HD SCAN – ULTRASOUND TECHNOLOGY FOR QUANTITATIVE EVALUATION OF THE INTERNAL QUALITY OF AS-CAST STEEL PRODUCTS)*

Ernst Lindemann[1]
Jochen Wans[2]
Martin Klein[3]
Tamara Gusarova[4]
Oliver Hofmann[5]

Abstract
The SMS group has developed the ultrasound technology "HD scan" for inspection of the internal quality of as-cast products. This method of sample analysis requires less preparation work and is safer than the current, most common technique of etching and/or sulphur printing. Furthermore, this technology offers a three-dimensional view into the sample of the cast product and thus more representative information for a better quality evaluation. The internal quality evaluation can be performed automatically and objectively by software based on clear statistical methods. A quantitative centerline segregation rating can be assigned to each sample, based on the size and distribution of segregates detected by the unit. Internal crack statistics (length, position, orientation, etc.) and narrow side profile can also be measured. Grain macrostructure can also be visualized which allows for a potential optimization of casting parameters like strand cooling, soft reduction or electromagnetic stirring. The accuracy of the new method was proven by parallel metallographic investigations of more than 100 samples of different steel grades and sample shapes. Automatic defect evaluation and classification was compared against macroetching results. It was found that HD scan identified more defects and the visualization of the macro structure could be performed in more cases than with macro etching. All tests, comparisons, further developments and analyses for various steel producers and steel treatment companies have been conducted at the HD scan unit, located at the SMS group headquarters in Düsseldorf, Germany (Figure 1). Based on the results, SMS group has designed a unit which can be used in industrial scale.
Keywords: Ultrasound; Macro etching; Internal quality, Automatic defect evaluation.

[1] *Dipl.-Ing. (FH), Senior Application Engineer, Technical Sales, SMS Siemag do Brasil, Belo Horizonte, Minas Gerais, Brazil.*
[2] *Dr.-Ing., General Manager Technical Sales Technical Sales Special Technologies / New Developments Department, SMS group, Düsseldorf, Germany.*
[3] *Dipl.-Ing., Technical Sales Technical Sales Special Technologies / New Developments Department, SMS group, Düsseldorf, Germany.*
[4] *Dr.-Ing., Development Instrumentation, R&D, SMS group, Düsseldorf, Germany.*
[5] *Dr.-Ing., Technical Sales Technical Sales Special Technologies / New Developments Department, SMS group, Düsseldorf, Germany.*

1 DISCUSSION

Historically, internal quality of as-cast products in the steel plant has been evaluated by macroetching or sulphur printing techniques. Sample preparation is a time consuming step of the procedure as the sample has to be scarfed in order to achieve high surface quality. Afterwards the etching technique is applied for visualization of centerline segregation, cracks, other defects and sometimes the macro structure of the sample surface.

The etching laboratory and all of its equipment is space-consuming and expensive to built and maintain. The purchase, removal and disposal of hazardous substances (acids) is quite cost intensive and poses a safety and environmental hazard. Not every steel plant possesses an etching facility, as some ship their samples to an outside laboratory. This can result in a loss of know-how and time.

Another large disadvantage of the macroetching procedure is the quality evaluation. Today, a digital picture of the sample surface is taken. The distribution of segregations is then compared to a classification picture catalogue, typically the Mannesmann Rating Scale. A lab technician assigns a segregation rating, usually on the scale of 1-5, on the basis of this one chosen random layer as a representative quality evaluation of the entire cast product. Etching results are known to be strongly dependent on etching conditions, like acid type, etching time or temperature, and subjective operator evaluation.

The HD scan unit was developed to improve the above situation. It consists of two ultrasound sensors which are accurately positioned over the steel samples. The sensors and samples are submerged in a water basin. The water acts as the coupling medium for the ultrasound wave to pass between the sensors and generate results.

