(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 558 062 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
27.07.2005 Bulletin 2005/30

(51) Int Cl.[7]: **H05B 7/02**, F27D 21/00

(21) Application number: **04100169.4**

(22) Date of filing: **20.01.2004**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR
Designated Extension States:
AL LT LV MK

(71) Applicant: **PROFILARBED S.A.**
4009 Esch-sur-Alzette (LU)

(72) Inventors:
- **BAUMERT, Jean-Claude**
  1232, Howald (LU)
- **THIBAUT, Jean-Claude**
  4962, Clémency (LU)

(74) Representative: **Schmitt, Armand et al**
Office Ernest T. Freylinger S.A.,
B.P. 48
8001 Strassen (LU)

(54) Method for monitoring wear of an electrode

(57) A method for monitoring wear of an electrode in an electric arc furnace comprising the steps of:

taking a digital picture of the still incandescent tip of the electrode;

applying a numerical edge detection filter to the digital picture so as to obtain a filtered image wherein abrupt changes in light intensity are represented as contour lines; and

analysing the contour lines to determine the shape of the electrode tip and the presence of cracks.

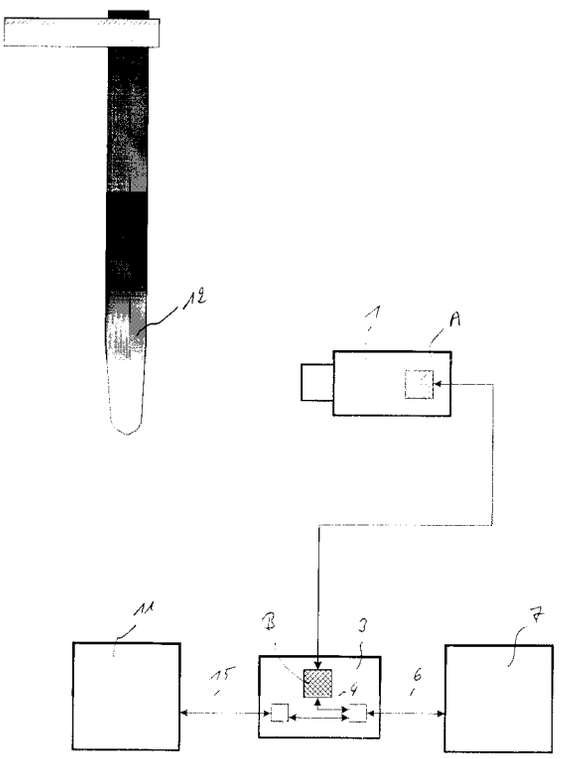


Fig.1

EP 1 558 062 A1

Description

[0001] The present invention relates to a method for monitoring on line and automatically the wear of electrodes, in particular graphite electrodes in an electric arc furnace (EAF).

Background of the Invention

[0002] Electrode consumption is an important factor to be taken into account in the optimisation of the electrode quality and thus in the optimisation of steelmaking process costs in an EAF. Knowing the wear of the electrodes allows improving the electrode quality and reducing electrode breakage. In fact, in addition to being costly, electrode breakages slow down production. Fishing a broken electrode tip out of the molten steel bath may interrupt production for up to 5 minutes if it settles on top. But a broken electrode could easily cause delays up to 45 minutes if it remains inside the bath. Electrodes are less likely to break later in the melt cycle, but it usually takes longer to get them out of the furnace in a later heat elaboration phase.

[0003] WO-A-00/74442 discloses a method of determining the electrode length and the bath level in an electric arc furnace. According to this method, the length of the electrode is determined by moving the electrode, at the end of each heat, down towards the top level of the steel bath and stopping the electrode movement when a specified stopping criterion is reached. Accordingly, the distance between the tip of the electrode and the level of the melt is approximately constant for each measurement. In this state a first electrode position (height) measurement is performed. Thereafter the electrode is raised outside the furnace vessel until its tip reaches the level of an optical beam path located at a predetermined height with respect to the bottom of the melt or the vessel. At this position a second measurement is performed. Based on the two measurements the actual length of the electrode, and thus the consumption of the length per molten scrap content of a basket can be determined. However, this method does not allow measuring the shape of the electrode, in particular the tip thereof, and the side wear of the electrode, caused for example by oxidation of the electrode graphite material during the steel-making process.

[0004] A report entitled "Überwachung der Elektrodenqualität und Verminderung des Elektrodenverbrauches von Lichtbogenöfen" by Gronau et al, published in "Technische Forschung Stahl" by the European Commission in 1988 (EUR12019DE) discloses a method for monitoring the quality of electrodes and the reduction of electrode consumption for an EAF at the time of the removal of the electrode from the furnace after the melt. The equipment used, however, allows only measurement campaigns limited in time. In fact, it does not allow the monitoring of the electrode in a continuous and automatic way.

[0005] Furthermore, for a comprehensive electrode wear monitoring, important information such as the form of tip cone and lateral wear, crack forming and crack propagation, nippling problems, tip cracking and "falling off", and loss of graphite material due to loose particles and droplets are required.

[0006] Accordingly, there is a need for providing a method and an apparatus able to deliver such information for the purpose of the evaluation of the electrode wear in a continuous and automatic way.

Object of the Invention

[0007] It is therefore an object of the present invention to provide an improved method for measuring the electrode wear in an electric arc furnace system.

[0008] This object is accomplished by providing a method for monitoring wear of an electrode in an electric arc furnace comprising the steps of:

taking a digital picture of the still incandescent tip of the electrode;

applying a numerical edge detection filter algorithm to the digital picture so as to obtain a filtered image wherein abrupt changes in light intensity are identified as contour lines; and

analysing the contour lines to determine the shape of the electrode tip and the presence of cracks.

[0009] Preferably, after the melting of each scrap basket, the method comprises signaling to a digital camera the passage of the electrode in front of the camera so that the camera may take a picture of the electrode. The picture is sent to a personal computer, which is preferably equipped with a suitable software for the automatic extraction of all the relevant information. The information is extracted by a dedicated software. All the information, e.g. raw pictures and extracted features, may be stored so as to constitute a picture archive and to be used for further analyses.

[0010] Preferably the dedicated software performs a picture analysis of the pixel picture. The picture analysis enables a follow-up of the electrode. In particular, it enables to study and know the influence of the dimensional tolerances, the

geometry of the nipples, the applied torque, the mechanical and electric properties as well as the condition of use of the electrode. This information thus allows optimising the quality of the electrode and rendering the use of EAF more economic.

Brief Description of the Drawings

[0011] The foregoing and other objects, features, and advantages of the invention, as well as presently preferred embodiments thereof, will become more apparent from a reading of the following description, in connection with the accompanying drawings in which:

Fig.1: is a schematic view of the apparatus according to the present invention;
Fig.2: is a schematic view of a camera location of the apparatus according to the present invention for the use at a dual shell electric arc furnace;
Fig.3: shows the rotation and annotation removal step in a picture analysis method according to the present invention;
Fig.4: shows the artificial colouring step of the image, for an electrode tip without electric arc deviation, in a picture analysis method according to the present invention;
Fig.5: shows the artificial colouring step of the image for an electrode tip with electric arc deviation, in a picture analysis method according to the present invention;
Fig.6: shows the electrode edge detection step in a picture analysis method according to the present invention;
Fig.7: shows the threshold detection step in a picture analysis method according to the present invention;
Fig.8: shows the non-linear filter matrix for light "grain" or spot removing step in a picture analysis method according to the present invention;
Fig.9: show the light "grain" or spot removing step after applying the filter of Fig.8 in a picture analysis method according to the present invention;
Fig.10: shows electrode tip zone detection step in a picture analysis method according to the present invention;
Fig.11: shows the result of electrode tip zone detection step of Fig. 10, as displayed according to the present invention;
Fig.12: shows an example of image pixels used for the electrode tip detection and numerical shape approximation step in a picture analysis method according to the present invention;
Fig.13: shows the result of electrode tip detection step of Fig. 12, as displayed according to the present invention;
Fig.14: shows the result of the linear approximation of the flanks of the electrode cone, as displayed according to the present invention;
Fig.15: shows the definition of the oxidized zone of the electrode, as determined according to the present invention; and
Fig.16: is a block flow chart showing an implementation of a picture analysis method according to the present invention.

