Possibilities to Use New Measurements to Control LD-KG-converter

Jari Ruuska[1)*], Seppo Ollila[2)], Lars Bååth[3)], Kauko Leiviskä[1)]

[1)]University of Oulu, Control Engineering Laboratory, Oulu, Finland
[2)]Rautaruukki Oyj, Ruukki Production, Raahe, Finland
[3)]Agellis Group AB, Lund, Sweden

Measuring from the converter is demanding. On the project financed by Rautaruukki Oyj and TEKES (the Technology Agency of Finland) the aim of the project was to develop the control of the converter during the blow by improving the usability of current measurements and by testing new measurements. Splashing measurement based on image analysis was found out to be good and it was taken into use. Also test experiment with Agellis-measurement showed promising results to measure levels within the converter.

Keywords: LD-KG-converter, control, RWI-measurement, splashing, steel making

INTRODUCTION

The control of converters used in steel making utilises different kinds of static and dynamic models. The measurements during the blow are used in predicting the end point of the blow. The most important blowing parameters are the height of the oxygen lance, the flow rate of the oxygen and bottom stirring gas. The blowing parameters are chosen before the start of the blow and normally they are constant during the blow. Of course, for example the lance program lowers the height of the oxygen lance. There is a potential to change the parameters by monitoring the measurements during the blow and by doing this, it would for example be possible to decrease iron losses during the blow. By using more optimal blowing parameters, it would be possible to decrease the wear in the lining of the converter and more blows could be done with one lining.

Steelmaking in LD-KG-converter is a batch process (typical heat size at Raahe Steel Works is 125 tonnes), where hot metal (about 80% of charge) and steel scrap (about 20% of charge) are charged into the converter. The main task of the converter is to remove carbon from hot metal. Temperature of steel rises from about 1300°C to almost 1700°C and the processing lasts about 18 minutes.

Excessive splashing and slopping in LD-KG-converter is a serious problem. It causes economical losses and therefore it is widely researched. The negative effects of splashing are well-known, for example lower iron yield, skulling of the vessel mouth and lance, hard blowing, poor dephosphorization and desulphurization [1]. To be able to prevent splashing, we need to know the factors that cause slag foaming. For example, Jung & Fruehan [2] investigated the effects of FeO-content, basicity, TiO_2, MgO and temperature of slag on foaming. The factors effecting on the amount of splashing are often

---

*Corresponding author: Tel.: +358-8-5532470, E-mail address: Jari.Ruuska@oulu.fi

investigated by using water models. Luomala *et al.* [3] investigated the effect of following variables: lance height, gas flow rate, lance nozzle angle, bottom blowing, lance position and foamy slag.

In this paper, some results from the project financed by Rautaruukki Oyj and TEKES (the Technology Agency of Finland) carried out in Control Engineering Laboratory are reported. The aim of the project was to develop the control of the converter during the blow by improving the usability of current measurements and by testing new measurements. With improved control, it is possible to decrease the variance of the blowing results and to improve the yield of the steel by decreasing the splashes during the blow.

1. Process Description, Current Measurements and Measurement Study

1.1 LD-KG-converter process [4]

The task of the steel converter is to lower carbon content (about 4.5%) of hot metal to target carbon content of steel (about 0.05%). Other tasks are to heat the melt enough for further processing, to remove impurities (for example sulphur and phosporus) and to melt the charged scrap. Blowing pure oxygen into hot metal decarburizes the melt. Oxygen reacts with carbon generating mainly carbon monoxide. LD-KG-converter (Linz-Donawiz Kawasaki Gas) (Fig 1) is a combined blowing BOF-converter with inert gas (Ar or N_2) stirring, which is achieved through multi-hole nozzle bricks in the bottom. Stirring is used to keep the melt homogeneous and to lower the oxygen level in relation to carbon content at the end blow.

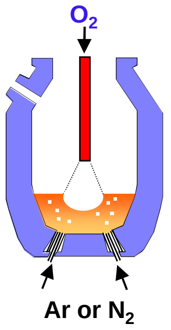


Fig. 1: LD-KG-converter.

1.2 Current Measurements

It is hard to make direct measurements from LD-KG-converter because of demanding conditions. This chapter describes the converter measurements that are used at Raahe Steel Works.

The blowing height of the oxygen lance is adjusted according to the bath height in the converter. Rate of decarburization is controlled with choosing the right lance pattern from pre-programmed patterns. The decarburization rate is estimated with an off-gas temperature measurement. Off-gas temperature data is also used in the dynamic model to predict the end-point carbon content.