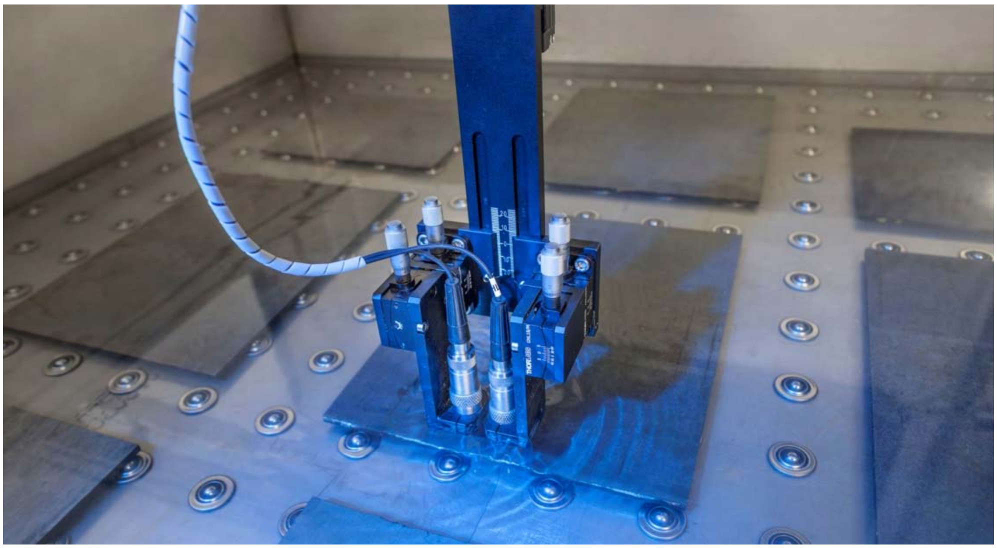

Figure 1: Ultrasound sensors of the HD scan unit scanning a steel sample

2 ULTRASOUND SYSTEM

Ultrasound is a widely known and well-established technique for non-destructive analysis of the inside of a material used in medicine and many other fields. In the steel industry, ultrasound testing is already used to evaluate the internal quality of as-rolled material.

HD scan utilizes two ultrasound sensors to provide a three-dimensional view into the sample. One ultrasound sensor is capable of scanning up to 100 layers within a thickness of six millimeters (Figure 2). By doing this, the method provides a much deeper and more representative view of the actual quality of the steel which was cast. With this information, the software can provide an automatic evaluation of the internal quality.

