized plant (top view).

Robot R2, smaller, is dedicated to welding and removal of slag between passes. It bears a wire feed unit Migatronic RWF Multifeeder and a cleaning tool. The MIG welding machine Migatronic SIGMA^2 500 C is located aside the robot [9]. Robot R1, bigger, is equipped with a M&H 8704 machine tool dimensional measurement probe [10] that is used to locate the crossing to be machined w.r.t. to the robot reference system. A d=40 mm SECO mill with four Square 6™ XNEX 080608TR-M13 MP3000 [11] inserts is the used to removal the damaged portions of the crossing before welding and for finishing after welding (Figure 3).

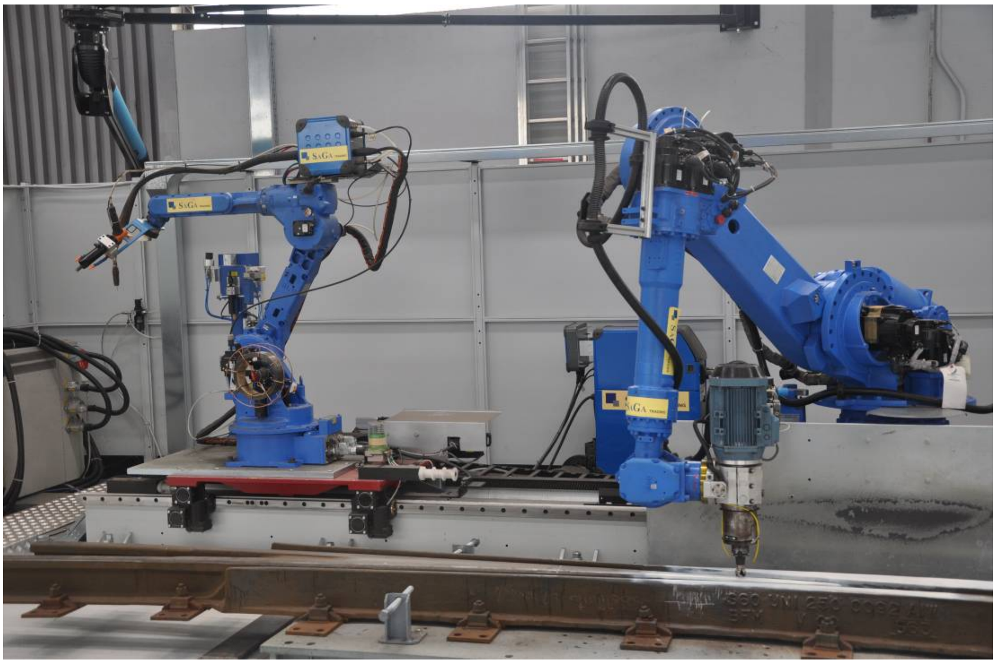

Figure 3: Welding robot R2 (Yaskawa MOTOMAN HP20D) equipped with the wire feed unit and the 19-needles scaler Beta 1944 (left). Milling robot R1 (Yaskawa MOTOMAN ES165D) equipped with measuring probe and milling spindle (right).

The robots can move along a roller guide system (linear traversing axis trackmotion Güdel Type TMF-3 [12]) which ensures the possibility of reaching the whole working area of a crossing.

Two areas, named A and B, can house a crossing to be restored. Both the robots R1 and R2 work in the same area until the operations on a crossing are completed, while in the other area another crossing is manually prepared to be restored.

Considering for example area A, the working cycle is as follows:

- a worn crossing is fixed in position by means of common fastenings tools with relaxed requests in terms of precise positioning;
- the crossing actual position is measured by the dimension probe, giving the rototranslation vector needed to align the robot to its coordinate system;
- the mill installed in the motor spindle of robot R1 removes the material in order to reach fresh parent metal;
- the NDT expert performs a PT to confirm that all possibly existing cracks were completely removed (further milling passes are applied until this condition is satisfied);
- robot R2 starts welding and scaling until the final requested raw shape is obtained;
- robot R1 mills the steel in excess obtaining a flat surface.

Restored crossing is then removed from the plant and finished by minor manual grinding and moved to a separate area where NDT are performed and geometry is checked. The restored crossing is then delivered to the shipping area. Milling is described later; a picture after welding restoring is shown in Figure 4.