To be able to estimate the actual distance between the oxygen lance tip and bath surface, the volume of converter needs to be known. The laser measurement for lining wear is done regularly three times a day. Using the laser measurement the lining is measured from whole converter. With this information it is possible to calculate the level of bath surface and the oxygen lance can be calibrated to the correct height.

It is possible to estimate the formation of slag foam during the blow with a sonic meter. Sonic meter measurement is based on measuring the intensity of the noise with a microphone placed nearby the mouth of the converter. The placement of the microphone is problematic and disturbances can exist. At Piombino's steel plant there is an adaptive control model based on sonic meter measurement; control parameters are the height of lance, the flow rate of oxygen and/or the amount of bottom stirring [5]. Dynamic lance height control (called Smart Lance) is in the use at Corus's Teesside Works [6]. In addition for example Birk *et al.* [7] have investigated the applicability of the sonic meter measurement to control the foaming of slag by using a water model.

A dropping sensor system is in use at all three converters at Ruukki's Raahe Steelworks. The dropping sensor is based on a normal temperature measurement with a thermocouple placed inside the sensor. With the dropping sensors it is possible to measure the momentary temperature of steel during the blow and the temperature and the oxygen content of steel after the blow [8].

1.3 Measurement Study

The dynamic control of the converter requires good reliability and accuracy from the measurements. In the literature study done in the project [9] the applicability of certain measurements was studied. The measurement objectives were off-gases, the surface of melt and slag, the vibration of the converter and the lance and the observation of metal splashing using image analysis.

2 Sonic Meter Measurement, RWI- and Splashing measurement

Some issues about these measurements are reported also in Ruuska *et al.* [10].

2.1 Sonic Meter Measurement

In the beginning of the project the capability of current sonic meter measurement was investigated. In the beginning of the study two issues were noticed that needed to be corrected. The frequency range of the measurement was incorrect as from time to time the incoming signal to process automation was cut off at 120 dB. It appeared that the signal from the sensor was transferred correctly, but in the process automation system the signal was cut off programmatically. After resetting of the frequency range, the signal was correct. Another problem was that the signal contained disturbances, which were assumed to be caused by the noise originating from the addition of lime. By averaging the signal it was possible to verify that the disturbance was caused by lime addition. This disturbance can be handled by "freezing" the signal, when lime is added. Figure 2 shows typical heat with sonic meter measurement and other measurements that have an effect on the variation of the sonic meter measurement. It was assumed that the sonic meter measurement's research wouldn't lead into remarkable improvements within short time period. It was noted though that it would be an interesting case for further studies.

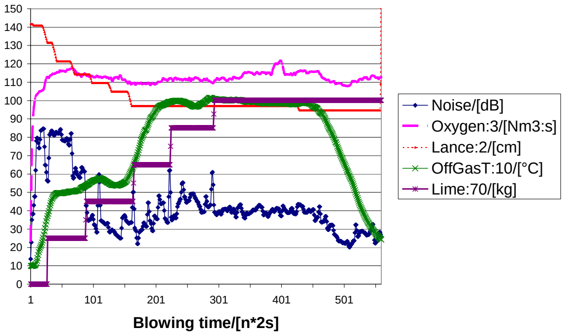


Fig. 2: Typical heat; sonic meter signal and other measurements

2.2 Agellis-measurement

Radio-wave interferometry uses radio waves to measure. The method is based on the fact that there is a slight change in the amplitude, phase and polarization of electro-magnetic radiation as it goes through the interface of two different materials. Agellis-measurement does not disturb the process; it can separate different layers of melt and slag and simultaneously measure the interface level height of each such layer. Agellis-measurement was tested at British Steel's Teesside Works [11]. A typical installation of an Agellis-instrument is shown in Figure 3.

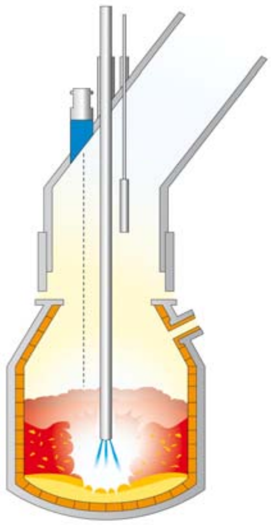


Fig. 3: Typical installation of Agellis-instrument

A test experiment was performed to measure the levels in one of the converters at Raahe Steel Works. The purpose was to determine the dynamic changes in the levels of slag and steel during blowing as well as the static levels after the blow. An Agellis-instrument was placed on the off-gas duct with a direct visibility to the melt when the converter is in its upright position. The instrument was placed in midpoint between the oxygen lance and the walls of the converter.

