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(54) Title: A METHOD FOR SIMULTANEOUSLY MEASURING THE POSITIONS OF MORE THAN ONE SURFACE IN METALLURGIC PROCESSES		
(57) Abstract A measuring technique and method are provided to simultaneously determine the positions of the surfaces of slag and metal bath in metallurgical processes. In the metallurgical process industry, e.g. in converter processes, it is important to measure the thickness of the layer of slag on top of the metal bath as well as determine the actual volume of metal in order to determine the weight of the charge. A large number of various methods have been tried, but no method is known to result in fast and accurate measurements of both surfaces from a distance and without mechanical means. The herein presented invention describe a method whereby radio waves are transmitted over a frequency band perpendicular towards the surfaces and how a receiver is used to compare the phase of the reflected waves relative the transmitted wave. The phase-change is measured for a number of frequency channels and a transform is then used to transform from the frequency space to the time delay space which gives the positions. The method is suitable for measuring overlapping surfaces at large distances from the reference level and which are separated by large distances. The estimated errors of the method are as low as 2 mm. If an interferometer is used as antenna then the data will also be sampled in the aperture plane and the three dimensional structure of the surfaces can be reconstructed.		

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A METHOD FOR SIMULTANEOUSLY MEASURING THE POSITIONS OF MORE THAN ONE SURFACE IN METALLURGIC PROCESSES

This invention relates to a method in metallurgical processes for simultaneously measuring the positions of more than one surface.

In converters, ladles, electric arc furnaces and other metallurgical vessels, it is desirable to know the exact position of the slag surface and the position of the interface between the slag and the liquid metal. Although many methods have been used in the prior art, no method has been at the same time fast, reliable and accurate. It may also be desirable to be able to measure the positions of other surfaces for example in order to control the thickness of the lining of vessels.

Changes in the pattern of electromagnetic wave fronts represent the most sensitive probes in physics. Electromagnetic waves may penetrate media of varying physical properties, changing its amplitude and phase in a way which is specific to the content of the media. Thus continuum radiation will be affected when penetrating a media in the sense that the amplitude will be attenuated and the propagation velocity will change, resulting in a sudden change of phase in the interface surface. The radioband is of particular interest in that here waves can penetrate deeper into dusty areas and penetrate through ceramic material, e.g. slag.

It is known that the interference between a transmitted wave and a reflected wave will create a standing wave pattern at a specific frequency determined by the positions of the null in this standing wave pattern and that the so determined wavelength of the signal will tell the position of a single surface, EP-A-60 597. Only the position of a single surface can be determined with this technique, which severely limits the usefulness of the method in metallurgic process industry. Furthermore, the amplitude of the standing wave is measured rather than its phase which severely limits the resolution and the tesability of the method.

It is also known that a distance can be measured if the transmitted signal is swept in frequency and the reflected and transmitted signal are mixed so that a low frequency (IF-)signal is created, DE-2812 871. The frequency of this IF-signal is dependent on the time-delay of the

reflected signal as compared to the sweeping time of the transmitter. This particular method can detect only a single surface.

It is also known that the angle of polarisation of a transmitted signal will change when it is reflected at a large angle at two surfaces, WO 91/10899 and US-A-4818 930. These methods are both transmitting at a single frequency at a large angle (larger than the Brewster angle) to the surface and can detect only the thickness of the layer between the two surfaces and only modulus the transmitted wavelength.

None of the above patent publications illustrates or discusses the phase change across the frequency bandpass and none of the above methods can therefore detect the *positions* of several surfaces simultaneously with an antenna system mounted at right angle to the surfaces. None of the above patents illustrates nor discusses the extension to three dimensional imaging of several surfaces. The method presented here is therefore significantly different from the above mentioned prior art.

It is an object of the invention to provide a method of this kind which is fast, reliable and accurate.

The time-delay of a signal relative another signal is in the Fourier-, or frequency space a linear shift of phase with frequency. If the object signal is transmitted towards and reflected in a surface, then the relative phase of the signals therefore will change linearly with frequency. If the signal is measured in steps over a frequency band, then a plot of phase with frequency would be a line with a slope corresponding to the delay of the reflecting signal compared to the reference signal. The distance can thus be measured via such a frequency stepped system. If the signal is instead transmitted towards a semitransparent medium, then part of the signal will be reflected, and part of the signal will propagate through the medium to be reflected in the next surface where the index of refraction again is changing. These doubly reflected waves will, when complex multiplied with the conjugate of the reference signal, show a more complicated curve of phase as a function of frequency. If data therefore are sampled as complex amplitudes in frequency channels over a frequency band, then the distances to *both* surfaces can be recovered. If then the signal is transmitted and received by an interferometer in the aperture plane, then the full three-dimensional structure of the two surfaces can be reconstructed. This is also true for a mixture where more than two surfaces are present.

