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Machine Vision Applications in Industrial Inspection VII

Kenneth W. Tobin
Ning S. Chang
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Introduction

Machine vision can be described as the bringing together of imaging devices, computers, algorithms, and robotics to automate manufacturing inspection, characterization, and control. Today's high-speed, complex manufacturing systems have required the development of automation technologies that can efficiently collect data, use historical information to provide context, and generate process knowledge. Intelligently designed systems can use this knowledge for automatic characterization and control of product quality and the manufacturing process. In this regard, machine vision technology continues to provide new and innovative opportunities to automate manufacturing systems.

This volume of papers represents the seventh year of the SPIE Conference on Machine Vision Applications in Industrial Inspection. This year saw an increase in the number of submitted papers as compared to previous years. We feel this conference reflects the continued availability, growth, and acceptance of machine vision technologies for use in industry around the world. Our sessions this year were organized into four topical areas: systems and process characterization, image processing and metrology, color and appearance, and pattern recognition. Application areas considered by this year's authors ranged broadly from printed circuit board, continuous web film, and semiconductor manufacturing, to leather, paper, textile, poultry, and ham product inspection. The areas of research presented ranged from infrared, stereo, and profilometry systems and techniques, to fractal scene analysis, tristimulus imaging colorimetry, and image database retrieval.

We would like to express our sincerest appreciation to the SPIE staff for their continued support of this conference and for their hard work and diligence to help ensure its success. We would also like to thank the following people for their help in organizing the conference and reviewing papers: Ravi Rao, Joon Han, Vijay Sankaran, Steven Floeder, and Emerico Natonek.

Kenneth W. Tobin
Ning S. Chang

Contents

SESSION 1

Systems and Process Characterization

IR-based system for short-circuit detection during copper electrorefining process

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ABSTRACT

In this paper an infrared system for short-circuit detection in the copper electrorefining process is presented. The system consists of an IR-camera, a computer, radiomodems and software including the developed algorithm to process a thermal image. The basic component of the proposed system is an infrared camera mounted in an air-conditioned protection unit on a moving crane. The video output of the infrared camera is connected to the input of a framegrabber card in a computer. The framegrabber card with software captures a thermal image of the electrolytic cell, then processes it to locate the hot spots (short-circuits in a cell). The inspection results are transferred directly by radio link to the control room to be printed and further processed. The system presented in this paper is a prototype that has been tested for several months. The test results indicate that strong short-circuits can be detected with the proposed system as reliably as with the currently used manual method (gaussmeter). The advantages of the proposed system are easier and faster measurements (all cathodes in a cell can be measured remotely at the same time) and possibility to gather new process information.

Keywords: IR-camera, image processing, copper electrorefining

1. INTRODUCTION

In this paper a prototype system based on the infrared camera for detection of the short-circuited electrodes in the copper electrorefining process is presented. The short-circuits between the electrodes (anodes and cathodes) can be detected by measuring the temperature of the cathode bars, the voltage between the anode and cathode or the magnetic field of the cathode bars produced by the electrode current. The methods based on these measurements are hand-held or crane-carried infrared scanners and cameras, hand-held gaussmeters and computerized cell voltage monitoring systems.[3,4]

Simple hand-held gaussmeter is an old and reliable method which is still in use in many electrolysis plants. It is a manual method and requires excessive walking on the electrodes which may cause new short-circuits. Furthermore, all cells have to be checked which consumes a lot of time and information about short-circuit situation can not be gathered easily.

The outline of the paper is following. The copper electrorefining process and the nature of the short-circuited electrodes is described in Section 2. In Section 3 the proposed system and its main components are presented. Section 4 describes the developed algorithm and software for searching short-circuited electrode(s) from thermal image of the electrolytic cell with the help of the images of the inspected cells. The system test and results are presented in Section 5 and Section 6 respectively.