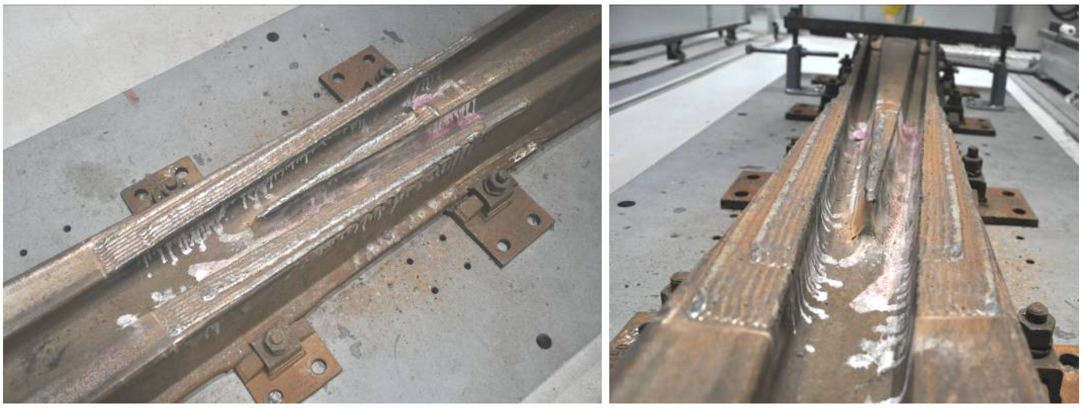

Figure 4: Appearance of a restored crossing after welding.

4 Milling with a robot --- problems faced and solved

4.1 Introduction

The most remarkable novelty introduced by the plant is the absence of the massive grinding operations requested to remove a large quantity of steel before welding. Grinding is known to be time consuming, producing sparks, dust, smoke and extremely high noise. This operation is inevitable for the in-service restoration but must be avoided in the robotized plant for several reasons.

First of all, grinding drawbacks are not compatible with precision machining inside a building. Who knows industrial plants knows that areas where grinding or sanding are extensively applied are destined to become dusty and contaminated in a short time, and this conflicts with the intrinsic cleanliness requirements of a robotized plant.

Second, forces requested to obtain an efficient grinding process can be rather high, as all the operators know, and they are not compatible with the chosen architecture of the robotized plant, where the robots are certainly flexible and easily programmable but cannot reach the typical stiffness of a machine tool.

Last but not least, chips produced by metal cutting with mills without lubrication are easy to remove, remain confined in a small area and the whole machining results in surfaces with extremely regular characteristics in terms of residual flatness and roughness, preparing at the best the field for the following finishing grinding operation.

The largest unknown was the dynamic behaviour of the milling robot R1. The manufacturer, in fact, describes the possible applications of his robots as follows [8]:

- Picking, Packing & Handling with the MYS-series
- Handling & General Applications with the HP-/MH-series
- Flexible Applications with the SDA-/SIA-series
- Spot Welding, Handling & General Applications with the ES-/MS-/VS-series
- Arc Welding with the VA-/MA-series
- Handling, Palletising, Picking and Packing with the MPP3 and the MPK-series
- Palletising with the MPL-series

It appears therefore clear that a robot *is not conceived to be a standard machine tool* and that the risk of incurring in the typical chatter problems linked to the use of too flexible machine tools was real. As this risk was well known from the beginning, tests were conducted on robot R1 find out its natural behaviour in terms of resonances.

4.2 Analysis of the natural response of the R1 robot arm

Natural vibrations in all three mutually orthogonal directions may be excited and can potentially affect the quality of the surface. While vertical oscillations have a direct consequence on surface roughness (that in this case in not a fundamental parameter as long as the crossing must be finished by manual grinding), lateral and longitudinal oscillations make the chip thickness varying continuously generating a self-excited vibration that can reduce tools life as well as triggering the safety auto-protection of the robot. The arm is in fact equipped with an accelerometer that stops the arm when accelerations exceeding a threshold are reached, and this can be the case when entering a resonance area.

With the milling robot arm positioned in correspondence of the nose tip of a crossing, the dynamic response of the robot was measured to find out the dynamic flexibility of the tool holder in the working area, which is approximately 1000 mm long and 240 mm wide while the height span (a few mm) was neglected having a relatively lower importance in the variation of the dynamic response during milling. The grid of measurement points is shown in Figure 5.

The response of the robot was measured in terms of point inertances on X/Y/Z directions by using an instrumented hammer and three 100 mV/g IEPE accelerometers. As an example, Figure 6 shows the setup of the measurements done in the vertical direction.