In this paper we present an interpretation of the data from a blow at Raahe on May 19, 2005 starting around 09:52 (Figure 4). This heat shows typical behavior as all levels increase similarly at start. We interpret this to be caused by the blow of oxygen at the center of the vessel that will push down the center portion while the outer parts will then rise. First a flux is added and it causes a small addition in the volume of foam. The oxygen first reacts with silicon in the slag to form moderate foam. In few minutes this reaction has reduced all free silicon and then the oxygen will react with carbon to form carbon-monoxide and carbon-dioxide. The increased gas pressure will then form more substantial foam. Notice that this is a very fast process, the slag level is rising by about 1 meter in about 10

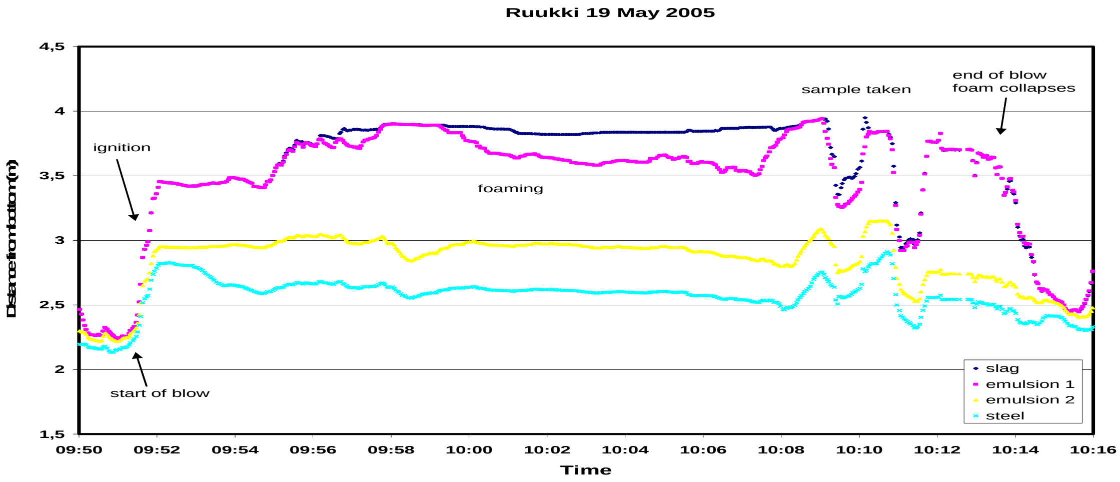


Fig. 4: Agellis-measurements of a heat

seconds. Two additional levels are forming at this point of the process. We interpret these levels to be the top of the emulsion of iron droplets in the foaming slag and an additional thicker emulsion forming close to the steel surface. The top emulsion should, and does in this case, be almost to the top of the foam producing a large reactive volume. The steel level increases at the start of the foam, possibly by bubble forming in the steel. The emulsion level decreases towards the end of the blow indicating that the blow rate is reduced. As the samples are taken, blowing is turned off temporarily and the slag is cooled off by the sampling procedure, thus temporarily collapsing due to gas released from the foam. A small burst of blow is given at the end to keep the heat. The foam then collapses as it should when the oxygen flow is turned off and the lance is lifted. The collapse could take up to a minute depending on the remaining amount of coal/oxygen after the blow. The vessel is then tilted for tapping and the instrument no longer has a visibility to the melt.

We conclude that the slag and steel levels can be measured before and after the blow and that the slag and emulsion layers can be measured during the blow. The tests indicate that the steel level is more problematic to measure during the blow, probably because the surface is disturbed due to turbulence.

2.3 Splashing measurement [12]

Splashing measurement is based on image analysis. At Raahe Steel Works, video cameras mounted near the vessel bottom are used to monitor steel and slag tapping. These existing cameras were utilized as the splashing measurement was developed. From the snapshot captured from the camera the picture pixels were analyzed. The amount of splashing was investigated inside a predefined area by counting the ratio of bright and dark pixels; the limiting value of brightness was predefined. The ratio of bright and dark pixels gives a numerical value for splashing. Splashing index for whole blow was counted from the momentary values.

