Automated Billet Surface Inspection

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Abstract

High quality aluminum billet casting requires a very good control of the process parameters. After removing the billets from the casting pit, two quality control inspections are usually performed. A first one is usually performed by an inspector for the surface and shape quality of the billet and a second one for its internal structure using ultrasonic technology. STAS has recently implemented, in a cast house in Canada, a new equipment named the "BSI3D" for Billet Surface Inspection in 3D. This equipment is fully automated and uses state-of-the-art proven 3D scanning and image analysis technologies. The BSI3D is a fully objective and consistent machine that can detect and record the surface defects characteristics. It is also programmed to precisely evaluate the bending of the billets i.e. straightness. This new equipment allows for optimization of the casting process, helps to improve the billet recovery rate and reduces overall operating costs. This paper presents an overview of this equipment, its performances and benefits.

Keywords

Billet • Surface inspection • 3D vision • Automation • Image analysis

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Introduction

In a world where sensors, vision systems and data can be more and more easily connected to automation, STAS engineers have in mind a cast house where the direct chill (DC) casting of aluminum billets would be fully automated from casting to packaging of the billets. Currently, many steps are still manually performed by operators such as the unloading of the pit and the inspection of the billets. With regards to the billets inspection, two levels of analysis are usually carried out. The first one is about the external surface aspect of the billet and its global geometry, such as straightness or deformation. The second one is associated with the quality (homogeneity) of the internal structure of the billet (center cracks and inclusions).

The first inspection level is commonly performed visually by an operator. This task is frequently performed by a dedicated operator, while it is sometimes combined with other tasks such as casting pit unloading. However, regarding the second level of inspection, that is ultrasonic inspection for detection of internal flaws, the task is already automated and there are several equipment units available on the market. This lights up the need and the potential benefits of automating the surface and geometric inspection of billets.

A few years ago, a paper was presented at TMS introducing a new automated surface inspection system for the DC billet [1]. However, the concept and the technology used showed significant limitation, and the product never entered the market. Since, no similar product was made available to the market, although the need and interest for the function has been confirmed.

This need was clearly identified by Alcoa's Aluminierie de Bécancour (ABI), and a project was launched to fulfill it. Considering its given experience regarding machine vision inspection systems in 2D and 3D [2], STAS was awarded the mandate to develop a system in late 2016. The global objectives were to implement a fully automated inline system to perform the surface inspection as well as the

necessary geometric measurements. The system, based on advanced image analysis and pattern recognition algorithms, needed to be benchmarked and validated according to the best-skilled operator for visual inspection. Moreover, the results of this system would be combined and superposed to those of the existing ultrasonic inspection, thus generating a 100% automated billet inspection.

A thorough development phase took place, from proofs of concept thru testbenches, up to the design and fabrication of a complete industrial unit. Advanced algorithms for image analysis, topographic analysis and geometric measurements were developed and optimized. The machine was designed to insure a stable mechanical behavior, with precise movement and suitable repeatability to eliminate potential noise in the image capture and to secure the precision of measurement. The unit was tested and optimized intensively in STAS production factories, using a lot of billets provided by the plant which had various and typical surface problems and deformations as samples and test material. In the final, the system's performance was audited and qualified in a Factory Acceptance Test, using a second lot of billets provided by the plant as reference material. The FAT took place in late 2017 and it was a success. At the time of writing, the system was still waiting to be commissioned, as the start up was delayed due to an actual labour conflict at the plant.

Notwithstanding the wait for online performance results, this paper will present the concept and the performance of this new equipment designed to perform the billet surface inspection automatically. Branded BSI^{3D}, for "Billet Surface Inspection in 3Dimensions", the system showed outstanding performance and operability. We will address the advantages of performing automated surface inspection, the performance overview and the capabilities of the BSI^{3D}.

Advantages Related to Automate the Billet Surface Inspection

The first advantage is the optimization of the DC billet casting lines. Any "operator-dependent" process can delay the casting line and reduce its performance. Using the BSI^{3D}, the inspection process is automatic and fast.