2. PROCESS DESCRIPTION

The copper electrorefining process produces copper essentially free of harmful impurities and separates valuable impurities from copper as by-products. The process takes place in cells containing an electrolyte of sulphuric acid and copper sulphate where the electrodes (anodes and cathodes) are inserted. The cathodes are connected on the current distributor bar along on one side of the cell and the anodes on the other side. The cell arrangement and electrorefining circuitry are described in the Figure 1 (a part of a cell is shown). The electric current passes from the anodes through the electrolyte to the cathodes next to them in the left hand cell. Between the cell electric current passes from the cathodes in the left cell to the anodes in the right cell.[3]

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An electric voltage applied over the cell makes an electric current to flow from anodes to cathodes through the electrolyte transporting copper from the anodes to the cathodes. The anodes contain impurities which either drop to the bottom of the cell or dissolve in the electrolyte. Electrorefining is continued for 10 to 28 days. At that point 80-85% of the anode is dissolved. Two or three cathodes are produced from each anode. Fully grown cathodes are removed from the cell after a period of 7 - 14 days plating. During the copper electrorefining process there are many things to be monitored and inspected. Inspections need to be done for example to measure and locate the short-circuits between the anode and cathode plates in the cells. Short-circuits are usually caused by bent starting cathodes, electrodes that are not completely parallel to each other or nodular cathode growths between cathode and anode.[3]

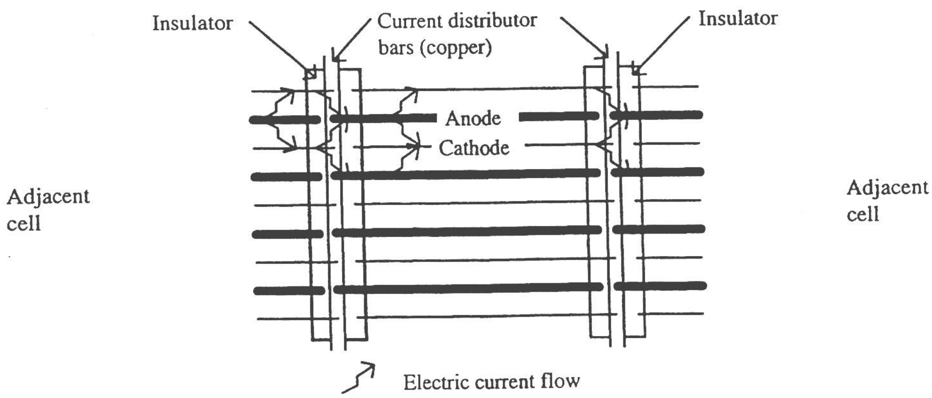

Figure 1. Electrode arrangement and electrorefining circuitry in a cell

In the case of short-circuits the electric current produces heat in the short-circuited electrodes and in the current distributing system instead of producing copper. Especially the cathode bars get very hot. Electrical waste means decreasing current efficiency and that is why the short-circuits must be eliminated as soon as possible.[3,4] The Figure 2[2] illustrates surface temperature of the cathode bars in a certain cell. The cathodes are numbered from 1 to 31 in the horizontal axis and temperatures (°C) are shown in the vertical axis. In the normal condition the surface temperature of the cathode bars is 50-60 °C while the short-circuited cathodes have a temperature about 90 °C and over. In the case presented in the Figure 2 there are two severe short-circuits and one is developing in cathode number 7 in a cell.[1]