Detailed Description of the Invention

[0012] Referring first to Fig.2, the present electric arc furnace installation comprises two electric arc furnace vessels (EAF) 13,14 and a graphite electrode 12 shared between the two EAFs 13,14.

[0013] After melting of one scrap basket, the electrode 12 passes from one EAF 13 to the other EAF 14. A digital camera 1 is arranged so as to be able to take a picture of the electrode 12 as it passes from one EAF to the other. Fig. 2 shows the passage of an electrode 12 from a first EAF 13 to a second EAF 14. As well known in the art, the passage of the electrode 12 from the first EAF 13 to the second EAF 14, or the other way around, is controlled by a programmable process controller (PLC) 11 (shown in Fig.1). The PLC 11 is connected to the digital camera 1 so as to be able to trigger the camera 1 when the electrode 12 is in a particular position in-between the two EAFs 13,14. As the PLC 11 controls the electrode position 12 and knows where the camera 1 is located, the PLC 11 can control the camera so as to take a picture at exactly that moment when the electrode 12 passes in front of the camera.

[0014] The camera 1 is preferably attached to stable beam or wall (not shown) of the steel mill building where one or more electric arc furnaces (EAF) are disposed. The camera 1 may be embodied as a CCD or CMOS sensor type digital camera provided with or without a digital signal processor (not shown).

[0015] As shown in Fig.1 the camera 1 is connected for remote control and data transmission purposes to an electronic data transmission box 3 via a link 2. The link 2 may be made of an optical fibre or any other electrical means. In case of using an optical fibre, to bridge long distances and prevent electro-magnetic interferences into the data transmission, an electrical-to-optical converter A is installed close to the camera 1 and a second similar converter B is installed inside the transmission box 3 The electro-optical converter B is connected to or provided within an electric

transmission box 3 which further contains or is connected to electrical communication modules such as current loop modules 8 and 10 which provide for direct electrical communication to both the PLC 11 and the personal computer (PC) 7 via links 6,15.

[0016] The personal computer (PC) 7 is used both for electrode image processing, image storage, a display for the furnace operator.

[0017] The current loop modules 8 and 10 of the electric transmission box 3 are connected via a link 9, preferably a wire link, to provide a direct communication between PC 7 and PLC 11.

[0018] Preferably all of the foregoing modules and converters may convey signals according to the RS232 interface standard, although the implementation of other communications standards, such as analog signal transmission, Ethernet, TCP/IP, or FireWire IEEE-1394, is intended to be within the scope of the present invention.

[0019] The picture taken by the camera 1 is transferred with suitable software to PC 7 for extraction of the relevant information. The software is dedicated program, which will be explained hereinafter in detail.

[0020] The pictures are stored in PC 7 and constitute a digital picture archive. The comparison between the current and one or more of the former pictures of a specific electrode contributes to establish the electrode consumption.

[0021] Particularly advantageously, according to one aspect of the invention, the information extracted from the picture includes electrode wear monitoring information such as electrode tip length, overall wear, tip loss, the form of tip cone and lateral wear, crack forming and crack propagation, side oxidation, nippling problems, overall cracking, "falling off" of the electrode tip, loss of graphite material due to the particles and droplets, and inhomogeneous temperature profiles that are related to the electrical arc deviations.

[0022] A preferred picture extraction method will be disclosed with reference to the following description. It is noted that the extraction method can be performed both in real time so to say "on-line" or at a later stage, namely "offline".

[0023] In the present non-limiting example each picture may by characterized by the following data:

encoding format: JPG,

colours: monochrome with 256 shades of grey,

encoding: of 8 bits per pixel,

resolution of a picture or frame: 632 x 480 pixels,

conversion factor: 5,0456 mm/pixel,

physical surface of the picture: 3,18 x 2,68 meter,

size of the JPG file: from 11 to 18 kB, with a 20% compression factor.

[0024] The digital filtering is defined as convolution product between two matrixes, the first matrix being defined by the picture such as and having a dimension (number of pixel) equal to that of the analysed picture, and the second matrix containing the weighted coefficients of the used filter. A preferred numerical filtering algorithm may use the following formula:

$$R_{[x,y]} = \frac{1}{M} * \left(\sum_{i,j} S_{[x+i,y+j]} K_{[i,j]} + \beta \right) \qquad (1)$$

wherein M is a constant (generally the sum of the weights assigned coefficients of the filter matrix), *R* is the filtered picture, *S* is the picture prior to filtering, ***K*** represents the weighted coefficients of the filter, and β is an offset constant.

[0025] An original picture, as described above, contains 632 x 480 pixels, each pixel being encoded by 8 bits, which permit 256 (2^8) shades of grey, wherein the value of 0 corresponds to black, or no exposure, and the value of 255 corresponds to white, or maximum exposure.

[0026] It is to be noted that the pictures supplied by a (digital) CCD camera, with integrated digital signal processor, generally contain two types of information, namely the pictures per se captured by the CCD camera which are used during the picture analysis and annotations added by the digital signal processor of the camera after the detection of the tip of the electrode.

1. Rotation and removal of annotations

[0027] The annotations are removed prior to the picture analysis. In the flow chart of Fig.16, the rotation and annotation removal step is indicated with reference numeral 101.

[0028] In the rotation step the picture is rotated by 90 degrees in the anticlockwise direction without distortion of its physical dimensions. This step is indicated in Fig.3.

[0029] Subsequently, as indicated at the right hand side of Fig.3 the annotations are removed from the rotated pictures. Therefore, the present method provides for a step of converting the annotation areas to a uniform dark grey shade. For instance, the grey scale value of the converted annotation areas may be comprised between the values of 0 though 10. The step of converting (providing a "makeup") to the annotation zone advantageously allows optimising a subsequent step of edge detection, which will be described hereinafter.

[0030] The grey converted annotation areas will no longer be considered during the subsequent picture processing.

2. Artificial colouring

[0031] Moreover, according to the method of the present invention, an artificially coloured picture of the electrode is obtained (indicated as step 108 in the flow chart of Fig.16). In the latter step the light intensity of the electrode, as shown by the camera picture, is associated with a surface temperature of the electrode. The artificial colouring step allows a better visualisation of the temperature gradient that is present on the electrode surface when the picture is captured by the camera. In addition this step of cartographing the light intensity emitted by the surface of the electrode advantageously allows to quickly estimate an asymmetry in the temperature resulting from a deviation of the arc during the melting process of the batch (indicated as step 109 in the flow chart of Fig.16). According to a currently preferred implementation of the present invention, the 256 grey shades are converted to 8 colours in the artificial colouring step, according to Table 1. The person skilled in the art will however readily understand that the number of grey shades and the number of artificial colours are not limited to the above figures, and that such figures can be conveniently chosen according to factors known to the person skilled in the art such as processing speed, required temperature gradient accuracy, etc.

Table 1

Grey Shade Level	Colour
0-31	Black
32-63	Brown
64-95	Green
96-127	Olive
128-159	Navy
160-191	Purple
192-223	Teal
224-255	Grey

[0032] Fig.4 shows the artificial colouring step, without arc deviation while Fig.5 shows the artificial colouring step, with arc deviation. In the present application, as the figures are shown exclusively in grey shades, the colouring cannot be seen.

[0033] As apparent from Fig.4, when there is no arc deviation, the hottest zone of the electrode is situated in the centre of the electrode.

[0034] In Fig.5, one can clearly see that the electrode is brighter (hotter) at its left side, namely at the side of EAF 13. The deviation of the hotter zone is shown to be computed at about 20% from the left edge of the figure. The vertical line provided within the surface of the electrode picture facilitates visualizing the arc deviation. Note that in Fig.4 the vertical line is running approximately at the centre of the electrode (about the axis thereof) while in Fig.5 the vertical line is displaced to the left side.

[0035] It should be noted that a step of computing the average light intensity may be provided within the context of the above artificial colouring step and after the rotation and annotation removal step. The latter average light intensity computing step provides for particular advantages when the average light intensity value provided therein is used in a threshold detection step which will be described hereinafter.