The second gain is the inspection by zones. The ultrasonic inspection level, which is related to the internal structure of the billet, often gives separate results for each 10 cm-long lengths of the billet. By having the surface inspection results aligned with the same lengths division, the billet can be partially accepted or rejected, depending on the length of the final products to delivery.

The automated inspection process generates automated alert related to specific casting problems including the mould number, etc. A precise history of the inspection results is also available in the database and can be accessed locally or remotely. As suggested in a DC casting operation manual [3] about problem-solving procedure, any problem must be documented, classified precisely (mould number, date time, casting parameters) to find the root cause efficiently and rapidly. The BSI3D fulfills exactly this task, allowing process optimization and is also fully aligned with industry 4.0 concepts.

The fourth benefit, and one of the most important, is the consistency of the inspection. The billets are always inspected using the same criteria, meaning there are no risks of process variations whatsoever. Moreover, the BSI3D offers the possibility to use custom inspection parameters depending on alloys, customers and products.

Finally, the automated inspection process can reduce manpower costs and is a step forward towards the complete automation of the casthouse.

Performances Overview

The BSI^{3D} is used for the automatic inspection of the surface defects and the straightness of an aluminium billet. The complete 3D point cloud model of the billet is acquired. It uses the latest technology in terms of 3D sensors to digitize the surface all around the entire billet length. The sensor also acquires the intensity level of each pixel and is thus able to obtain a high quality like photography of the billet in 3D. The x, y and z coordinates are used to detect the defects having a deformation like holes, waves, scratches, and the photo of the surface is used to find defaults only visible in 2D intensity level (like water stains).

The resolution of the deepness of the surface defect is from 0.04 mm whereas the resolution on the circular direction is from 0.15 mm depending on the billet size. Such high resolution allows to detect very small defects.

Figure 1 shows a close-up view of the 3D intensity level of a billet area scanned with the BSI^{3D}. Figure 2 demonstrates how the billet straightness is measured using a sequence of circle centers over the total length of the billet. In the presence of a bent billet, the BSI^{3D} can automatically compute the good angular position to avoid any blocking on the conveyer or to raise an alarm if the deflection is too high to go forward with the process. Figure 3 illustrates the detection of a small oxide patch on 3D intensity image and the corresponding 3D point cloud area where the surface defects are deeper than 1.5 mm. Figure 4 shows an example of a vertical tear. We can see the initial 3D point cloud on the left and the highlighted default detected automatically on the right. Figure 5 presents an example of out-of-AIRSLIP™ section on a billet. The coloured spots highlight the locations detected by the system as defective.

To develop the defects detection algorithm, a lot of billets of different alloys presenting different surface defects and
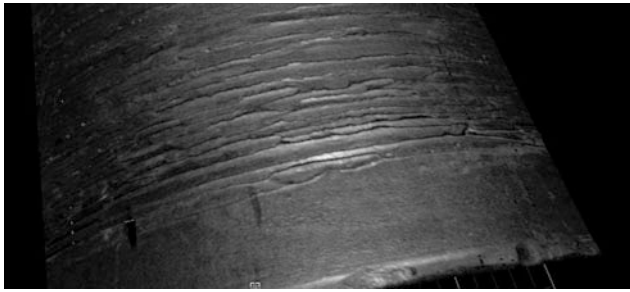
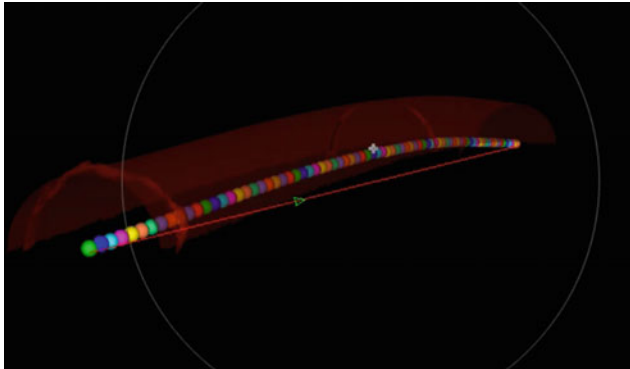**Fig. 1** Close-up view of the 3D intensity level