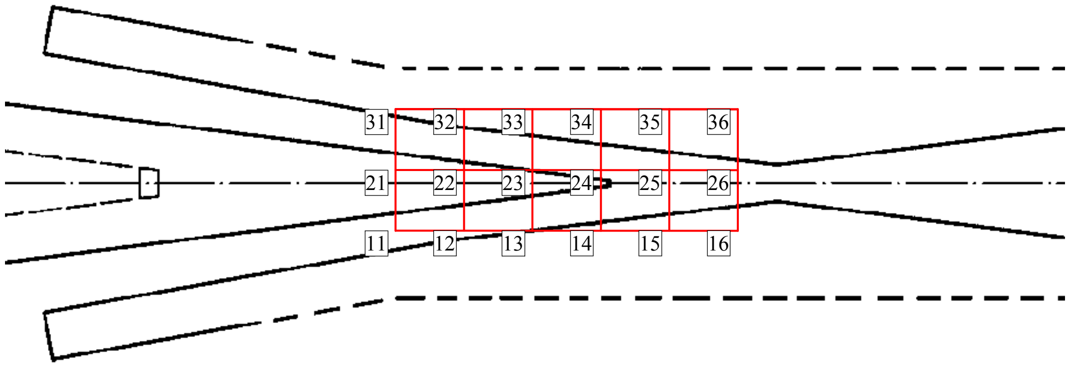

Figure 5: Vertical inertance measuring grid covering all the working area. Point 24 corresponds to nose of the crossing.

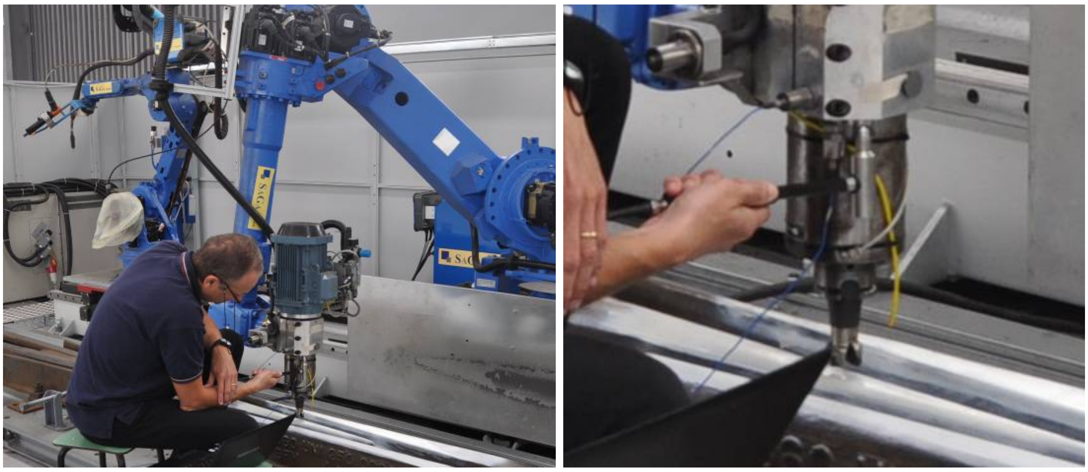

Figure 6: Measurement of the point FRFs at the spindle.

Receptances (mobilities) were therefore derived from inertances, and are shown in Figure 7. It can first be observed that mobilities are scarcely influenced by the working position, allowing a comparison also of average curves.

The most important resonance in the transversal X direction and in the longitudinal Y direction are respectively at 13.75 Hz and at 15.5 Hz. Both these frequencies are rather low. Quite different is the situation on the vertical Z axis, where beyond two peaks at low frequency (10 Hz and 15.5 Hz), the response is dominated by the peaks at 33.75 Hz and, to a minor extent, 41.75 Hz. Above around 25 Hz, the response in the vertical direction is more than 100 times that in the other directions and this, as indicated the following, is the region where spindle should rotate to optimize cutting.

The goal of the job was therefore to find the best cutting conditions such that cutting forces poorly excited the vibrations of the spindle, resulting therefore in a good surface quality while keeping the machining time low.