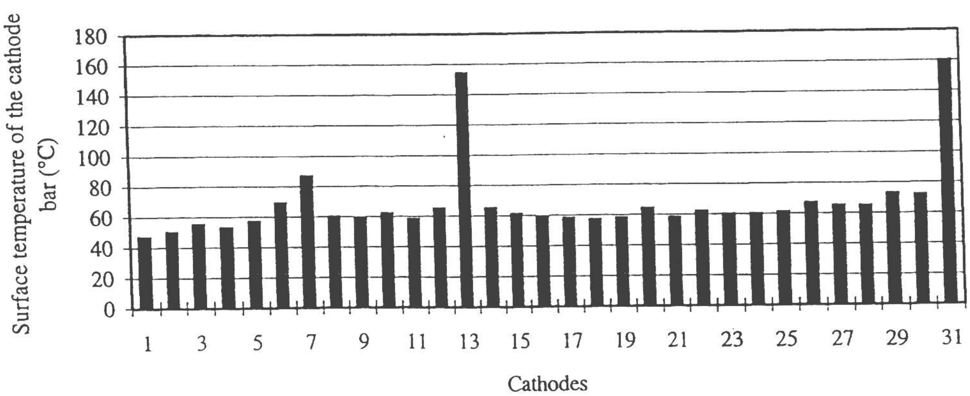

Figure 2. Surface temperatures of the cathode bars in a cell

3. SYSTEM DESCRIPTION

The IR-camera mounted in an air-conditioned protection unit on a crane above the electrolytic cells acts as a measuring device by producing a thermal image of the cells to be processed by the computer and software. The system is described in the Figure 3. The IR-camera used in the system is SeekIR™ (Flir Systems™) a hand-held model with nominal bandpass 8-14 µm. The infrared camera is mounted at the appropriate height so that the whole cell width is seen using a wide angle lens installed to the infrared camera. The IR-camera is protected against the severe conditions of the refinery hall by installing it into an air-conditioned protection unit. The video output of the infrared camera is connected with the coaxial cable to the computer. The system uses the crane positioning system to determine the right moment to grab an image. At the same time section and cell number are passed to the software to identify the inspected cell. The framegrabber card Matrox Meteor (Matrox Imaging Products Group) together with the developed software captures a thermal image of the electrolytic cell, then processes it to locate the hot spots in the image (= short-circuited anode/cathode pairs in a cell). After the inspection procedure the results are transferred by radio link to the another location to be printed for the inspection personnel and further processed.

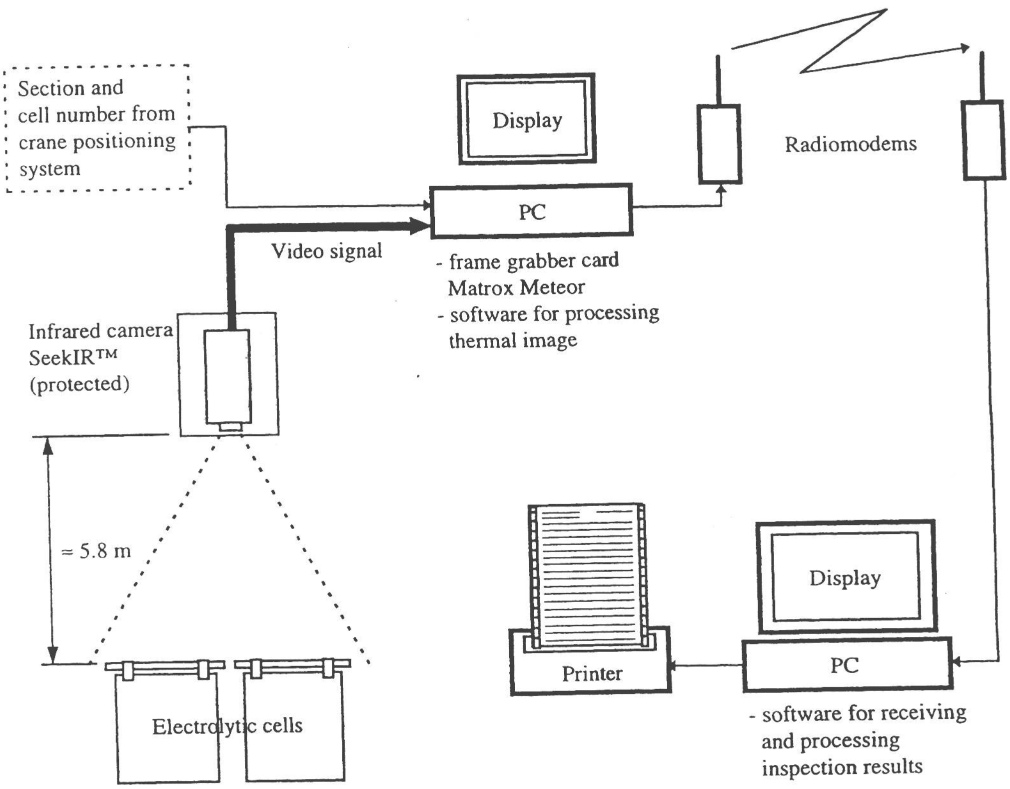

Figure 3. The system flow diagram

The proposed system is meant to be a tool for short-circuit detection similarly as a gaussmeter. The advantage of the proposed system is that the electrolytic cells can be measured remotely. Remote measurement prevents excessive walking on the electrodes which is one of the reasons for the short-circuits. The other advantage is the possibility to gather valuable statistical information about short-circuit situation in the refinery. The system described in this paper is a prototype tool for short-circuit detection during the copper electrorefining process. So there is no need to obtain information about the absolute temperature values of the cathode bars, which might be useful for research purposes.