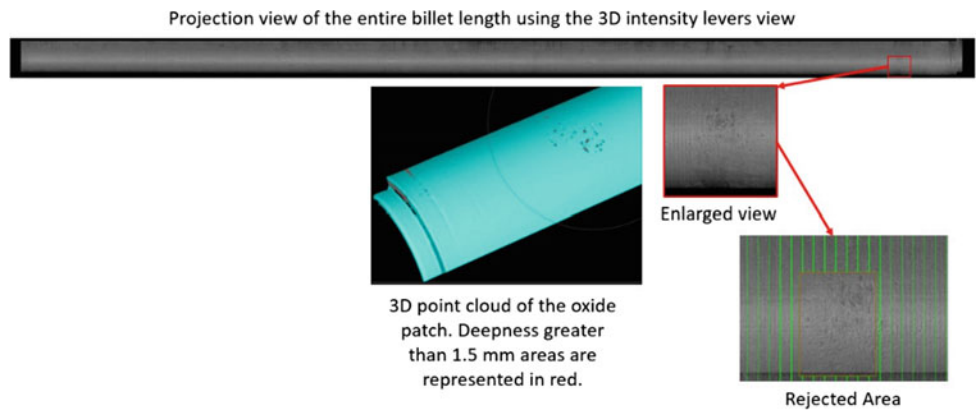**Fig. 2** Measurement of the billet bending