2.3.1 Splashing data

For the investigation data was collected from BOF no. 1 between November-December 2004. The data from image analysis together with other process data were collected into the database from the plant automation system, information being collected from November to December –04. In total, about thirty variables were collected. The validation of the variables was carried out in co-operation with the steel plant personnel.

Normal pre-processing, for example the excluding of the heats that didn't have all data needed, was done first. The average splashing index is 1049,95 and its standard deviation is 506,40 for 481 heats. Figure 5 shows the variation of splashing index chronologically and Figure 6 the histogram of the splashing index. As Figure 5 shows, there clearly exist some circumstances that cause strong splashing. The variables and their combinations that cause strong splashing were studied next.

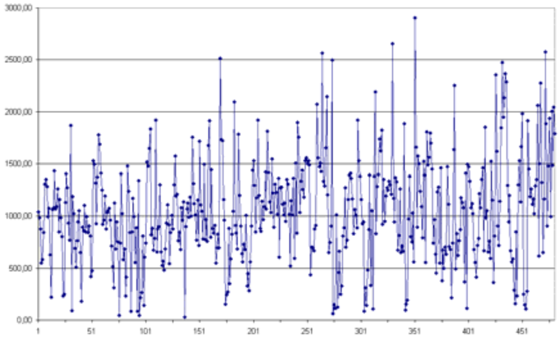


Fig. 5: The trend curve of the splashing index.

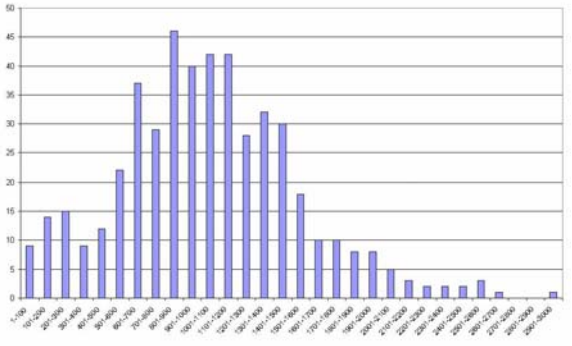


Fig. 6: The histogram of the splashing index.

2.3.2 Variables effecting on splashing

By analysing data and discussing with plant personnel, several variables were found out that should have effect on splashing. For every variable the ratio between different groups is counted to see the difference in average splashing index. It can be seen from Table 1. that the heat size has the biggest effect on splashing. Other variables that have a strong effect on splashing are amount of ferrosilicon (FeSi) added in the early stage of the heat and the amount of charged scrap. In Table 1. Heat105k means small heats (amount of hot metal + scrap is less than 120 tonnes) and Heat120k means bigger heats (more than 120 t of hot metal + scrap) respectively. FeSi* is the amount of added FeSi, [kg], Lime/Heat is the ratio telling how much lime is used to form slag and C-% is carbon content at the end of the blow.

Table 1. Splashing indices on prelimary grouping

Group	Average	Std dev	Ratio
Heat105k (76 heats)	691,33	381,79	1
Heat120k (402 heats)	1121,01	498,19	1,62
FeSi0 (131 heats)	864,05	449,40	1
FeSi38-200 (150 heats)	932,36	487,62	1,08
FeSi200+ (197 heats)	1269,77	476,26	1,47
Lime/Heat(<5.0%)(226 heats)	1109,61	491,58	1,11
Lime/Heat(>=5.0%)(256 heats)	1001,66	514,72	1
Scrap/Heat(<22%)(209 heats)	902,79	457,51	1
Scrap/Heat(>=22%)(269 heats)	1169,16	512,44	1,30
C-%<=0,035(252 heats)	977,98	446,19	1
C-%>0,035 (226 heats)	1136,01	555,02	1,16

It can be seen from Table 1. that the smaller heat size has reasonable low splashing, so the research will be focused on the bigger heat size. Figure 7 shows the effect of added FeSi on splashing index. Splashing index increases with increased FeSi amounts.