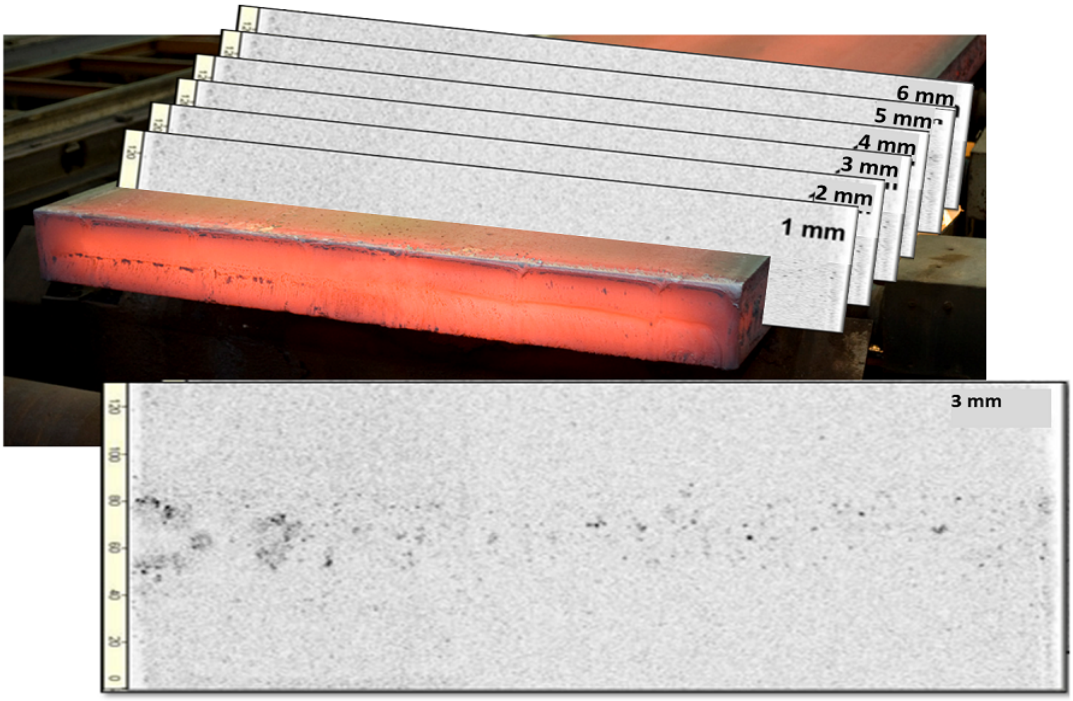

Figure 2: Multiple scanned layers in one slab sample

The second ultrasound sensor sends a soundwave through the complete sample thickness and its reflected signal is evaluated to retrieve the macro structure of that sample.

By carrying out numerous tests, analyses and investigations, clear statistical rules were derived to describe the segregation evaluation and classification procedure. Flaws determined in the sample are highlighted in red (Figure 3).

Then the location of the centerline segregation band is determined automatically, as the metallurgical middle of a sample is not necessarily its geometric middle. The size of the centerline segregation band is predetermined, but can also be adjusted manually. Afterwards, the flaws in the segregation band are automatically evaluated, depending on their number, size, and other parameters. Finally, the centerline segregation classification rating is calculated by an equation. Customer specific product classification rules can be implemented as the calculation is adjustable.

ISSN 1982-9345

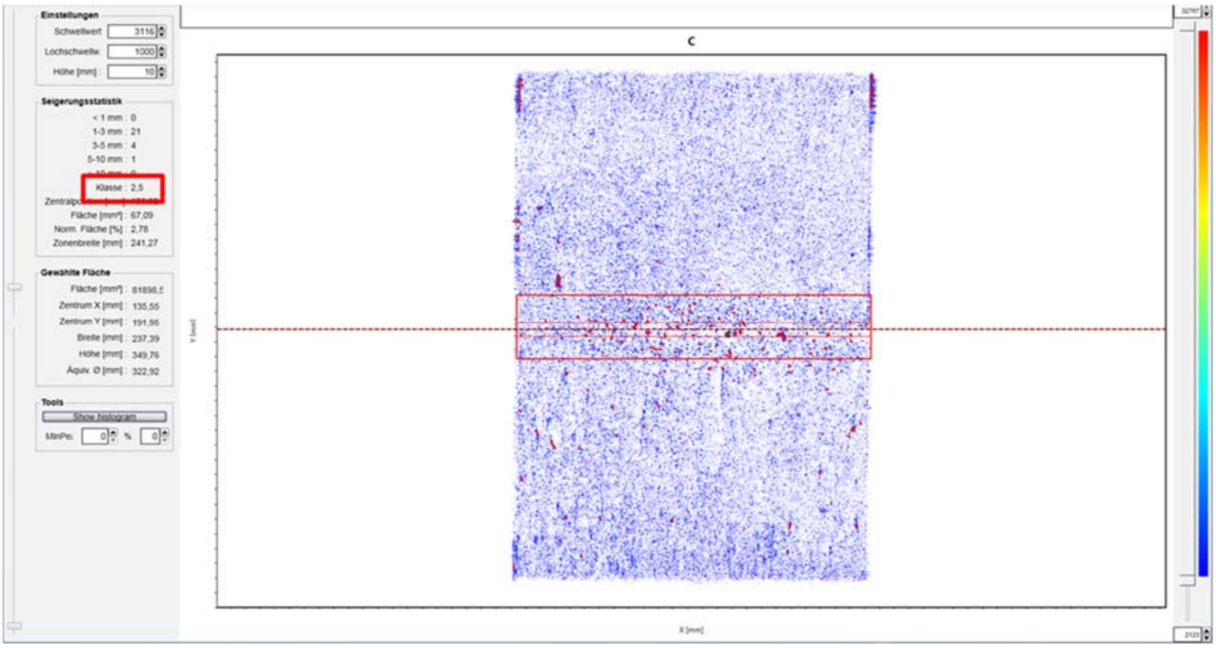

Figure 3: Example of automatic estimation of segregation rating for a slab sample [1]