The invention will be more closely described with reference to the drawings.

Fig 1 shows a schematic representation of a system in accordance with the invention for measuring the positions of multiple surfaces.

Fig 2 shows schematically a metallurgical vessel to which the invention can be applied.

Fig 3 is a diagram showing a point-spread-function (PSF) of the frequency pass band obtained from an experiment described with reference to Fig 1 and 2.

Fig 4 is a diagram of the reflections from the slag surface and metal bath surface obtained from the same experiment.

An example of the invention is shown in Figures 1 and 2. A signal is created at a defined frequency with a signal generator 1. This signal is transferred via a cable to a powersplitter 2 where one path is conveyed via a cable to an antenna 3. The second path is conveyed via a cable to a phase comparator unit 4 where it is used as reference signal. The antenna transmits the radio signal as a circular polarisation towards the metal metallurgical vessel in the form of a ladle 10 shown in Figure 2. The signal is aimed at perpendicular angle to the surface of the metal bath in the vessel 10 and reflected at the surfaces of the slag and metal bath as shown in Figure 2 and received by the same antenna 3 in the opposite circular polarisation due to the odd number of reflections. The received signal is transmitted through a cable to the phase comparator 4 and there complex multiplied with the conjugate of the reference signal. The amplitude and phase of the complex conjugate multiplication is stored in a table by a computer 5 and the signal generator is stepped in frequency and a new measurement is taken. This procedure continues until a fixed number of frequency channels have been measured separately over a frequency band. The equipment is controlled by a computer which also stores the data and does the signal analysis.

The reference wave received at time t_0 and at frequency w may be written as:

$$U_{\text{ref}}(w) = e^{j\omega t_0}$$

The signal reflected from the first surface and referred to the same receiving time t_0 can be written as:

$$U_{S1}(w) = e^{j(w(t_0 - 2Dl_{slag}/c))}$$

The signal reflected from the second surface and referred to the same receiving time t_0 can be written as:

$$U_{S2}(w) = e^{j(w(t_0 - 2Dl_{slag}/c - 2Dl_{bad} * n_{slag}/c))}$$

Dl_{slag} and Dl_{bad} are represented in Fig 2.

Dl_{slag} is the distance to the first (slag) surface, from a reference position in the antenna represented as a level 11. Dl_{bad} is the distance between the two surfaces (slag and metal bath), c is the velocity of light in air, and n_{slag} is the refractive index of the medium between the two surfaces. The complex conjugate multiplication, or cross correlation in the time domain, of the reflected and reference signals is then: (U^* is the conjugate of U)

$$S_{corr}(w) = U_{ref}^*(w) \cdot U_{S1}(w) + U_{ref}^*(w) \cdot U_{S2}(w)$$

or, if the frequency is restricted to a pass band $B_{pass}(w_l, w_h)$:

$$S_{corr}(w) = B_{pass}(w_l, w_h) e^{j(-w2Dl_{slag}/c)} + B_{pass}(w_l, w_h) e^{j(-w(2Dl_{slag}/c + 2Dl_{bad} * n_{slag}/c))}$$

The inverse Fourier-transform will transform from the frequency to the time-plane (delay or distance-plane). $B_{pass}(w_l, w_h)$ can be approximated with $Rect(w_l, w_h)$:

$$F^{-1}S_{corr}(Dt) = \text{sinc}(Dt - 2Dl_{slag}/c) + \text{sinc}(Dt - 2Dl_{slag}/c - 2Dl_{bad} * n_{slag}/c)$$

The time-delay response of the system is usually called the Point Spread Function in optics, and is in this case the Fourier transform of the frequency pass band. This response is measured by studying the response of a metal reflector at a known distance. The distances to the surfaces are then reconstructed from the observed signal by deconvolving with the measured Point

Spread Function. The distance can then be referred to a specified reference level, Dl_{ref} , through a translation of the time co-ordinate: $Dt' = Dt - 2Dl_{ref}/c$. The reference level may be a previously measured metal reflector in the signal path, or the edge of the metal container.