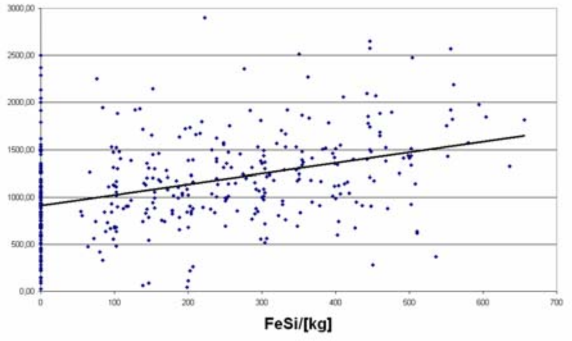


Fig. 7: Splashing index versus added FeSi.

2.3.3 Variables effecting on splashing in bigger heats

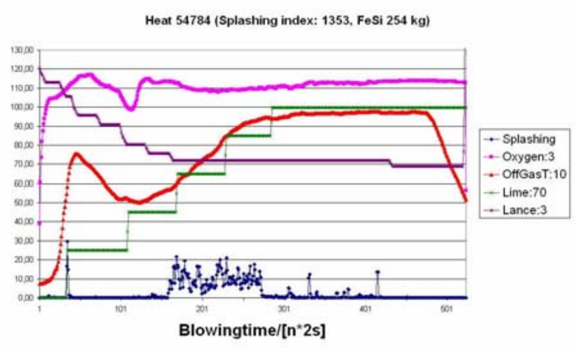
As we focused only on bigger heats, we needed to see, if those variables used in the whole database still had same effect on splashing. As observed from Table 2., Lime/Heat, Scrap/Heat and C-% have much lower ratio as earlier, so that means that their effect isn't that significant. More likely there is a different operation mode for these according to the heat size, for example different percentage of added lime for the smaller heat size. Added FeSi has still a significant effect on splashing. Added FeSi was grouped a bit differently to get more heats on the lowest group; it was noticed that about 100 kilograms of FeSi can be added into heat without having effect on splashing (FeSi0 ~= FeSi/Heat<0,00075). As many of variables didn't have that much effect anymore inside the bigger heat size group, new variables that have effect on splashing need to be considered. Research about that will be reported later.

Table 2. Splashing indices on Heat120k-group

Group	Average	Std dev	Ratio
Lime/Heat(<5.0%)(225 heats)	1114,33	487,51	1,00
Lime/Heat(>=5.0%)(172 heats)	1138,74	510,56	1,02
Scrap/Heat(<22%)(130 heats)	1027,31	457,32	1,00
Scrap/Heat(>=22%)(267 heats)	1172,42	509,50	1,14
C-%<=0,035(181 sul.)	1087,98	418,79	1,00
C-%>0,035(216 sul.)	1155,85	553,42	1,06
FeSi0(125 sul.)	926,51	483,19	1,00
FeSi/Heat<0,0015(102 heats)	1026,67	438,45	1,11
Fesi/Heat>0,0015(170 heats)	1329,72	464,53	1,44
Fesi/Heat<0,00075(152 heats)	928,13	476,46	1,00
0,00075<=Fesi/Heat<0,0015(75 heats)	1063,06	429,72	1,15
Fesi/Heat>0,0015(170 heats)	1329,72	464,53	1,43

3. Practical considerations

As some variables effecting on splashing have been found, next thing to be considered is how to utilize this knowledge in the control of LD-KG-converters. Let's first look at two heats; one, where FeSi is added in the early stage of the heat and another, where FeSi isn't added at all. We can see from Figure 8 that adding FeSi effects strongly on the off-gas temperature. That is natural as silicon oxidizes easier than carbon and the off-gas temperature is a function of decarburization rate. The progress of blow is disturbed and the high decarburization rate after silicon oxidation leads to strong splashing. How to avoid this? It would be easy to say that over 100 kilograms FeSi-addition is not allowed in the early stages of the blow. It isn't that simple anyway as FeSi is needed to bring the extra heat to the charge. Another option would be to add less scrap, but the scrap amount must be selected according to the target steel production amount.



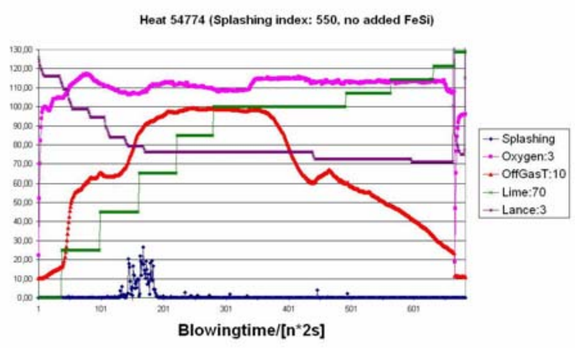


Fig. 8: Example about FeSi's effect on splashing index.