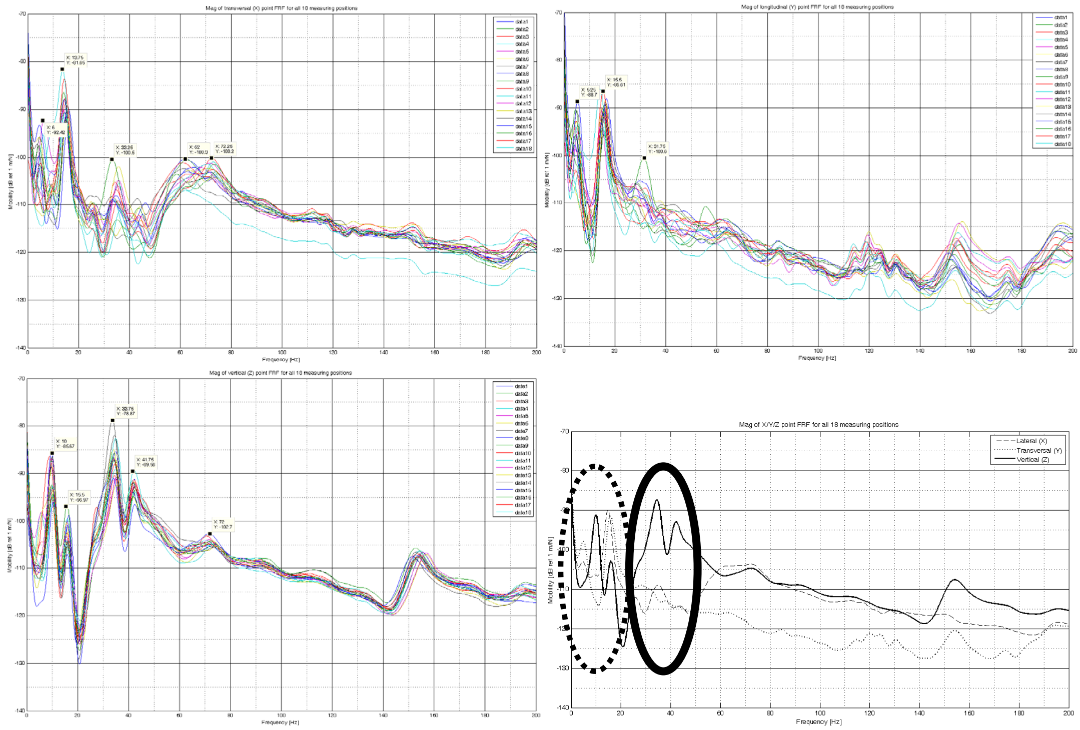

Figure 7: Vertical receptance in X (top left), Y (top right) and Z (bottom left) directions. Superposition of average curves (bottom right) with indication of the lateral/transversal resonance (in the dashed ellipse) and of the vertical resonances (in the thick line ellipse).

4.3 Machining tests and selection of cutting parameters

Milling produces a set of continuously varying forces in the three orthogonal directions that can affect the dynamics of the robot arm and of the spindle. Through a series of tests conducted on a specimen (see Figure 8), spindle accelerations and current absorption of the motor were measured, while the surface quality resulting from the milling operation was visually checked (Figure 9).

These tests fully confirmed the results obtained from the dynamic flexibility measurements and the cutting parameters were therefore chosen with the aim of:

- selecting the highest possible cutting speed to reduce to a minimum machining times, that in the case of finishing can last up to 2h50min;
- selecting therefore the antiresonance at 39 Hz (=2340 rpm) to limit as much as possible abnormal amplifications that may lead to bad cutting conditions that result in chatter which decreases tool life and in poor quality of the milled surface;
- finding the lowest cutting forces acting properly on feed and on cutting depth.