The transform contains the structure in the depth-direction. If the data are also sampled in the aperture plane by using an interferometer as transmitter and receiver antennas then a further two dimensional transform over the aperture-plane will show the structure over the remaining two dimensions. In the case of an interferometer as antenna the measurement will also have an aperture plane term for each measured point (u,v) in this plane:

$$F^{-1}S_{corr}(Dt) = (\text{sinc}(Dt - 2Dl_{slag}/c) + \text{sinc}(Dt - 2Dl_{slag}/c - 2Dl_{bad} * n_{slag}/c)) e^{j2P(Q_x u + Q_y v)}$$

Here Q_x, Q_y is the position in the image plane. u,v is the position in the Fourier, aperture, plane of the interferometer elements, which in this case consists of individual radio horn antennas the signals of which are cross correlated against each other as well as complexly multiplied with the conjugate of the reference signal. The transmitting interferometer will create a plane wave front parallel to the surfaces. The receiving interferometer will detect the changes of phase over the wavefront and thus measure positions of the surfaces as above, but in three dimensions over an area of the surfaces.

The above described technique and apparatus was used in a test experiment where a metal bath was iron. On top of the metal bath was a melted slag of known composition from a metallurgic plant. Figure 4 shows detections of the slag surface as well as the metal bath surface. The levels refer to an arbitrarily chosen reference level (the floor). In this way, the thickness of the slag can be found in secondary metallurgy (ladle metallurgy) with great accuracy (1-2 mm).

Fig 3 shows the point spread function (PSF) of the frequency band for the best experiment.

CLAIMS

We claim:

1. A method for simultaneously measuring the positions of more than one surfaces in metallurgic processes, characterised in that it comprises transmitting a radio signal over a frequency band, receiving the signals reflected from the surfaces, measuring the phase difference between the transmitted and reflected signals over the frequency band and making a transform from frequency domain to time domain resulting in the said positions.
2. A method as claimed in claim 1 characterised in that it comprises stepping a signal generator in discrete frequency steps over the frequency band and receiving the reflected signals for each frequency step, comparing the phase difference of the transmitted and reflected signals in each step over the frequency band and making a discrete transform from frequency domain to time domain resulting in the said positions.
3. A method as claimed in claim 2 characterised in that it comprises transmitting a radio signal in circular polarisation from an antenna mounted so that the transmitted wave is aimed perpendicular to the surfaces and the reflected wave is received in the same antenna but in the opposite circular polarisation.
4. A method as claimed in claim 3 characterised in that the phases of the signals are compared by doing a complex conjugate multiplication in the frequency plane, i.e. a cross correlation in time domain, for each discrete frequency channel.
5. A method as described in any one of 1, 2, 3 or claims 4 characterised in that the antenna is formed by an interferometer and the three dimensional structure of the surfaces are imaged by a three dimensional transform from frequency and aperture plane to time and image plane.