Fig. 3 Oxide patch detection
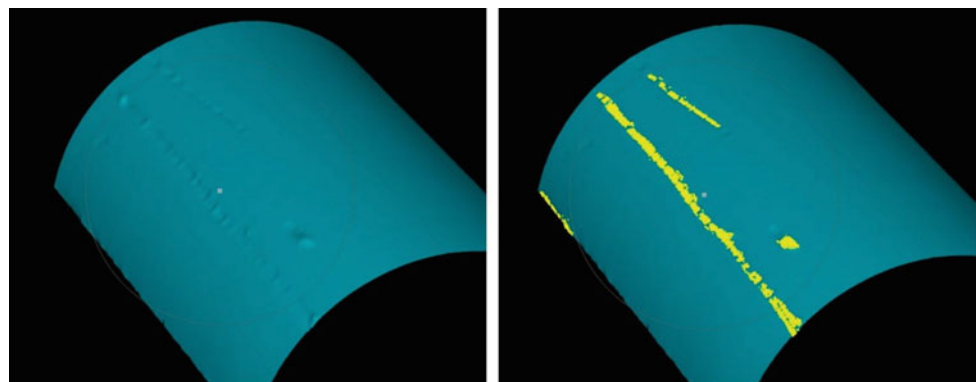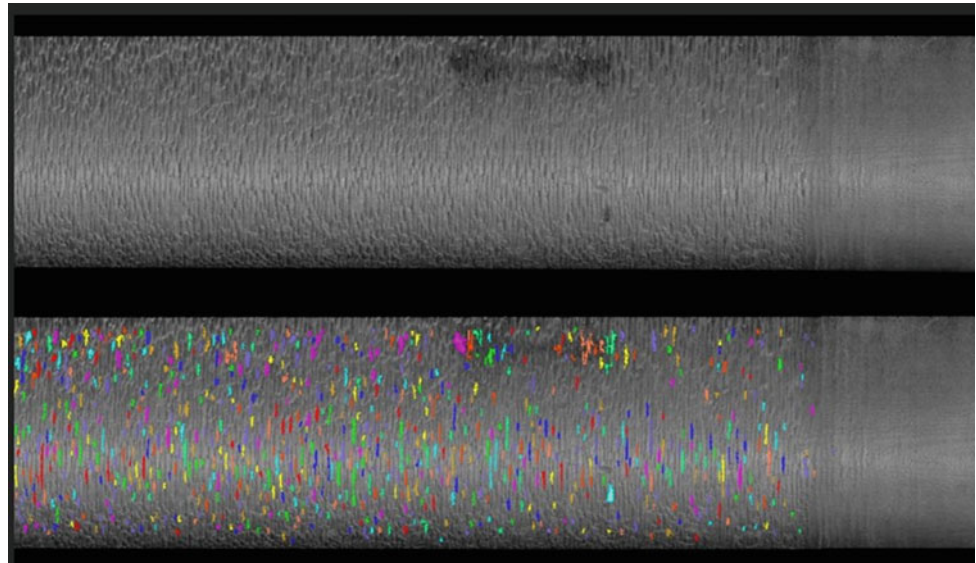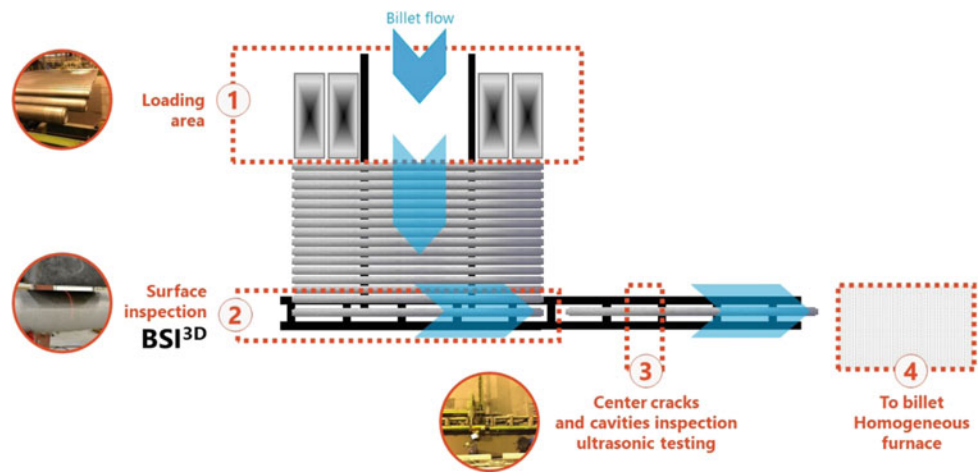
deformation have been shipped to STAS shops. The status of each billet has been rigorously analyzed and documented. Each billet has numbered. The circumference has been divided into 3 sections of 120° each in order to correspond with the scanning area of the BSI3D. ABI assigned its best-skilled operator for the manual inspection to STAS shop for a few days and each billet has been characterized and commented and recorded in detail by this inspector. Then, we were able to scan the billets with the BSI^{3D} and compare automated inspection results with the recorded comments of the operator for each billet. The results spoke for themselves. All the types of defects could be detected, characterized and localized.

Moreover, the criteria are fully customizable. Globally, the maximum deepness of a defect is set, and the maximum surface area involved.

Physical and Operational Characteristics

In the current industrial application, the BSI^{3D} is installed just after the loading area, at the location where the billets change 90° in their direction flow. Figure 6 presents a top view of the BSI^{3D} localization. The billets are removed from

Projection view of the entire billet length using the 3D intensity levers view

3D point cloud of the oxide patch. Deepness greater than 1.5 mm areas are represented in red.