3. Edge detection

[0036] Furthermore, according to the present invention, there may be provided an electrode edge detection step (indicated as step 102 in the flow chart of Fig.16). The electrode edge detection step is preferably carried out on a copy of the picture or pictures provided, following the rotation and annotation removal step.

[0037] The electrode edge detection step is carried out based on a digital edge detection filter comprising two digital filters of the type described hereinabove.

[0038] Preferably each of the digital filters is comprised by a 3 x 3 matrix. The first (N-S) of the digital filters detects the edges in a North-South orientation and the second (E-W) of the digital filters detects the edges in an East-West orientation. The RMS value of the filtering by the two filters provides for an edges detection of the electrode in the above-mentioned orientations.

[0039] The coefficients of the two matrixes (N-S and E-W filters) are preferably chosen as indicated below:

$$N-S\begin{bmatrix}1 & 1 & 1\\ 0 & 0 & 0\\ -1 & -1 & -1\end{bmatrix} \qquad E-W\begin{bmatrix}1 & 0 & -1\\ 1 & 0 & -1\\ 1 & 0 & -1\end{bmatrix}$$

[0040] The row transitions of the light intensities (edges) obtained by electrode edge detection step are shown in Fig.6. The results of the edge detection step are important for the subsequent handling of the picture analysis.

4. Threshold detection

[0041] According to the present invention a threshold-detecting step is provided, which is illustrated in Fig.7 (and indicated as step 103 in the flow chart of Fig.16). The threshold for the light intensity is preferably defined as being average light intensity multiplied by 2. As explained, the average light intensity may be provided after the rotation and annotation removal step. The detected threshold is applied to the picture obtained at the end of electrode edge detection step.

5. Removing light grains

[0042] Following the threshold detecting step there is provided, according to the present invention, a step for removing the light "grains" or spots (indicated as step 104 in the flow chart of Fig.16), as illustrated in Fig.8 and 9. The "grains" at the inner side of the electrode, which are apparent both in the right hand section of Fig.7 and in the left hand side of Fig.9, are understood to be a consequence of a significant temperature gradient on small surfaces, while the "grains" outside the electrode are believed to be caused by droplets of water illuminated by the tip of the electrode and by glowing graphite particles falling therefrom.

[0043] The step of removing the light "grains" is preferably carried out by means of a non-linear digital filter which is recomputed for each new light intensity which, for instance, for a pixel having the original light intensity c will be a function of the maximal and minimal light intensity of two neighbouring pixels, as shown in Fig.9. In the preferred method of the present invention the following formula is used:

$$I_c = \min(\max(a,b,c), \max(b,c,d), \max(c,d,e),..., \max(c,h,i)) \qquad (2)$$

wherein a through *i* are the light intensities of the pixels shown in Fig.8.

[0044] Preferably, the step of removing grains is repeated up to 15 times to obtain the result shown in the right hand side of Fig.9.

6. Tip detection

[0045] According to the invention, the picture, preferably the picture obtained after the removing of the light grains, is scanned (swept), for instance from bottom to top and from left to right to detect the tip zone of the electrode, as shown in Fig.10. The exterior boundaries of the tip of the electrode are determined by an algorithm, which computes the variables *Tip_i_Min, Tip_i_Max, Tip_j_Min* and *Tip_j_Max.*

[0046] The sweeping or scanning of the picture is started from the left bottom side of Fig.10, and when the first 3 successive white pixels are detected on the same horizontal line the algorithm, which is familiar to those skilled in the art, detects *Tip_j_*Max which represents the lowest point of the electrode tip zone. *Tip_j_Min*, which is the highest point of the electrode tip zone, is set to be, for instance, about 50 pixels higher.

[0047] The values of *Tip_i_Min*, *Tip_i_*Max, which represent the respective left and right boundaries of the electrode tip zone, are determined by sweeping about 50 lines from left to right and upwards, after detecting the value *Tip_j_Max.* Again, 3 successive white pixels of the same vertical line are indicative of the detection of *Tip_i_Min* and *Tip_i_Max.*

[0048] The results of the detection of the electrode tip zone including the variables *Tip_i_Min, Tip_i_Max, Tip_j_Min* and *Tip_j_Max* are shown in Fig.11.

[0049] Fig.12 shows by way of example the extraction step of the pixels of the electrode at the height of the electrode tip so as to obtain the representation of the electrode tip shown in Fig.13 (and indicated as step 105 in the flow chart of Fig.16). Note that the pixels representing the electrode tip are extracted preferably following the step of light "grain" or spot removing.

[0050] In Fig.12, where, by way of example, a picture zone of 5 lines and 24 columns is shown, the white squares represent the white pixels of the picture. As the picture zone is swept, from left to right and from bottom to top, in line 5 all of the four white squares (pixels) are marked (crossed), as the condition of at least 3 successive pixels on a line is met. The same occurs in line 4. However, the pixels in an already marked column (namely the pixels M4, N4, 04, and P4 will not be marked (crossed). In line 3 the condition of 3 successive pixels on a line is not met, and therefore no pixel will be marked. In line 2, all of the pixels will be marked as the condition of 3 successive pixels on a line is met and the pixels do not belong to an already marked column. In line 1 the condition of 3 successive pixels on a line is not met, and therefore no pixel will be marked.

[0051] In this manner all of the 50 lines of the picture of the electrode tip zone are swept, and the pixels retained as above are subjected to a numerical approximation of degree 2 (parabolic) (indicated as step 106 in the flow chart of Fig. 16) according to the equation:

$$y = k_0 + k_1 x + k_2 x^2 \tag{3}$$

[0052] The coefficients k_0, k_1 and k_2, as well as the coefficient y representing the quality of the approximation, are computed on the basis of the coordinates of the retained (crossed) pixels. The results of the parabolic approximation of the electrode tip are shown in the right hand section of Fig.13.

7. Flank detection

[0053] In addition to the detection and representation of the tip of the electrode, the present invention also advantageously provides for the feature of the detection of the flanks of the electrode cone (indicated as step 110 in the flow chart of Fig.16). As the starting point for the latter electrode flank detection feature may be envisaged the "grainless" picture shown in the right hand side section of Fig.9. The sweeping zone for the flank detection comprises an area starting from *Tip_j_Min* up to the top of the picture and from *Tip_i_Min-10* (pixels) to *Tip_i_Max*+ 10 (pixels) - see also Fig.10. This zone is swept from top to bottom and from left to right.

[0054] The first and the last white pixel of each swept line is used for respective linear approximations of the left and right flanks (indicated as step 111 in the flow chart of Fig.16), as per the following equation:

$$y = kx + d \tag{4}$$

[0055] Accordingly, the angular coefficients of the straight lines allow estimating the lateral wear of the electrode. In other words, the more the electrode is worn, the steeper is the slope of the straight line. Fig.14 shows the result of the linear approximation of the flanks of the electrode.

8. Electrode tip size determination

[0056] Based on the steps of determining the tip of the electrodes and the flanks thereof, the present invention further provides for a step of determining the size of the tip of the electrode (which is indicated as step 107 in the flow chart of Fig.16). In particular, the size of the tip of the electrode is defined mathematically by the following three equations:

Tip:

$$y = k_0 + k_1 x + k_2 x^2 \quad (5)$$

Left flank:

$$y = k_{Left} x + d_{Left} \quad (6)$$

Right flank:

$$y = k_{Right} x + d_{Right} \quad (7)$$

[0057] By solving equations (5) and (6) one can find the coordinates of the two intersection points between the parabola and the straight line representing the left flank.

$$x_1 = \left((k_1 - k_{Left}) + \sqrt{(k_{Left} - k_1)^2 + 4k_2 (d_{Left} - k_0)} \right) \Big/ (-2k_2) \quad (8)$$

$$x_2 = \left((k_1 - k_{Left}) + \sqrt{(k_{Left} - k_1)^2 + 4k_2 (d_{Left} - k_0)} \right) \Big/ (-2k_2) \quad (9)$$

$$y_1 = k_{Left} x_1 + d_{Left} \quad (10)$$

$$y_2 = k_{Left} x_2 + d_{Left} \quad (11)$$

with (x_1,y_1) representing the first intersecting point and (x_2,y_2) representing the second intersecting point.