FIGURE 1

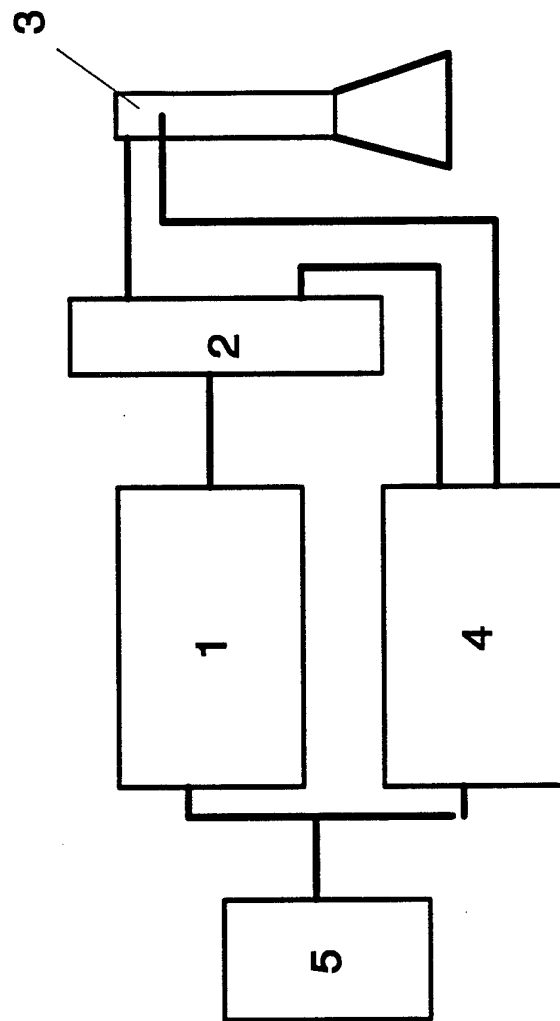


FIGURE 2

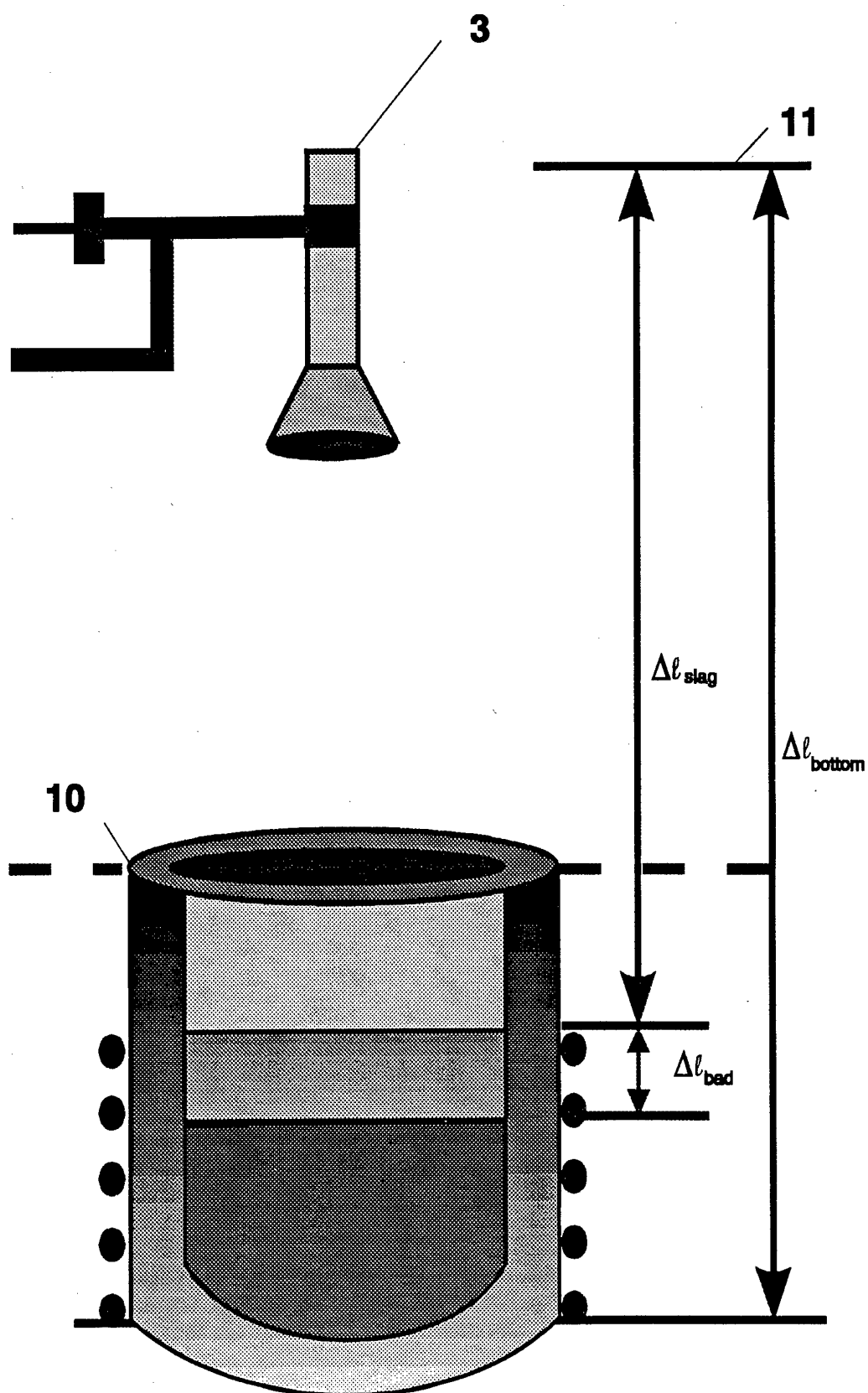


FIGURE 3

power spectrum

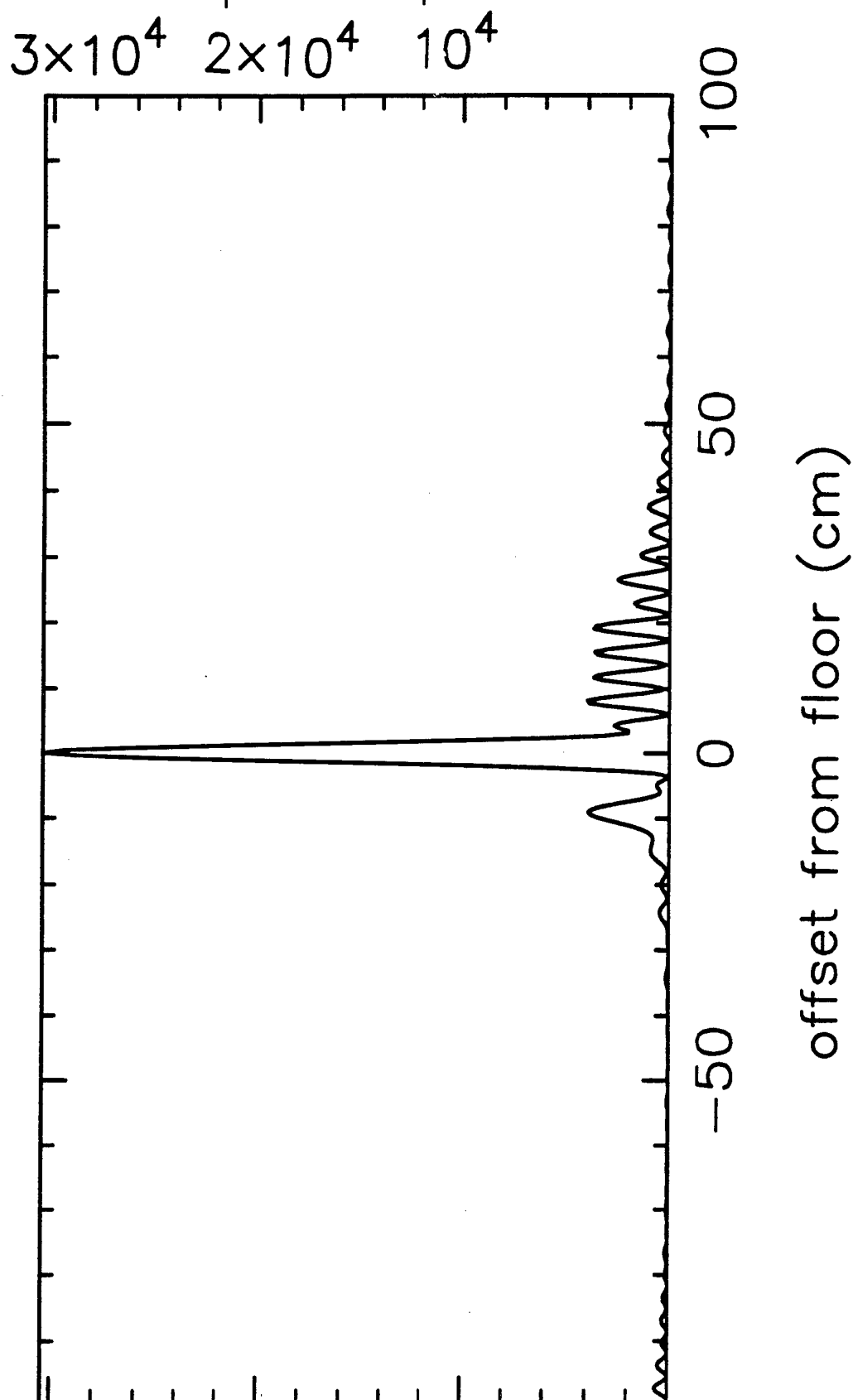
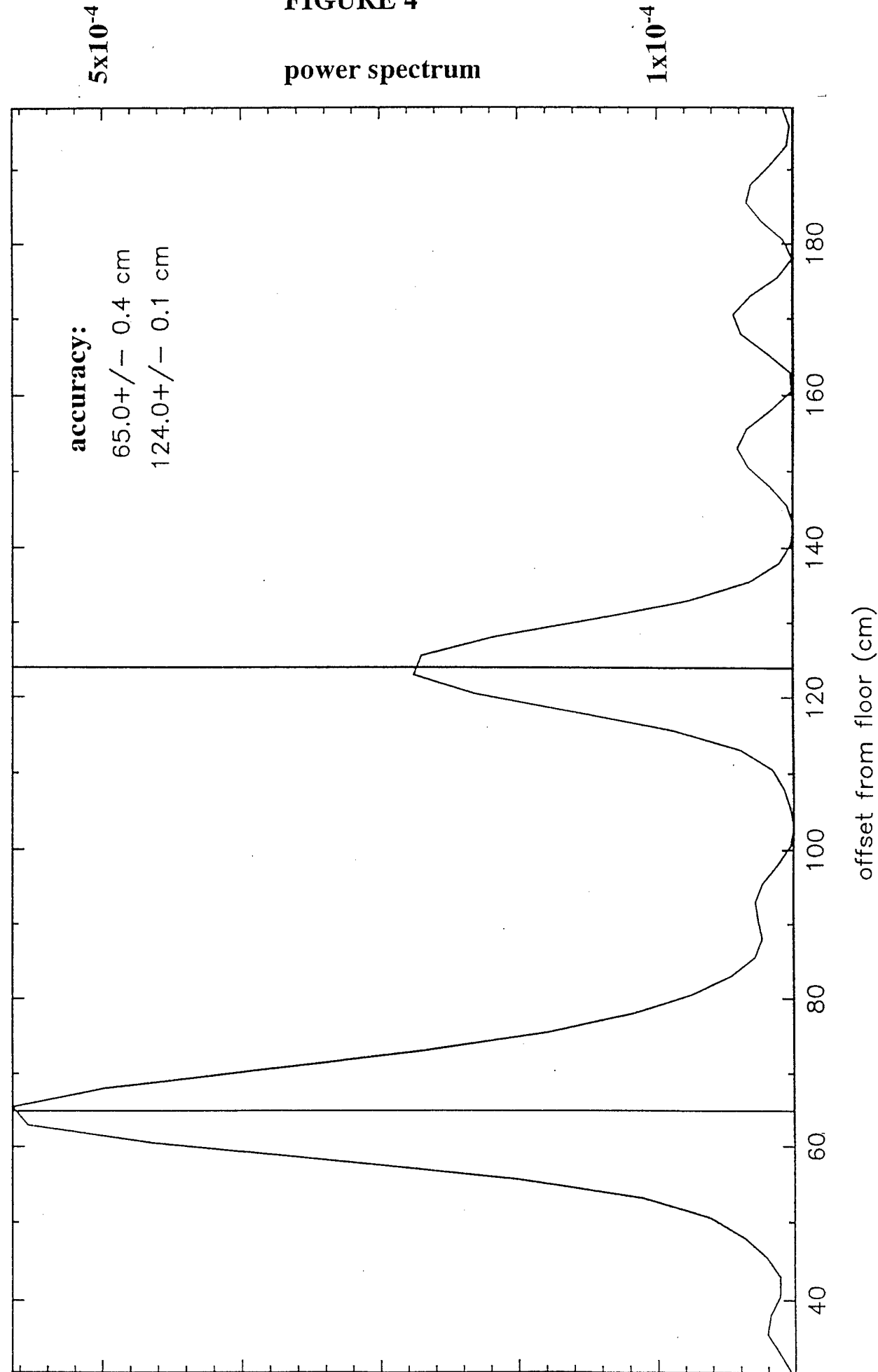


FIGURE 4

power spectrum



INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 94/00099

A. CLASSIFICATION OF SUBJECT MATTER

IPC5: G01N 22/00, G01S 13/88, G01F 23/28, B22D 2/00
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC5: G01N, G01S, G01F

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4737791 (BUFORD R. JEAN ET AL), 12 April 1988 (12.04.88), column 5, line 9 - line 61, abstract --	1-5
A	US, A, 5115242 (AKIO NAGAMUNE ET AL), 19 May 1992 (19.05.92), claim 1, abstract --	1-5
A	DE, B2, 2812871 (SUMITOMO METAL INDUSTRIES, LTD), 2 August 1979 (02.08.79), claim 1 --	1-5

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP, A2, 0060597 (CISE-CENTRO INFORMATIZAZIONE STUDI ESPERIENZE), 22 Sept 1982 (22.09.82), page 3, line 2 - line 17 -- -----	1-5

INTERNATIONAL SEARCH REPORT
Information on patent family members

26/02/94

International application No.
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