The samples used for this procedure are similar to the ones from the etching method: cross sections of slabs, blooms or other kinds of cast products perpendicular or parallel to casting direction. One difference is the necessary surface quality. Grinding is not necessary, a roughly milled surface is sufficient and even rust on the surface does not disturb the ultrasound signal. Also saw cut of high quality is doing.
The samples are placed into a water basin and then the automatic procedure is started. The sensors scan the samples without touching their surface, operating at a distance of 10-20 mm above the sample surface. As mentioned earlier, two sensors work in parallel, one for the analysis of internal defects, the other to gather the macro structure. The feedback, with predefined rules, can be presented in a two or three dimensional view of the sample interior (Figure 4).
The software package allows not only the detection of defects, but also displays their three-dimensional orientation. This allows a view into the origin and direction of the defect and can result in counter measures at the caster which are more likely to succeed. This could not be done using other analysis methods.

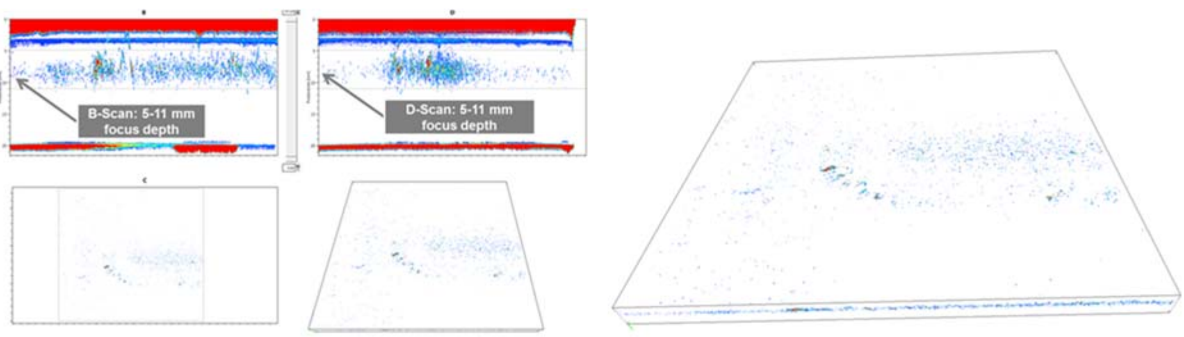

Figure 4: Two (left) and three dimensional (right) images of HD scan analysis of internal defects (sample depth = 5-11 mm)

2.1 MACRO STRUCTURE ANALYSIS

Ultrasound visualization of macrostructure has been performed previously by others, but it was primarily used for optimization of magnetic stirrers [2, 3]. The ability of ultrasound to sense differences in macro structure is mainly due to the variation in grain size and structure of the steel sample [4]. However, differences in the orientation of crystallographic lattice between grains and the reflection of the ultrasound wave at the grain boundaries are also influencing the ultrasound pattern. The exact evaluation of the ultrasound signal is converted into the macro structure, as shown in figure 5 on a cross section of a bloom.
In the left image, the homogeneity of cooling during casting is interpreted. Red represents higher cooling speeds and blue represents lower cooling speeds. The stirring direction and intensity can also be derived from the angle of the dendrites.

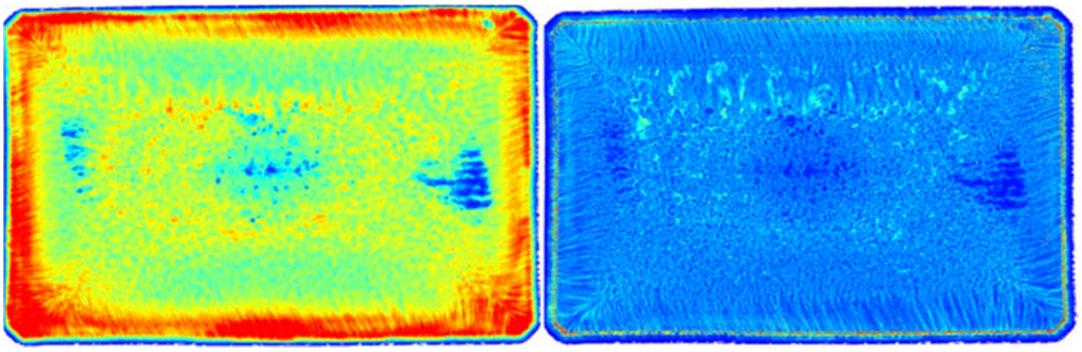

Figure 5: Ultrasound visualization of cooling conditions during casting (left) and macro structure grains (right) on a cross section of metal blooms sample [1]