[0058] Similarly, the coordinates of the two intersection points between the parabola and the straight line representing the right flank can be computed as follows:

$$x_3 = \left(\left(k_1 - k_{Right} \right) + \sqrt{(k_{Right} - k_1)^2 + 4k_2 (d_{Right} - k_0)} \right) \Big/ (-2k_2) \quad (12)$$

$$x_4 = \left((k_1 - k_{Right}) + \sqrt{(k_{Right} - k_1)^2 + 4k_2 (d_{Right} - k_0)} \right) \Big/ (-2k_2) \quad (13)$$

$$y_3 = k_{Right} x_1 + d_{Right} \quad (14)$$

$$y_4 = k_{Right} x_2 + d_{Right} \quad (15)$$

with (x_3,y_3) representing the first intersecting point and (x_4,y_4) representing the second intersecting point.

[0059] Only two of the four solutions of the above equations represent the intersections of the straight lines with the parabola at the level of the electrode tip. The other two are discarded. The small circles in Fig.14 represent the retained intersection points. The distance between the two circles of Fig.14 is defined as the size of the tip of the electrode, which is also referred to as L_{Tip} and shown in Fig.15.

9. Determination of length of *wear*

[0060] Advantageously, the present invention also provides for the calculation of the length of the oxidised part of the electrode (also indicated as step 107 in the flow chart of Fig.16). As known in the art, the conical shape of the electrode is subject to changes during its lifetime. The calculation of the length of the non-cylindrical section of the electrode, which represents the length of the oxide is performed according to the following formula:

$$L_{Oxy} = (Tip_j_Max - Tip_j_Min) + (D_{Nom} - L_{tip})/(abs(1/k_{Left}) + abs(1/k_{Right})) \quad (16)$$

wherein Tip_j_Min, Tip_j_Max, L_{tip}, k_{Left}, and k_{Right} are as defined above, and D_{Nom} represents the nominal (known) diameter of the cylindrical section of the electrode 12.

10. Determination of presence of cracks

[0061] Yet another feature of the present invention is envisaged in the provision of the length of the cracks appearing on the electrode surface (indicated as step 112 in the flow chart of Fig.16). Accordingly the latter length of the cracking detecting step is based on the edge detection step, in a zone spaced by 10 pixels from the detected flanks and extending from the tip of the electrode. A sweeping of this zone provides for an accurate detection of the total cracking length of the electrode.

[0062] The step of detecting the length of the cracking of the electrode may advantageously be performed by setting a threshold such that all pixels having a light intensity higher than, for instance, 96 are counted. The count number is divided by 2 (as the cracks are detected on the 2 edges of the electrode) and multiplied by (in the presently envisaged non-limitative specific embodiment) 5,04 mm - see JPG picture data - to yield the total length of the cracks.

[0063] A block flow chart showing an advantageous implementation of a picture analysis method according to the present invention is shown in Fig.16. However, the person skilled in the art will readily understand that some of the steps shown in the flow chart of Fig.16 may be omitted and/or the order thereof changed. Such steps may be advantageously implemented on a personal computer such as PC 7.

[0064] As can be seen in a step 100, the original picture, preferably in JPG format as explained above, is inputted from the camera 1 to the PC 7. In a subsequent step 101 the original picture is subjected to the electrode rotation and annotation removal step. Thereafter, the flow chart branches off to the electrode artificial colouring step 108 and to the electrode edge detection step 102. The result of the electrode edge detection step 102 is used by the subsequent electrode threshold detection step 103. In turn the resultant of the electrode threshold detection step 103 is provided to the grain- or spot-removing step 104. Thereafter, based on the grain free data output of the step 104, the tip of the electrode may be detected in step 105. Based on the latter data, the parabolic approximation is performed in step 106. The resultant of the parabolic approximation, step 106, is used along with the electrode artificial colouring step 108 to obtain the arc deviation of the electrode in step 109. Step 105 can also branch off to the electrode (left and right) flanks detection step 110, which is followed by a linear approximation step 111 of the left and right electrode flanks. The resultant of step 111 can also be used in step 109. Furthermore, based on steps 106 and 111 the size of the tip of the electrode and the oxidation length can be computed in step 107. Finally, the total length of the cracks of the electrodes is computed in step 112 based on steps 105, 106, and 111.

[0065] The invention, as described and shown herein, is amenable to changes and modification by adding further detection steps based on the foregoing detection steps without departing from its scope.

[0066] For instance, the "falling off" of the electrode tip could be detected by analysing its cross sectional shape and the cracks thereof. Alternatively, the fall of the electrode tip could be detected by analysing at the same time the length of the tip and the slope of the flanks thereof. Finally, the temperature of the electrode surface could be analysed to provide the furnace operator with data necessary to achieve optimal operation.

[0067] Where technical features mentioned in any claim are followed by reference signs, those reference signs have been included for the sole purpose of increasing intelligibility of the claims and accordingly, such reference signs do not have any limiting effect on the scope of each element identified by way of example by such reference signs.

Claims

1. A method for monitoring wear of an electrode in an electric arc furnace comprising the steps of:

taking a digital picture of the still incandescent tip of said electrode;

applying to said digital picture a numerical edge detection filter algorithm so as to obtain a filtered image wherein abrupt changes in light intensity are represented as contour lines; and

analysing said contour lines to determine the shape of the electrode tip and the presence of cracks.

2. The method as claimed in claim 1, wherein:

a threshold filter is applied to said filtered image prior to analysing said contour lines.

3. The method as claimed in claim 1 or 2, comprising the step of:

removing light grains by means of a numerical filter prior to analysing said contour lines.

4. The method as claimed in any one of claims 1 to 3, wherein the step of analysing said contour lines to determine the shape of the electrode tip:

detecting the lower contour line of the electrode tip and approximating it with a parabolic curve;

detecting the contour line corresponding to each of the flanks of the electrode tip and approximating it with a straight line.

5. The method as claimed in any one of claims 1 to 4, further comprising the step of:

detecting asymmetries in the light intensity of the electrode tip to get aware of electric arc deviations.

6. The method as claimed in any one of claims 1 to 5, further comprising the steps of:

a) positioning a camera at the electric arc furnace;

b) providing a link between the camera and a process controller of the electrode;

c) activating the camera along with the moving of the electrode, such that a picture of the electrode can be captured by the camera after the melting of each scrap basket of the electric arc furnace; and

d) providing the captured picture via a further link to a picture storing and processing means.

7. The method as claimed in claim 6, further comprising the step of signalling to the camera the passage of the electrode in front of the camera by means of the process controller.

8. The method as claimed in any one of claims 6 and 7, further comprising the step of storing the captured picture at the picture storing and processing means.

9. The method as claimed in any one of claims 1 to 8, further comprising the step of comparing the captured pictures of the electrode with the picture of an unused electrode.