Enlarged view

Rejected Area

Fig. 4 Vertical tear

Fig. 5 Out-of-AIRSLIP™

Fig. 6 Top view of the BSI^{3D} localization

Fig. 7 Configuration of the BSI^{3D} installed at ABI
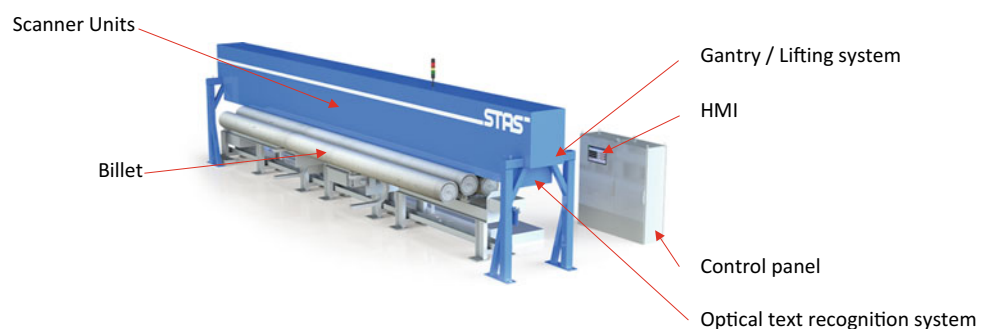
the casting pit with the crane and introduced in the loading area of the horizontal conveyer. Then, they are aligned on each other waiting for the surface inspection area, after they progress through the center cracks and cavities inspection machine.

Figure 7 shows the configuration of the BSI^{3D} installed at ABI in Quebec. The cycle time is about 80 s but may be

reduced if needed using different components and configurations. The maximum billet length for this unit is 8800 mm and the billet diameters range from 178 to 381 mm. The BSI^{3D} can be easily designed for different billet lengths and diameter ranges.

The version of the BSI^{3D} installed at ABI scans 120° of the billet surface at the time. It means that three (3) scans are
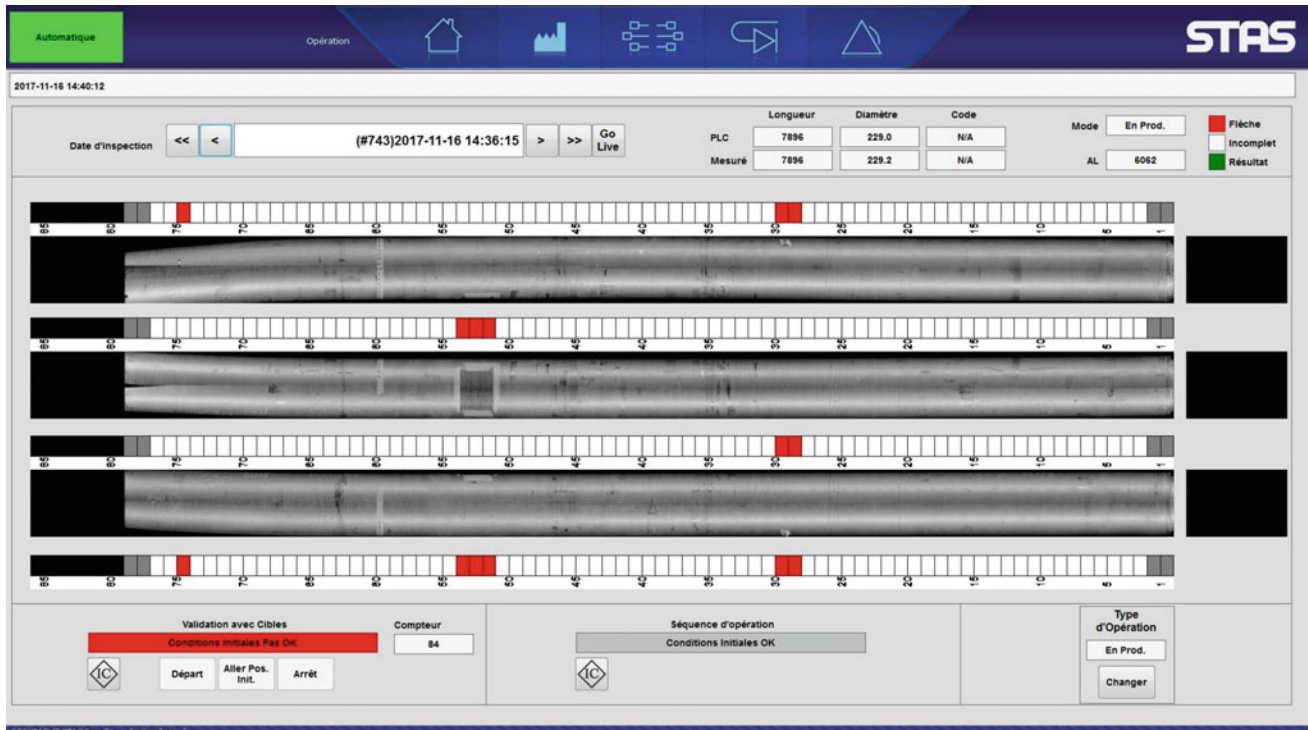
Fig. 8 Home page of the HMI