An additional sample requirement for macro structure analysis and quantification is the flatness of the sample surface, with preferably ±0.5 mm deviation. Without this flatness, unwanted artefacts can appear in the ultrasound view (see red color in upper right corner of image on left in Figure 6). In the right image, the determination and quantification of columnar and equiaxed zones is displayed.

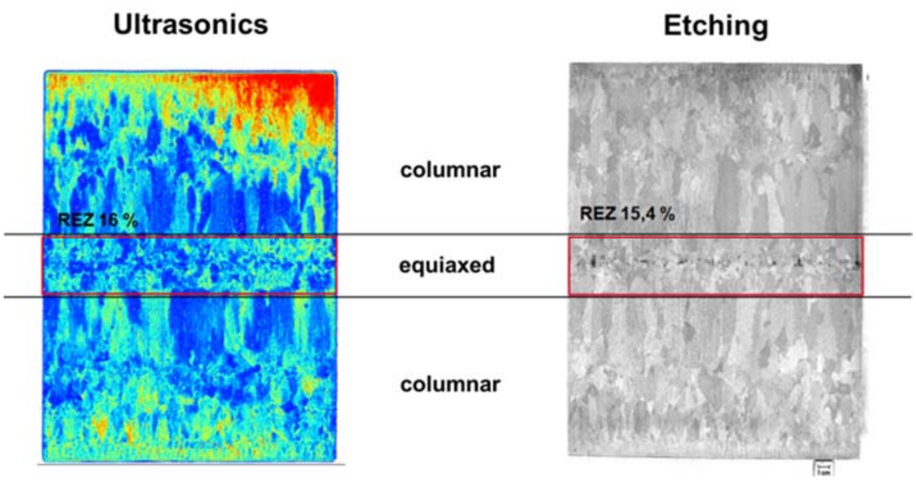

Figure 6: Unwanted artefacts of ultrasound scanning on a non-flat sample (red in upper right corner of left image) [1]

ISSN 1982-9345

2.2 COMPARISON ULTRASOUND VS MACRO ETCHING

During the development of HD scan, various verification tests were performed. Flaws detected by ultrasound were checked against metallographic investigations of the sample. The sample was scarfed to the defined depth which was analyzing by HD scan. Then the result of macro etching was compared to the associated layer of the ultrasound result. An example of a billet sample is shown in figure 7.
These figures display the similarity of the ultrasound and macro etching results. The left image shows the macroetch and the right image displays the ultrasound results. In the ultrasound results, flaw-free areas are shown in deep blue, whereby flaws are presented from light blue to red, depending on severity. Cracks in all four billet corners and center segregation were detected by both methods.