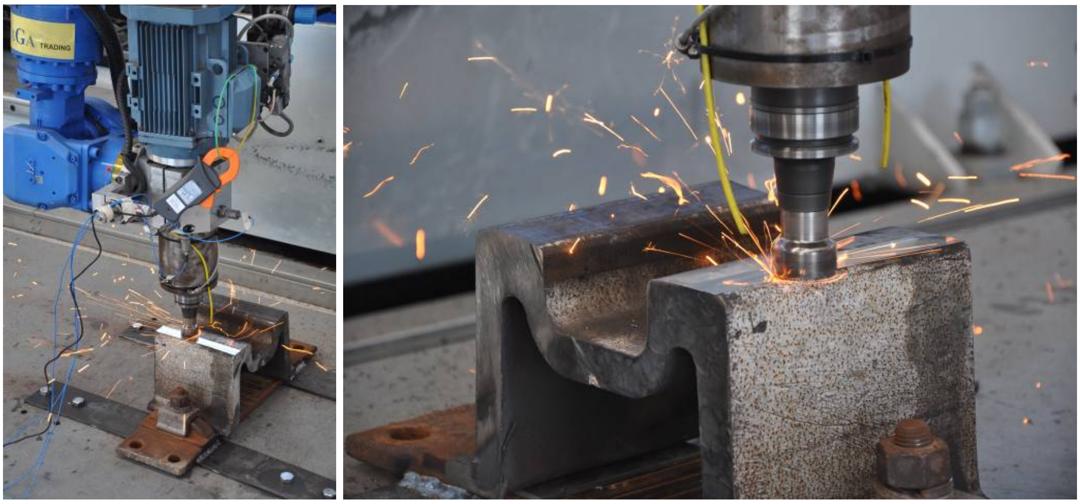

Figure 8: Machining tests on a specimen taken from a cast AMS crossing. The three accelerometers and the current clamp are visible (left). Detail of the machining process (right).

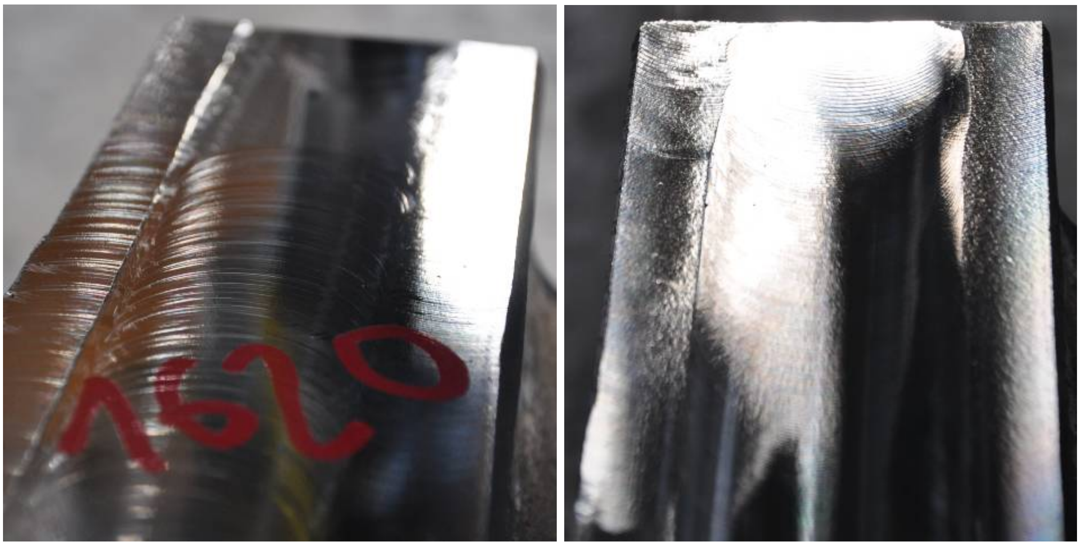

Figure 9: Resulting quality of the surface after test milling at 1620 rpm (left) and 2340 rpm (right) with the same feed.

These selections led to exceptionally stable machining conditions (Figure 10) which are in line with those that can be obtained with much larger, heavier, more expensive and less flexible milling machines.

The difficulties faced and solved in finding the correct tool quality are worth to be described. It is well known that the original austenitic manganese steel, containing about 1.2% C and 12% Mn, was invented by Sir Robert Hadfield in 1882. Hadfield's steel was unique in that it combined high toughness and ductility with high work-hardening capacity and, usually, good resistance to wear [12]. The reader is referred to [14] for the currently standardized manganese steels.

Figure 10: Example of the quality of crossing surface after final milling.

Austenitic manganese steel is one of the worst materials in terms of machinability [15], resulting in large tool wear and poor surface quality. If the geometry of the tool is wrong, machining results almost impossible (a desired effect in safes!) damaging almost instantaneously the tool tip due to the high resulting friction. Manganese steels are strongly work hardening, and tool manufacturers often propose special inserts to mill this material.

The geometry of the insert has a large influence on all cutting parameters (cutting forces, chip temperature, cutting edge duration, etc.) and all the characteristic angles of the insert were checked during numerous tests conducted jointly with the manufacturer (SECO tools), that proposed the quality Square 6™ that gave extremely satisfactory results.