It can be seen from Figure 5 that there are some heats that have significantly stronger splashing. It can be assumed that there are many different variables causing stronger splashing. We need to be able to find those circumstances that lead into stronger splashing and then find ways to avoid them.

Looking at the heat size, it was noticed that if batch size is adjusted a bit, for example if biggest heat would be 135.5 tonnes instead of 138.5, splashing would go down with 8% (from 1125 to 1044). Of course it would cut down the production and it assumes that the heat size is only variable that contributes to higher splashing in those blows.

4. Conclusion

Requirements for measurements those are applicable to LD-KG-converter are high because of extremely difficult conditions. In this project splashing measurement was found out to be a useful tool and it now in use at all three vessels at Raahe Steel Works. The experiments with Agellis-measurement to detect different steel and slag layers during oxygen blowing proved to be promising. There are still some problems to be solved, for example to protect the unit from skulling.

In this study, it was found that the splashing in LD-KG-converter is caused by many variables. It was found that two most important variables are the heat size and addition of ferrosilicon.

Some ideas about avoiding strong splashing were given. For example it would be ideal not to add FeSi in the early stages of the blow and to limit the heat size to have more favourable volume to heat size -ratio.

This study shows that it is possible to find new measurements also into demanding conditions of LD-KG-converter. It takes quite a bit effort to find suitable measurements though. Anyway, studying this process is rewarding as even small findings will give remarkable economical benefits as the annual production is big.

References

[1] M. Bock, J. Schoop, C. Oehler: “The Influence of Blowing Techniques, Bottom Stirring and Lance Design in the LD-processes on Slag Formation, the Formation of Lance and Converter Skulls and Converter Lining Life”, 3rd European Oxygen Steelmaking Conference (EOSC), Birmingham, United Kingdom, Oct 30 – Nov 1, 2000, pp. 163-177.

[2] S. Jung, R.J. Fruehan: “Foaming Characteristics of BOF Slags”, ISIJ International, Volume 40, No.4, 2000, pp. 348-355.

[3] M.J. Luomala, T.M.J. Fabritius, E.O. Virtanen, T.P. Siivola, J.J. Härkki: “Splashing and Spitting Behaviour in the Combined Blown Steelmaking Converter”, ISIJ International, Volume 42, No.9, 2002, pp. 944-949.

[4] E.-P. Heikkinen, J. Heino: “Good to know for a metallurgist: The making of iron, steel and ferro-alloys” (in Finnish), University of Oulu, Oulu, 1999, 134 pp.

[5] C. Bencini, A. Poli, E. Lunardi: “Dynamic slag control in LD/LBE process at Ilva/Piombino steel shop”, 1st European Oxygen Steelmaking Congress, Düsseldorf, Germany, June 21-23, 1993, pp. 137-141.

[6] P.D. Smith, G. Harland, D. Bryce: “Enhancements in blowing control at Teesside BOS plant”, 2nd European Oxygen Steelmaking Congress; Taranto, Italy, Oct 13-15, 1997, pp. 387-396.

[7] W. Birk, I. Arvanitidis, P.G. Jönsson, A. Medvedev: “Physical modeling and control of dynamic foaming in an LD-converter process”, IEEE Transactions on Industry Applications, Volume: 37 Issue: 4, Jul/Aug 2001, pp. 1067 -1073.

[8] K. Laine: “The usage of the dropping sensors for controlling the temperature of steel in converter” (in Finnish), Master’s thesis, University of Oulu, 1998, 94 pp.

[9] H. Tenkku & J. Ruuska: “Literature study about the applicability of certain measurements to control LD-KG-converter” (in Finnish), University of Oulu, Report B 53, Oulu, December 2004, 32 pp.

[10] J. Ruuska, S. Ollila, K. Leiviskä: “Measurements used to control LD-KG-converter” (in Finnish), *Automaatiopäivät’05*, Helsinki, Finland, 6.-8.9.2005, pp. 311-316.

[11] M.S. Millman, L. Bååth, D. Malmberg, E. Price: “Radio Wave Interferometry fo Bos Slag Control”, ICS 2001, 2nd International Congress on the Science & Technology of Steelmaking, University of Wales Swansea, UK, April 10-11, 2001, pp. 309-320.

[12] Visetec (2004) Project Documentation, Raahe, 7 pp., http://www.visetec.fi