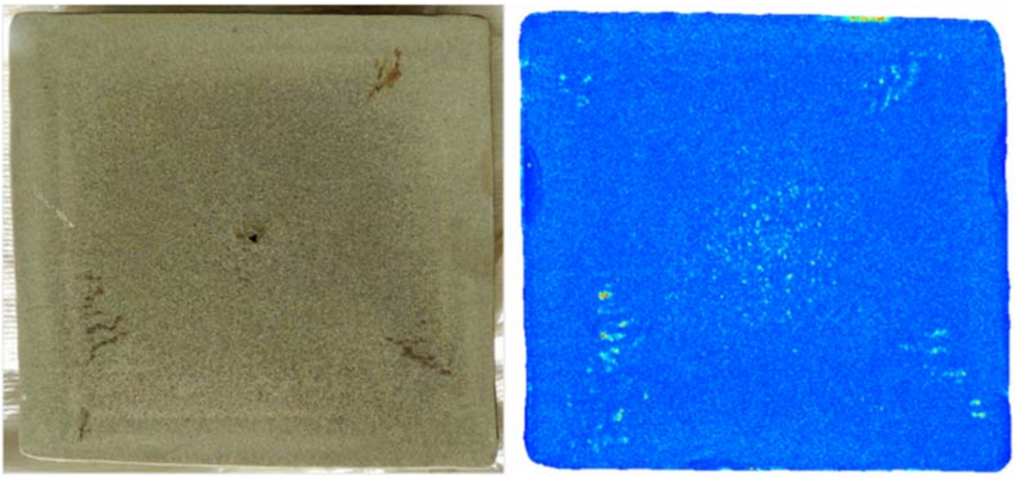

Figure 7: Comparison of macro etching (left) and ultrasound (right) results for a billet sample [1]

The verification techniques mentioned above is work and time consuming. Therefore, the verification was also performed with another method. For more than 100 samples the estimated quality ratings between the ultrasound data and the macro etching were compared. Over 80% of the samples lie nearly in the same quality class, only with deviations from ± 0.5% (on a scale of 1-3, with 0.5 increments). Any discrepancies were due to a different defect distribution over the sample depth that was only detected with the ultrasound method.
In figure 8, a macroetch for the surface of a thin slab and an HD scan result over the sample depth are compared. Whereas no defects were detected by macro etching on this plane, ultrasound testing showed multiple defects over the depth of the sample. In order to prove ultrasound test results, the sample was cut along the dashed line at the position of one defect and analyzed under microscope after metallographic sample preparation. The defects were found deeper in the sample, as confirmed by the ultrasound method.

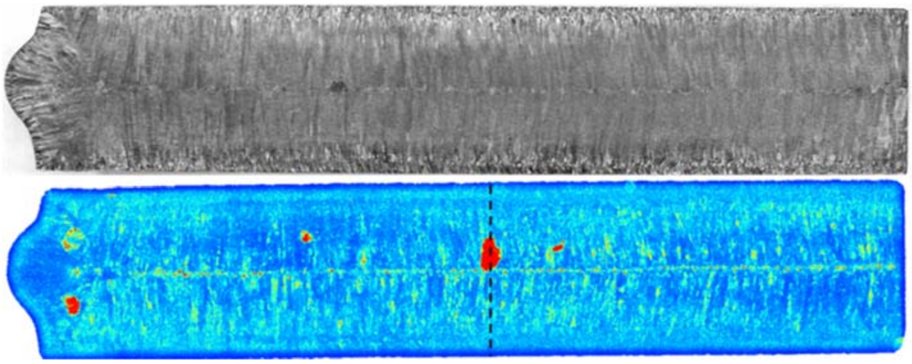

Figure 8: Testing results of a thin slab sample: macro etching on the surface layer (above) and ultrasound results for the volume (below)[1]

Scanning with the ultrasound technique allows objective data acquisition, independent of etching parameters, operator and segregation type. This method provides a realistic image of the sample that is not dependent on one randomly chosen layer. Besides, a three-dimensional analysis is advantageous for the determination of the defect expansion in the material. To get a similar conclusion by macro etching an immense effort is necessary, because every layer has to be excavated and processed. The clean and safe ultrasound technology is less labor intensive and does not require hazardous substances. Therefore, no special safety precautions have to be taken and no special equipment is needed.
The specially developed HD scan software provides results in a three-dimensional view. Virtual cutting allows the operator to scan layer by layer through the sample. These two-dimensional pictures can then be used for a comparison with the macro etching results. The sophisticated software gives the possibility for an automatic sample quality evaluation including segregation rating, crack statistics and profile parameters. Similar results acquired by macro etching are possible but very time consuming.

3 INSTALLATIONS

HD scan was designed, assembled and optimized for cast material analysis. The pilot equipment consists of an ultrasound unit, ultrasound sensors, a water basin and a PC including software for automatic evaluation. The sensors are movable in three axes and reach every position in the water basin. The size of the basin is 1.5 x 1.5 m^2 (Figure 9). Samples up to this size could be treated. Nine samples of 30 x 20 cm^2 can be placed in the basin in parallel and be scanned in batch mode.
Scan times vary based on the size of the sample and resolution of the scan (i.e. how many layers). An 8.5 x 11” sized sample can be scanned in approximately 40 minutes, at the highest resolution. Samples are loaded into the basin, the program sets it up, and the operator can hit start and walk away as all samples will be scanned automatically, for example overnight.