required to cover the entire billet surface. The rotation of the billet between each scan is automated. The billet is immobile during the scan allowing very high precision of the point cloud acquired. Indeed, if the billet would turn on itself or would go forward on rolls during the point cloud acquisition or the scanning process, the surface defects of the billet would introduce small displacements introducing noises. This would be very difficult to remove. Moreover, if the billet were bent on its length, noises would also be introduced.

The home page of the HMI of the BSI^{3D} is shown on Fig. 8. We can observe a projection view of each 120° scans in the middle. The little red squares indicate rejected areas and the bottom line located under the 3 pictures summarizes the rejected slices for each scan. The same slice length unit is used by the ultrasonic inspection process which is performed right after the BSI^{3D} surface inspection. Thus, the acceptance or the rejection of each slice is determined using both surface and internal inspections. Depending on the final billet length to be delivered to the customer, good sections can be used, even if the billet has some defect slices. At the saw, defects sections are disposed into the recycle container and the good logs are used. If the billet does not contain sufficient defect-free length, it is moved toward the rejection area.

The BSI^{3D} is also supplied with a sophisticated optical character recognition system to get automatically the code of the mould written on each butt. Figure 9 shows an example of the image analysis performed to highlight the code which presents a very low contrast.

The BSI^{3D} also comes with its internal database to give access to the results history and to facilitate the data

Fig. 9 Low contrast optical character recognition
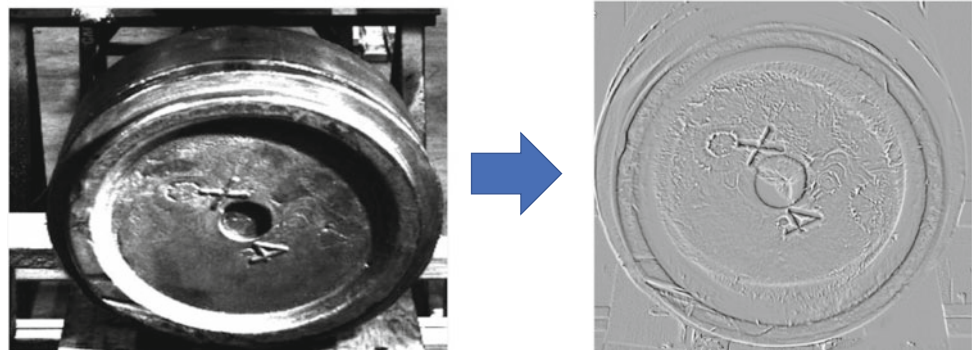
transmission to the plant database. A communication module is also integrated allowing the use of 4.0 technologies like cloud reporting and remote technical support.

Conclusion

An automatic billet surface inspection system has been developed by STAS. This equipment uses the latest technology in terms of 3D vision and allows a measurement resolution as low as 0.04 mm. The billet is immobile during the scanning process, which ensures high precision readability. The BSI^{3D} has been tested intensively in STAS shops using a first lot of billets having different surface defects and deformations and it showed overwhelming performances. The factory acceptance test (FAT), using a second lot of billets, has been a success and the customer was very satisfied. Following the FAT, the BSI^{3D} has been installed at ABI in September 2018. However, at the time we edited this paper, given the lockout situation at ABI, The BSI^{3D} has not been started. In fact, ABI does not produce billets during the lockout.

References

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