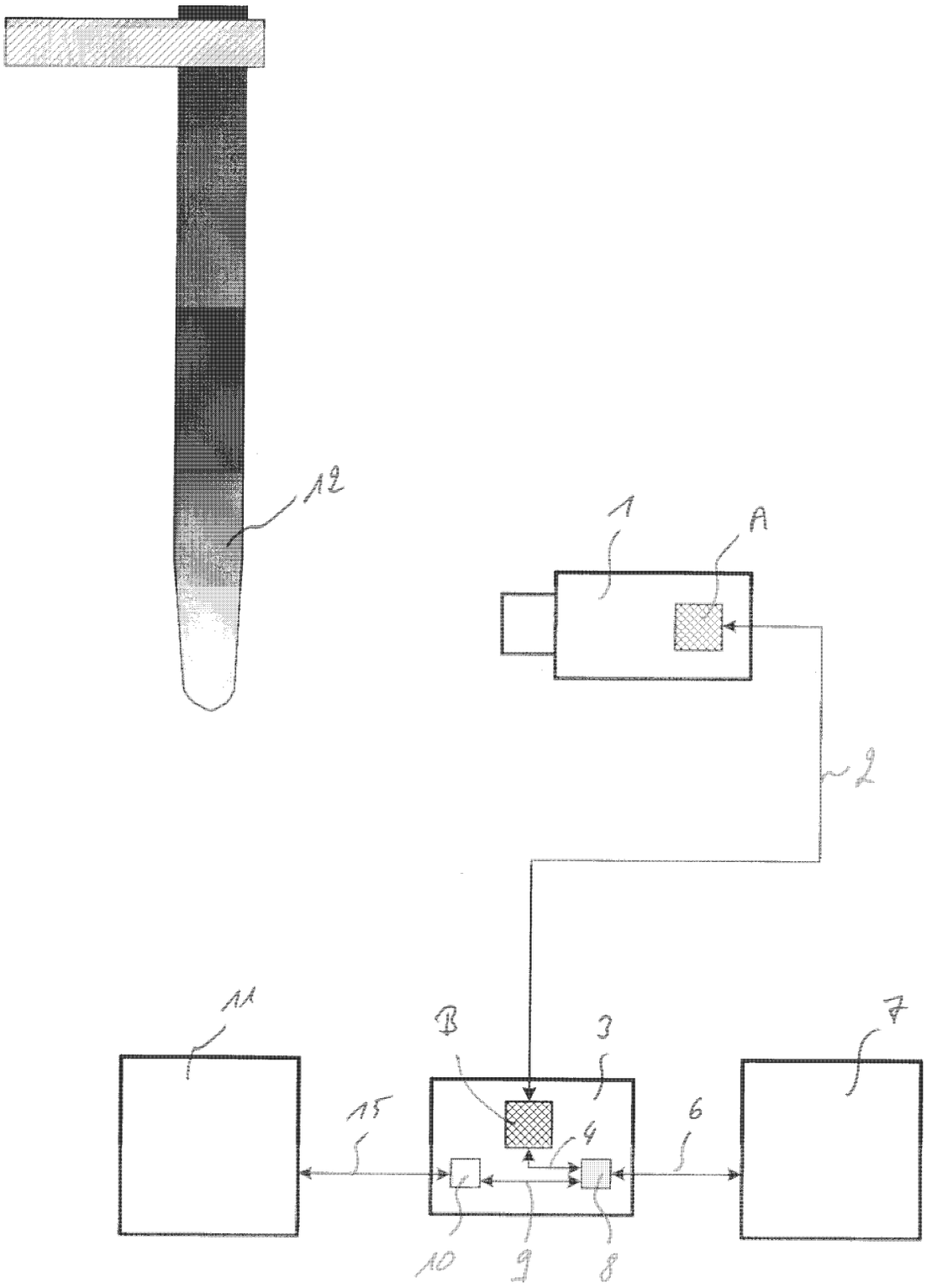


Fig.1

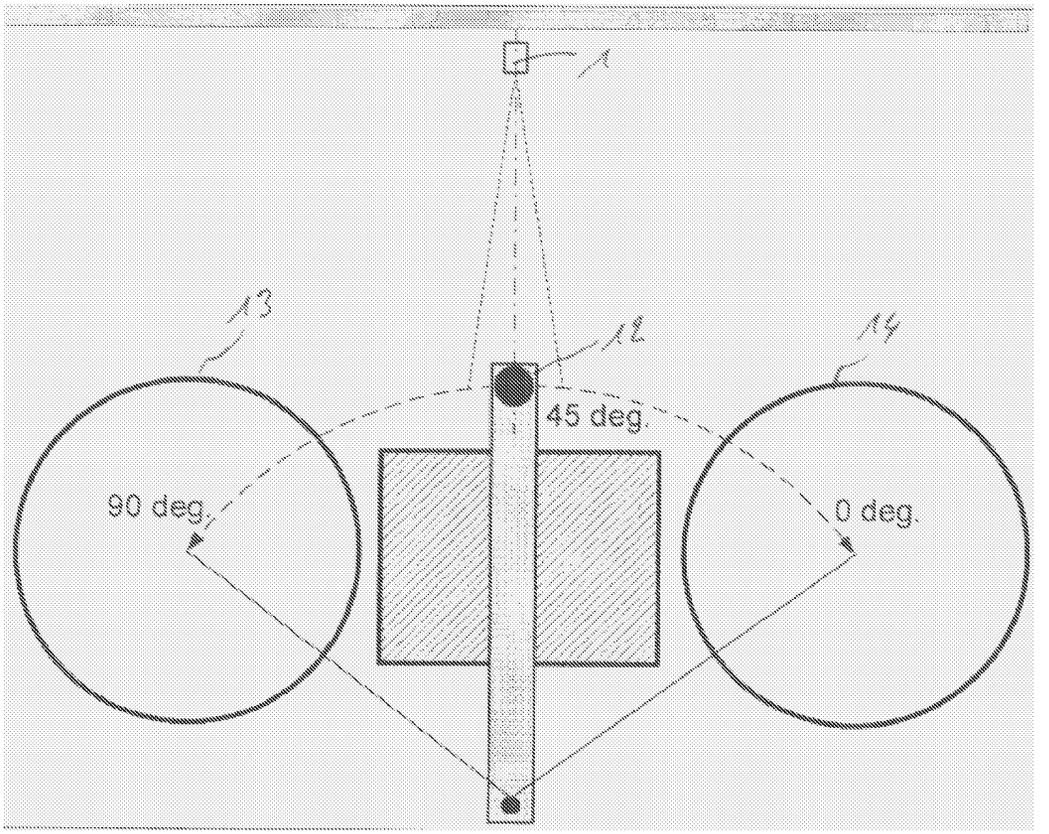

13
12
14
45 deg.
90 deg.
0 deg.

