USING MICROWAVE INTERFEROMETRY TO IMPROVE THE BLAST FURNACE OPERATION

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Abstract

There are many known technologies that can be used to monitor surfaces, but the most of them requires a transparent environment to be functional. In the Blast Furnace where the environment is full of dust and fume at high temperatures those technologies are not applicable.

With a functional technology in such an environment the burden surface could be analysed and monitored, which in its extension would lead to a way to control the charging operation in the BF and thus a better use of raw material and also a better gas utilization.

In this paper we will discuss the use of microwave technology as one technology with the potential to create a topographical image of the burden surface in the Blast Furnace during operation.
Introduction

In the Blast Furnace hot metal is produced which in subsequent production steps is converted to different steel grades used by production industry such as car manufacturer, material to build infrastructure and many more applications. Within steel and metal production the Blast Furnace process provides approximately 2/3 of the global production.

Blast furnace performance is strongly dependent on controlling the gas distribution. Materials charging in the furnace is thereby one of the most important control parameters. On a global scale studies have been carried out with the objective to understand the charging equipment and its influence on the material distribution, e.g. angle of repose and charging materials interacting properties. These investigations assumed rotational symmetry in the blast furnace and are consequently restricted to 2D modelling or experiments.

For many years the only way to determine the burden surface position in a Blast Furnace was by stock rod measurements or similar mechanical methods. These methods have in many Blast Furnaces nowadays been replaced with radar technology doing the same job however with an increased accuracy and to a substantially lower price. Radar technology is also used to determine the burden profile along a radius in the furnace by organising several radars as a row matrix along the radius providing spot measurements along the radius. Another approach is a radar antenna mounted on an axis that is moving along the radius in the furnace continuously measuring the profile during movement. Yet another application is to organise a number of radars as a square matrix in the furnace and use this information to get an image of the burden distribution. In common for those radar application is that they assume charging symmetry in the furnace to provide a full image of the burden surface. Knowing that the burden distribution topography is dependent on the charging materials such as coke, lump iron, sinter, fines and pellets all with different interacting properties it is difficult to say that the produced image, based on the described measurements, of the burden surface is true.

With the knowledge of the distribution of the burden surface, the furnace can be controlled in a much more efficient way due to gas distribution generating less emission and by the end of the day an improved economic outcome. By knowing the burden distribution it is possible to control the gas distribution in the furnace and in this respect improving the gas utilisation.

In this paper we will discuss the use of microwave technology as one technology with the potential to create a topographical image of the burden surface in the Blast Furnace during operation by introducing radar interferometry. A fully functional technology has the potential of measuring in real time meaning that the material distribution after each charging sequence can be updated, signal treated and delivered as a 3D topographical image to the control room. In its extension this is expected leading to a better control of the gas distribution in the furnace and thus a better use of energy. More details about the Blast Furnace process can be found in ref. [2].
Experimental performance

Radio interferometry has successfully been used for astronomical research and the technology is used to produce high resolution images of astronomical objects under investigation. Radio waves, microwaves, can detect and reveal objects that are not visible in the visible range of the spectrum due to the presence of clouds of cosmic dust. In this respect the technology should also be suitable for application on a Blast Furnace to control and monitoring the burden surface during production since the environment inside the furnace is hostile with high temperatures, dust and fume. The antenna described in the following was especially designed to operate in such an environment.

Antenna

The most important hardware component in the experimental set-up is the antenna as it sets the overall performance of the complete measuring system. A planar patch antenna array has been designed and built for radar interferometry. The antenna array consists of 32 rectangular patches on a ceramic loaded Teflon substrate. The patches are individually coupled to the microwave electronics in two orthogonal circular polarisations; see Figure 1 for the patch structure.

![Frontend of the patch antenna](image1)

![Backend of the patch antenna](image2)

*Figure 1. Frontend and backend of the patch antenna.*

The radar interferometer is intended for topographic imaging in industrial environment, in this case a Blast Furnace. The basic material in the antenna is a ceramic loaded Teflon substrate and because of the environment in the BF the antenna would never survive without a proper protection. In our case we used a silica disk with physical properties to cope with both environmental and signal conditions required by the antenna. The disk will be positioned between the antenna and the environment it is designed to operate in.
Interferometry principles

In Figure 2 to the left is an elementary interferometer with bandpass receiver amplifiers, the geometric time delay and a receiver with lowpass filter bandwidth shown. By measuring the phase shift between the received signals the difference in travelled path length for the received signals is estimated. If the spatial vector distance between the antennas is known the position of the signal source can be calculated.

Figure 2. Elementary interferometer and the interferometer application setup.

To the right in the figure the application of the interferometer technology on a thought topographical surface is indicated. This approach constitutes the base of the signal treatment, described elsewhere [1], to produce a 3D topographical image of the object under investigation.

Experiments

The functionality of the interferometer was tested and verified using a single antenna. Also a complete interferometer set-up was tested and evaluated. A VNA(Vector Network Analyser) was used for the measurements as a signal source.