The cutting speed of 294 m/min eventually selected (d_{tool}=40 mm) exceeds the normal operating conditions of coated tungsten carbide inserts reinforced with Ti(C,N) / Al_2O_3 / TiN particles applied with PVD or CVD processes. That's why at the moment tests are in progress with different inserts (CBN, ceramics, etc.) to further increase the frequency of the spindle above 50 Hz (3000 rpm) in order to avoid any effect from robot arm resonances. The resulting cutting speed (=377 m/min) is certainly very challenging but productivity improvements could be very interesting and worth to be investigated.

5 Production and economical considerations

The design of the RSW® plant started in 2010. The works were fully internally funded and the final plant was delivered and tested successfully in the early 2013. The plant was therefore patented [16].

At the moment the following crossings can be restored according to RFI specifications: S60 U/170/0.12, S60 U/250/0.12, S60 U/250/0.092, S60 U/400/0.094, S60 U/400/0.074, S60 U/1200/0.055. The crossing S60 U/1200/0.040 as well as any other crossing geometries can be programmed; one of the most important feature of the plant is in fact its high flexibility, that allows to prepare a working cycle for virtually any crossing in approximately 2 working days.

The success of the RSW® plant is intrinsically linked to the economical viability of the restoration process. Although this figure can change on the basis of distance and different countries practice, according to Italian current prices a restored crossing has a cost which is lower than 30% of a new crossing, including shipping costs.

SAGA s.r.l. has recently signed a contract with RFI to restore 770 AMS crossing castings in three years, which is in line with the minimum supposed annual need of restored crossings to respect the business case (approximately 250 crossings/year).

The saturation productivity of the plant is nevertheless quite bigger; even if some optimization is under study such as changing the material flow and other logistic issues in the plant, it is roughly estimated that the current RSW® plant can work around 1200 crossings/year.

6 Conclusions and further developments

A new patented robotized plant named RSW® for the restoration of austenitic manganese steel crossings was described. Technical and productivity issues were all discussed, with particular reference to tackling the potential chatter problems arising from the fact that the robot used for milling is much more flexible than a conventional milling machine. Results from tests were completely satisfactory, and the RSW® plant is fully operational today.

Considerable productivity improvements could be obtained by investigating different milling strategies and tools. This research is at the moment in progress and the first results are expected to be reported at *The Second International Conference on Railway Technology: Research, Development and Maintenance*, 8-11 April 2014, Ajaccio, Corsica, France.

References

[1] EN 15594, "Railway applications - Track - Restoration of rails by electric arc welding", 2009

[2] CEN/TC256/WG4 draft standard, "Railway applications – Track – Restoration of cast manganese crossings by electric arc welding", WI WI00256606, 2013.

[3] Rete Ferroviaria Italiana, "Gestione delle attività inerenti l'esecuzione degli apporti di metallo su rotaie e apparecchi del binario", RFI DPR PS IFS 096 A, 2013 (in Italian).

[4] EN ISO 15613, "Specification and qualification of welding procedures for metallic materials – Qualification based on pre-production welding test", 2004

[5] EN ISO 3834-2, "Quality requirements for fusion welding of metallic materials. Comprehensive quality requirements", 2005.

[6] EN 13674-1, "Railway applications - Track - Rail - Part 1: Vignole railway rails 46 kg/m and above", 2011.

[7] EN 15689, "Railway applications - Track - Switches and crossings – Crossing components made of cast austenitic manganese steel", 2009

[8] Yaskawa Motoman Robot Overview, http://www.yaskawa.co.jp/en/

[9] www.migatronic.com

[10] www.mh-inprocess.com

[11] www.secotools.com

[12] www.gudel.com

[13] Austenitic Manganese Steels, web page consulted on 21.10.2013 http://www.keytometals.com/page.aspx?ID=CheckArticle&site=kts&NM=69

[14] ASTM A128 / A128M - 93(2012), Standard Specification for Steel Castings, Austenitic Manganese, http://www.astm.org/Standards/A128.htm, 2012.

[15] E. Kuljanic, M. Sortino, G. Totis, F. Prosperi, "Evaluation of commercial tools for machining special-alloy Hadfield steel", International Virtual Journal – MTM Machining Technology Material, Vol. 7, pp. 96-99, 2012.

[16] European patent in progress, "Metodo per rigenerare un cuore di un deviatoio usurato", protocol BO2013A 000572, registered on 17.10.2013 (in Italian).