Fig.2

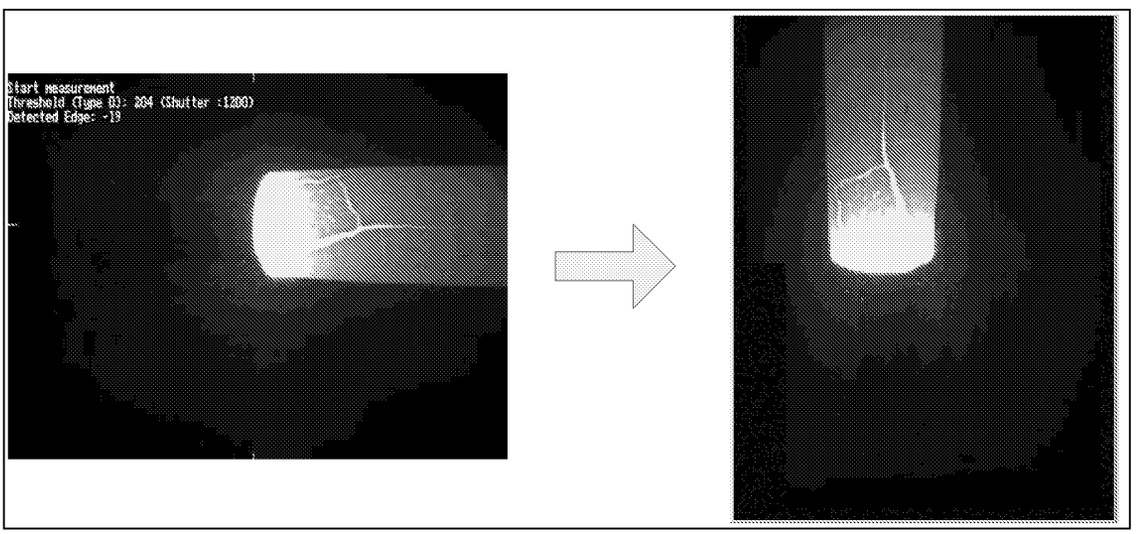

Start measurement
Threshold (Type 0): 204 (Shutter :1200)
Detected Edge: -19

Fig.3

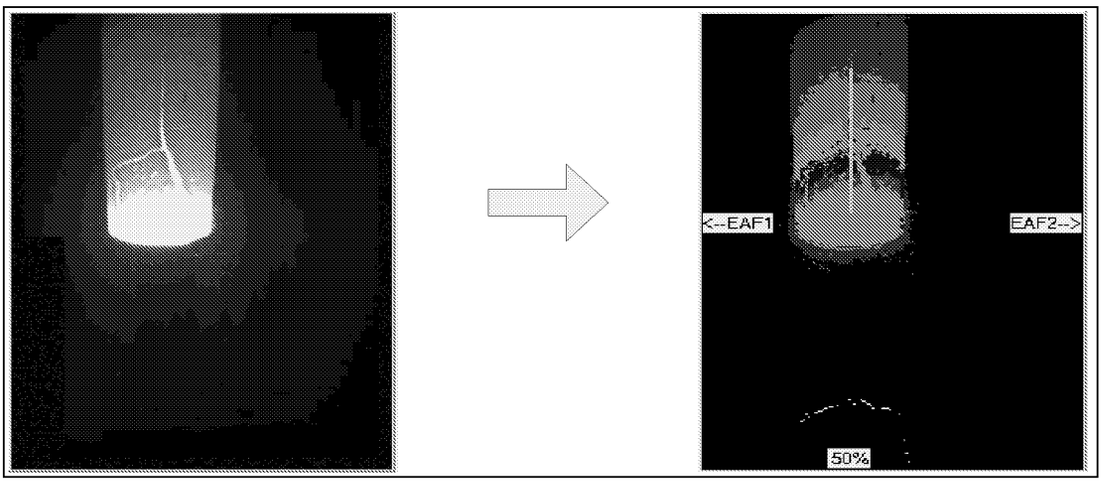


Fig.4

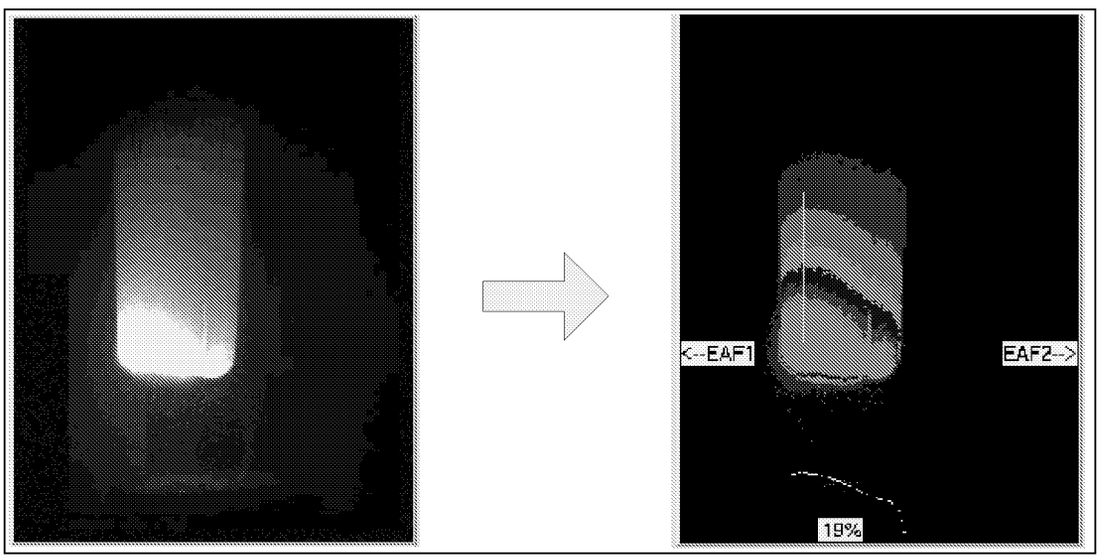


Fig.5

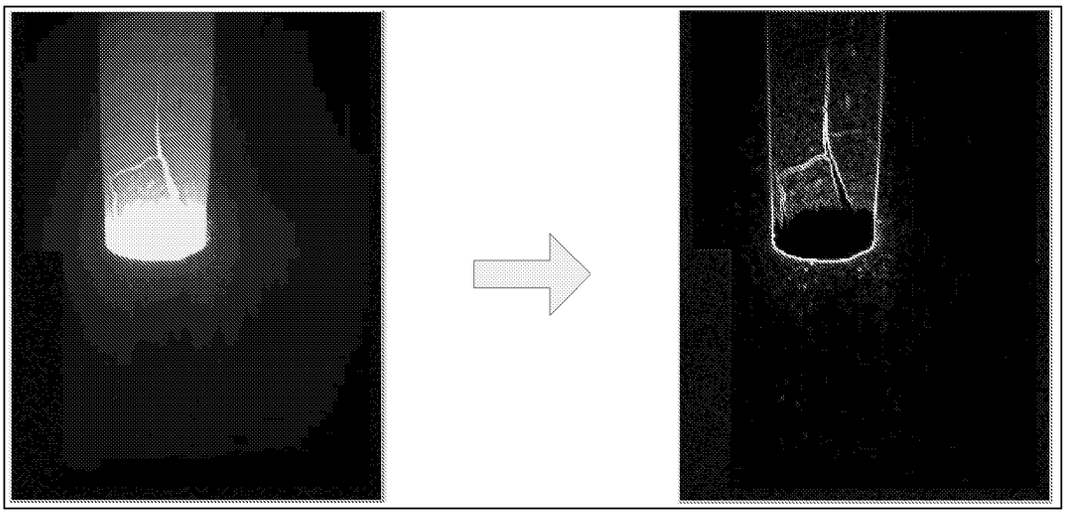


Fig.6

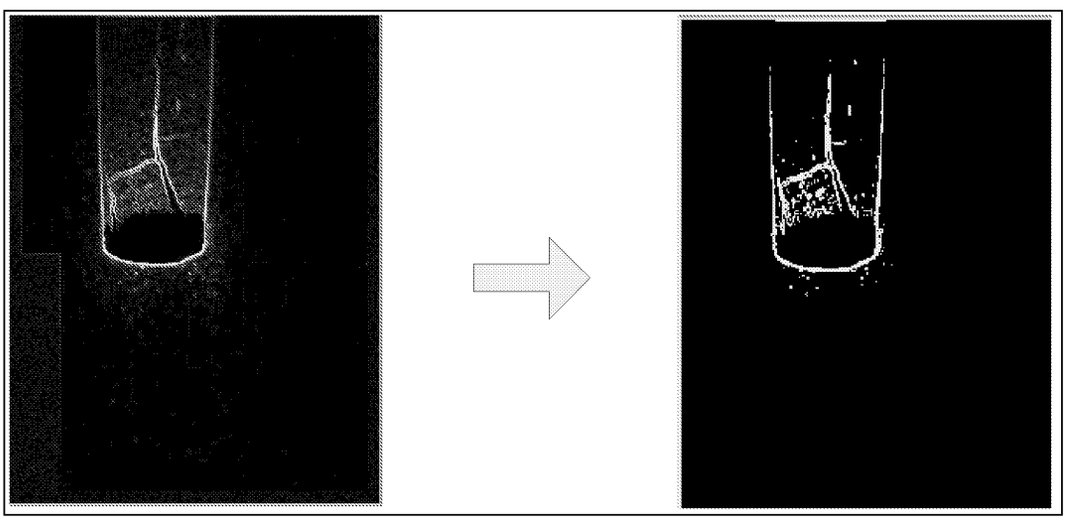