Figure 9: Ultrasound testing unit at SMS group for up to nine samples [1]

The HD scan applications developed so far, and the potential in this technology, requires further steps, including the development of a facility useable in industrial environments. In the pilot unit, the process itself and the software were developed. Placing the unit in industrial scale requires that other aspects are considered, like optimization of the work flow and safety precautions. Based on a current customer inquiry, the construction of a unit in industrial scale was performed (Figure 10). The unit consists of a steel structure and the necessary basin. As mentioned, the basin dimensions are scalable, but in this case the size is 1.800 x 500 mm^2. This basin size was selected to be able to scan an entire slab cross section.

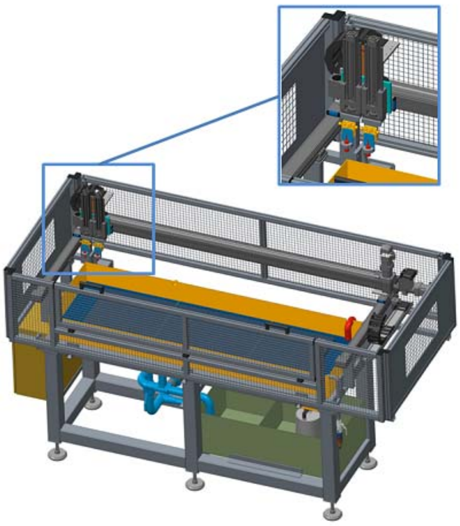

Figure 10: HD scan device in industrial scale

The smooth and accurate movement of the sensors is a key factor in the proper analysis of the sample and is realized with three axes control. The exact height positioning of the sensors is performed by self-locking screw drives (see detail in figure 10). The positioning of the samples can be done manually or with an existing crane. To guarantee easy and clean sampling, water is pumped into a tank beneath for filtering and back into the basin after this work. The entire unit is guarded and covered for safety reasons. The sampling, up to now, is done manually, which only allows a batch operation for the samples placed in the bath in parallel. A totally automatic batch service can be supplied with small constructive modifications.

4 CONCLUSIONS

Ultrasound testing was proven to be a reliable and accurate method for quality evaluation of steel samples. This new technique provides more information with less effort and less risk to health and environment. HD scan results are objective and are automatically calculated and stored, including information about defect distribution and macro structure. The large amount of information gathered could contribute to the optimization of casting parameters, such as strand shell cooling, soft reduction or the use of mold and strand stirrers.
Slabs and steel sheets thicker than 12 mm can be analyzed easier, safer, environmentally friendlier and automatically. This method is available not only to steel producers to control their products, but can also be used by steel treatment companies to analyze their material and with that to optimize their processes.
The know-how available at SMS group and the continuous exchange with plant operators allowed SMS to build, operate, and tune the pilot facility. An industrial scale facility is the next step to apply the HD scan to practice.

REFERENCES

1 T. Gusarova, S. Schulze, A. Runge, M. Reifferscheid, Ultrasound testing for the internal evaluation of cast steel product, 2nd ESTAD Conference, 15th-19th June 2015, Düsseldorf
2 M. Raj, J.C. Pandey, Evaluation of the effect of electro-magnetic stirring on soundness of continuously cast billets using ultrasound technique, Proc. National Seminar on Non-Destructive Evaluation, 2006, pp. 31-38
3 M. Raj, R. K. Saini, K. Balasubramanian, Development of an ultrasound C-scan imaging technique for optimization of electromagnetic stirrer to improve steel billet quality, 18th World Conference on Nondestructive Testing, 16th-20th April 2012, Durban, South Africa
4 M. Raj, J. C. Pandey, Optimisation of electromagnetic stirring in continuously cast steel billets using ultrasound C-scan imaging technique, Ironmaking and Steelmaking, 2008, Vol. 35, pp. 288-296