Simulations

Simulations of electromagnetic reflections from different targets were performed with a simple ray-tracing algorithm realised in a Matlab script. Simulated measurement data from an interferometer was generated by the ray tracing algorithm, and processed by a domain transforming algorithm. The same domain transforming algorithm, transferring data from spatial frequency domain to spatial delay domain, was used for the measured data. A third algorithm was used for presentation of the images. Yet other algorithms were made for testing CLEAN.

The ability to position reflectors was verified together with the theoretical resolution of the interferometer, see Figure 3. The object in this image is delimited by a surface
generated by connecting the points in the space where the intensity of the response has fallen to half of its maximum. The distance to interferometer origin is coded by colour. The radial half-power limits of the response, extends from approximately 1525 mm to 1775 mm, which gives a radial resolution of 250 mm. In Figure 4 the result from a run of a straightforward 3D implementation of CLEAN on a simulated surface consisting of sixteen scatterers is shown. The surface sixteen scatterers are evenly distributed on a slanting plane, in xy- and xz-plane. The correct position of the scatterers are indicated by the crossings of the help grid lines, note that the z axis is reversed compared to other images. Even with this modest model of the surface the computation time was very long and the weakest scatterers were not detected. However, the possibilities of improvements are vast in this area, with a number of different methods not tested within the project.

![Figure 3](image1.jpg)

*Figure 3. Simulated response from a point scatterer 1600 mm below the origin of the interferometer.*

![Figure 4](image2.jpg)

*Figure 4. CLEAN algorithm output from simulation of 16 scatterers evenly distributed on a slanting plane.*

**Laboratory experiments**

The imaging possibility was tested by moving around an active point source on the laboratory floor. This verified the coordinate system and also that we were able to find
the position of a reflector in all three space coordinates, see Figure 5. The active point source was later replaced with a passive metallic reflector made out of copper, see Figure 6. A tilting of the mirror reflector, about its specular angle, was detected as a change in intensity in the images from the interferometer.

Figure 5. Sequence of images acquired with the interferometer. The sequence shows an active point source, consisting of an antenna transmitting a coherent signal, which moves on the floor of the laboratory.
A coke surface was constructed on the floor of the laboratory, see Figure 7. The surface was manually altered and measurements were taken between each alteration. Difference images made by subtracting the datasets showed sensitivity to these surface changes. The sensitivity was improved by moving the transmitter antenna, from within the array to an external position, thus reducing crosstalk.
Pilot Plant experiments

The first trials outside the laboratory were performed on a full scale charging model at Dillingen Hüttenwerk in Germany where a model of Blast Furnace burden material surface was measured and detected. At this occasion the electronic and the antenna were encapsulated in a steel box manufactured for this specific series of trials. In Figure 8 a sketch of the test site show the position of the interferometer seen from above. Figure 8 also show a photograph of the test site with the rotating chute from below. Encircled, to the right in the image, is the encapsulation box containing the instrument.

![Sketch of Pilot plant measurement setup and position of interferometer.](image)

*Figure 8. Sketch of Pilot plant measurement setup (as seen from above) and position of interferometer (as seen from below).*

The white spot is the silica ceramic plate that protects the antenna substrate. In Figure 9 is a photograph showing a sinter surface in the charging model. Manually made alterations in this sinter surface was verified and positioned with the radar interferometer, as in the rightmost of Figure 9. A full reconstruction of the surface, using a simple mathematical model gave promising results. However, these results could not be confirmed when compared to reference laser measurements, see Figure 10. A real physical surface is far to complex to be solved by the simple CLEAN-script running on an ordinary computer.
Full scale trials

After the series of trials at the full scale charging model were terminated the interferometer unit was being slightly modified to be used on a production BF. Since the protective requirements are high on instrument to be used on production furnaces the encapsulation had to be of a new design. In this case the access port on the BF was the limiting factor and the encapsulation could not have a larger diameter then than 250 mm. Since the diameter of the antenna is 180 mm it fits well in the new encapsulation. In Figure 11 the antenna array together with a switch matrix is shown before mounted in the encapsulation. The front side of the antenna can be purged with nitrogen and the encapsulation it self is water cooled.
The experimental radar interferometer was mounted on a running industrial BF close to the rotating chute. The subsequent trials did not work well and no signals could readily be interpreted and not before long we faced a system breakdown. It is still not understood what caused the breakdown but pressure changes, corrosion, thermal induced tensions, or ballistic objects are among suggested causes.

**Conclusion and discussion**

From a laboratory as well as a pilot perspective it is obvious that the technical approach is possible but it is also clear the much work is left before fully functional equipment is realised.

To further develop the technology it is important to improve the resolution of the measurements.

To enable imaging a new mathematical model must be developed where the full use of polarimetric signal information for classification of burden surface material, together with historical data to build up a complete view of the surface will be utilised.

Since the very reason for the breakdown on the Blast Furnace trial is not fully understood further investigations due to the antenna protective materials must carried out.

**Future Work**

Since it is beyond the obligations of both MEFOS and Halmstad University to build a first prototype of a radar interferometer this job has been discussed with an instrument manufacturing company, Agellis Group AB. Presently a generic platform is under construction and is estimated to be finished during June 2008.
References