Fig.7

-	-	f	-	-
-	-	g	-	-
a	b	c	d	e
-	-	h	-	
-	-	i	-	-

Fig.8

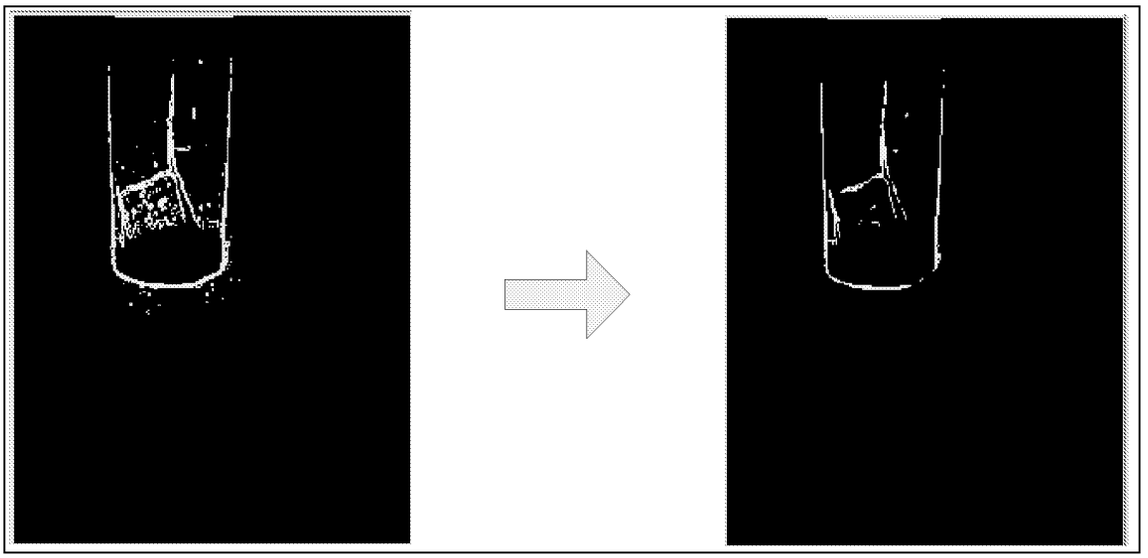


Fig.9

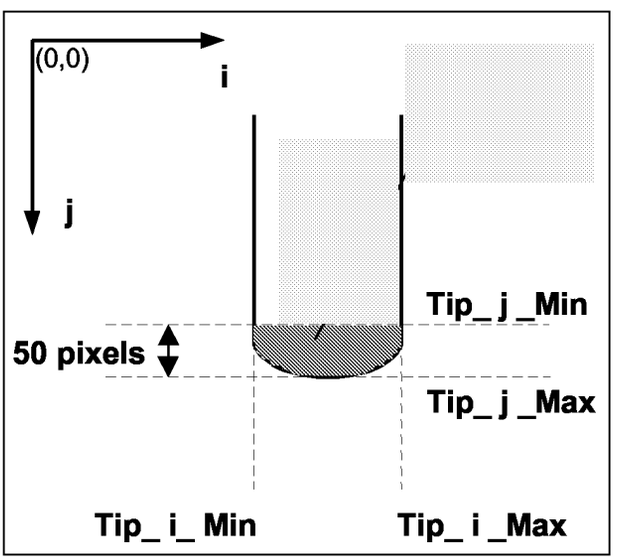


Fig.10

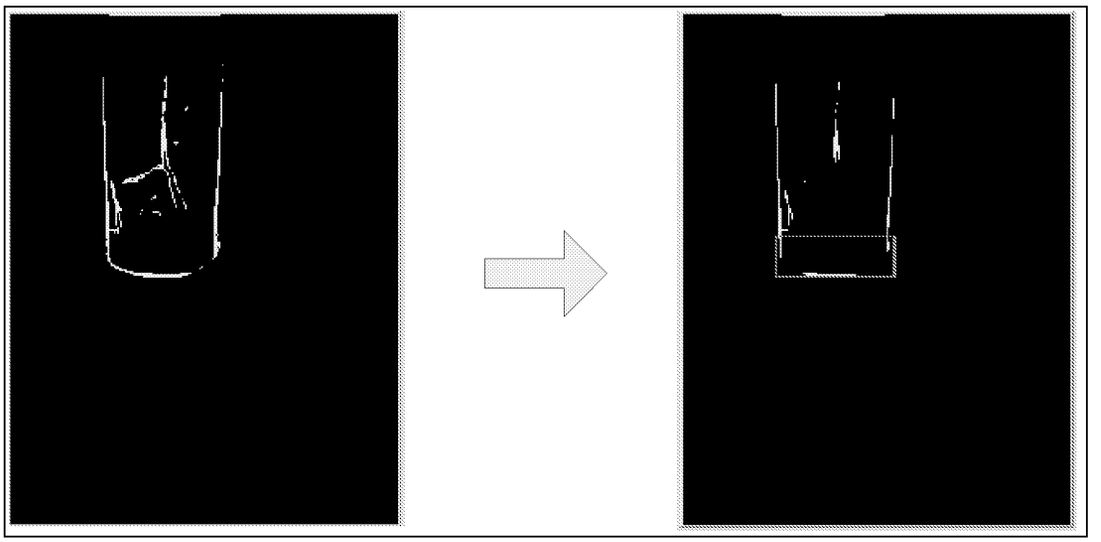


Fig.11

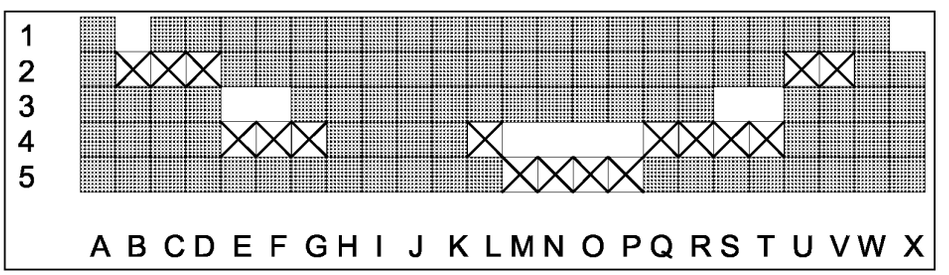
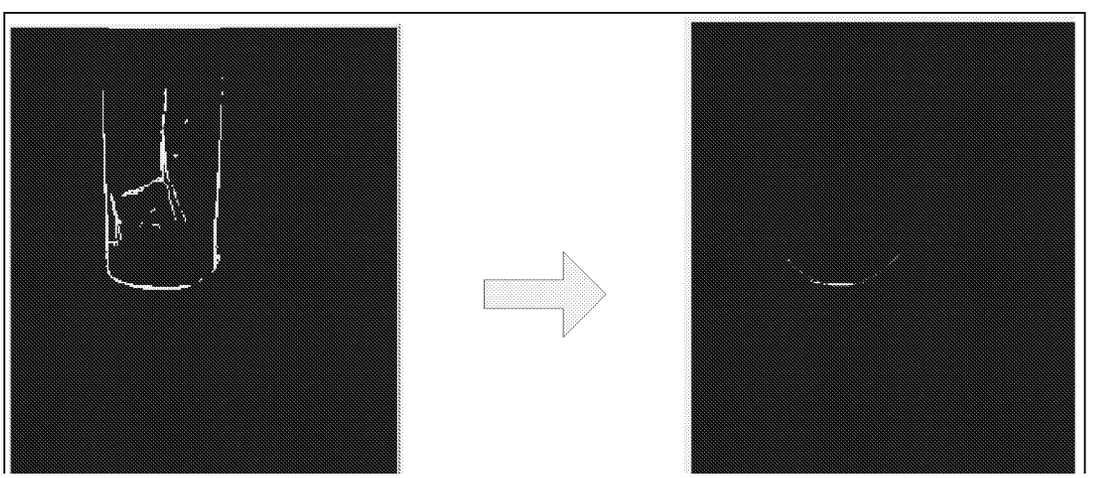


Fig.12



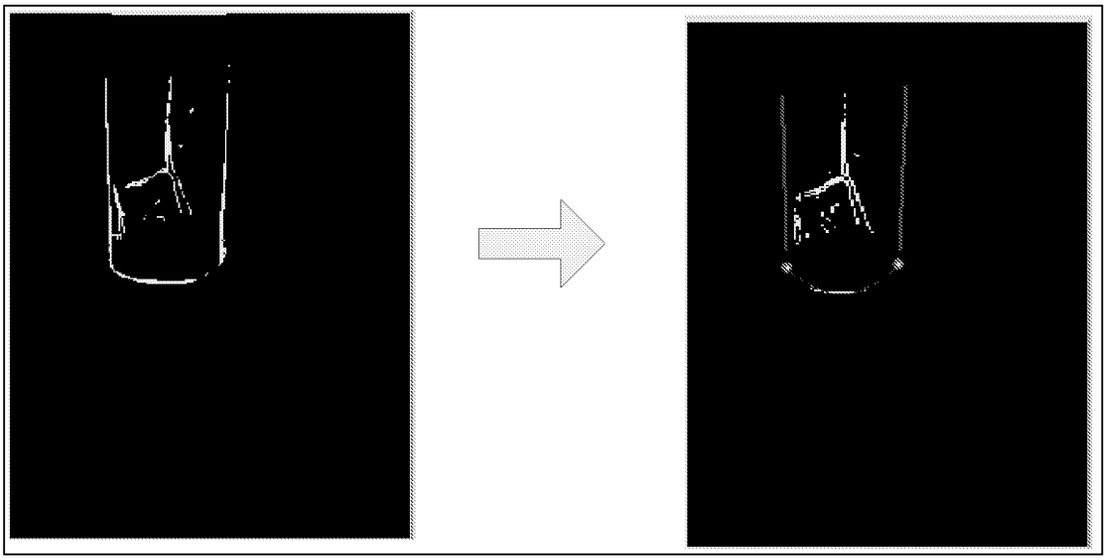


Fig.14

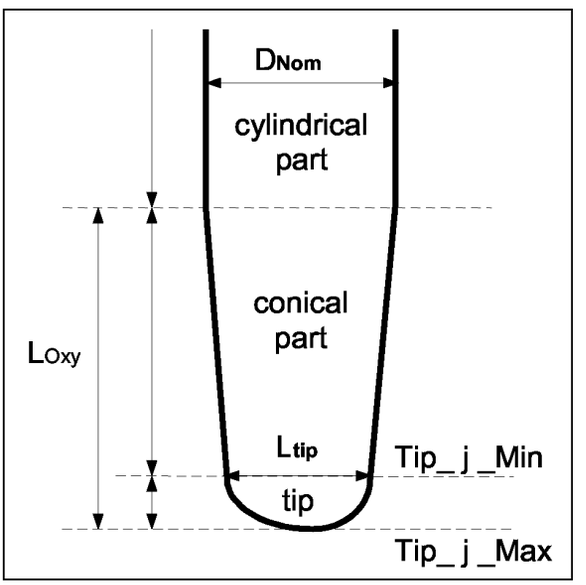

DNom
cylindrical part
conical part
LOxy
Ltip
Tip_ j _Min
tip
Tip_ j _Max

Fig.15

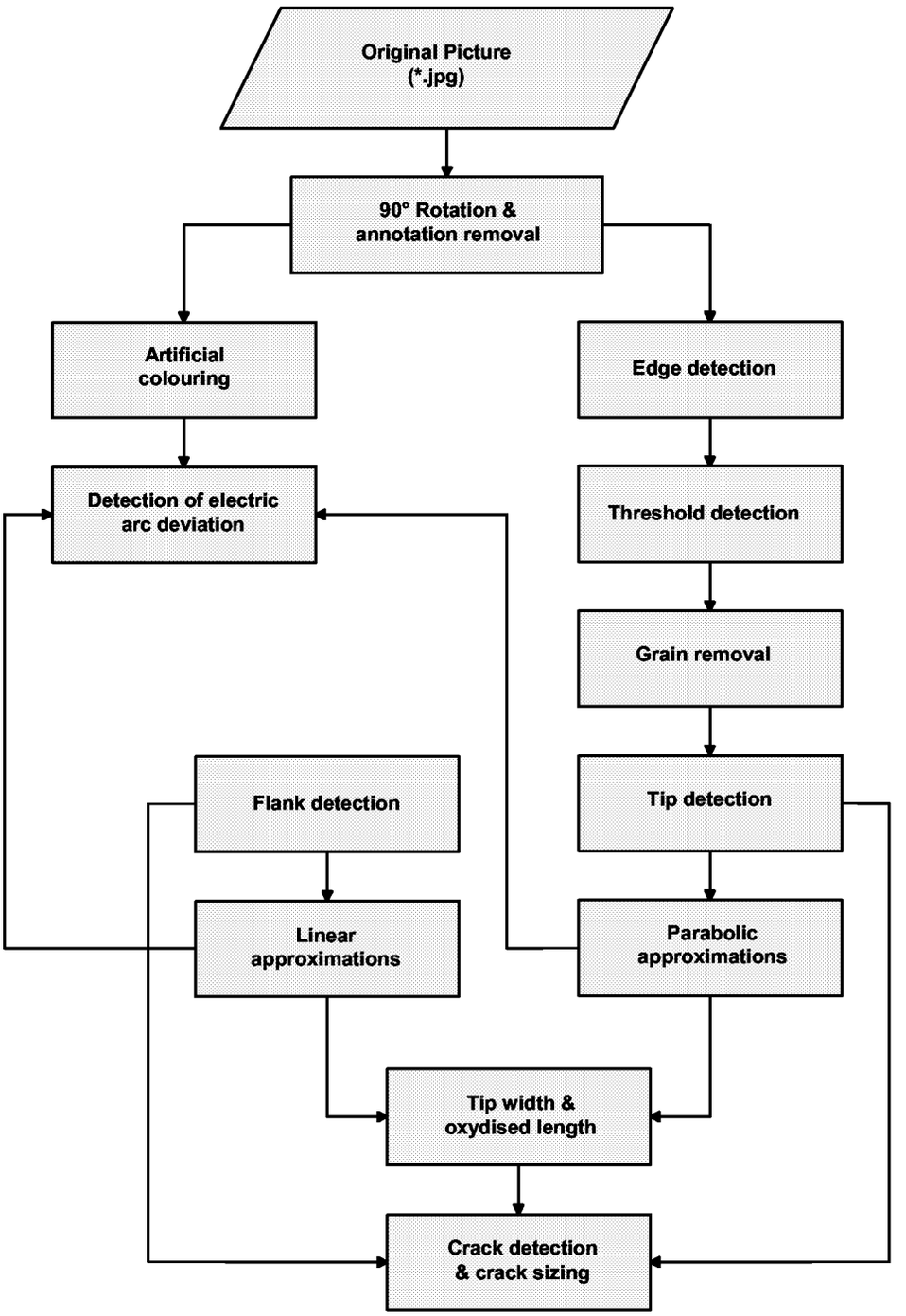

Original Picture
(*.jpg)
90° Rotation &
annotation removal
Artificial
colouring
Edge detection
Detection of electric
arc deviation
Threshold detection
Grain removal
Flank detection
Tip detection
Linear
approximations
Parabolic
approximations
Tip width &
oxydised length
Crack detection
& crack sizing

Fig.16

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 04 10 0169

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	WO 02/28084 A (UCAR CARBON COMPANY INC) 4 April 2002 (2002-04-04) * the whole document * ---	1	H05B7/02 F27D21/00
A	PATENT ABSTRACTS OF JAPAN vol. 2003, no. 12, 5 December 2003 (2003-12-05) & JP 2003 243151 A (TOSHIBA CERAMICS CO LTD), 29 August 2003 (2003-08-29) * abstract * ---	1	
A	PATENT ABSTRACTS OF JAPAN vol. 2002, no. 07, 3 July 2002 (2002-07-03) & JP 2002 081992 A (MITSUBISHI HEAVY IND LTD), 22 March 2002 (2002-03-22) * abstract * ---	1	
A	US 4 435 818 A (FLECKER PIERRE ET AL) 6 March 1984 (1984-03-06) * abstract * ---	1	TECHNICAL FIELDS SEARCHED (Int.Cl.7)
A	US 2003/235231 A1 (REYES JORGE ET AL) 25 December 2003 (2003-12-25) * abstract * -----	1	H05B F27D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	21 June 2004	Garcia, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 04 10 0169

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

21-06-2004

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 0228084 A	04-04-2002	AU 9296001 A	08-04-2002
		BR 0107268 A	25-03-2003
		CA 2392788 A1	04-04-2002
		CN 1397007 T	12-02-2003
		EP 1327352 A2	16-07-2003
		TW 538632 B	21-06-2003
		WO 0228084 A2	04-04-2002
JP 2003243151 A	29-08-2003	NONE	
JP 2002081992 A	22-03-2002	JP 2002081634 A	22-03-2002
US 4435818 A	06-03-1984	DE 3120856 A1	23-12-1982
		FR 2507051 A1	03-12-1982
		GB 2099145 A	01-12-1982
US 2003235231 A1	25-12-2003	WO 0188472 A1	22-11-2001
		AU 5803701 A	26-11-2001
		BR 0110901 A	11-03-2003
		CA 2409756 A1	22-11-2001
		EP 1299692 A1	09-04-2003

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82