4. THE DETECTION ALGORITHM

Image processing is used to interpret the thermal images of the electrolytic cells. A preliminary version of the detection algorithm has been presented in Mäkipää et al.[1]. The basic idea of the developed algorithm is first to search and calculate the edges and lines of the electrolytic cell to position the cell to be inspected. The second step is to determine the exact position of each cathode plate in the cell so that using tresholding the short-circuited cathode can be located. An example of the thermal image captured with the IR-camera is presented in the Figure 4. The image is captured when the IR-camera is in a position where two displayed cells can be seen. The reason is that this makes it easier to locate the cell in the image. The cell to be inspected is displayed in the upper half of the image. The infrared camera is installed at height from where all 31 cathodes in a cell can be measured at the same time. In the Figure 4 there are three short-circuited cathodes. In the images white indicates warm or hot area while black indicates cooler areas.

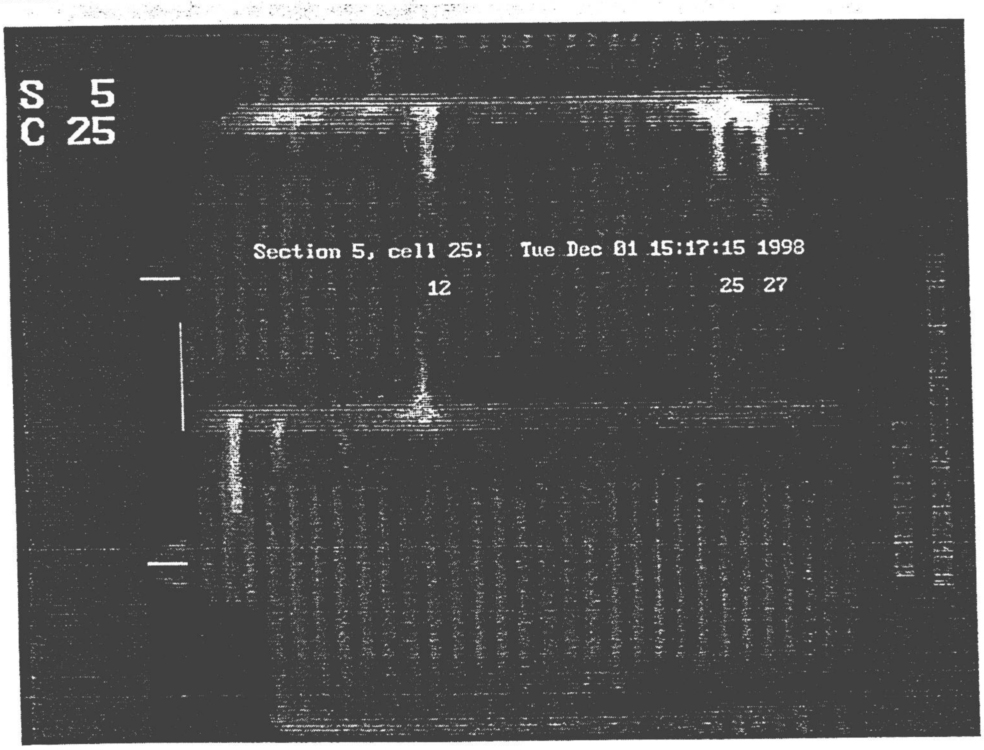

Figure 4. An example of thermal image of the electrolytic cells

The algorithm uses the geometry of the cell to determine the center line of the cell (= the center line of the overflow drain). The overflow drains of the cells can be seen on the left in the Figure 5. The algorithm tries to find the edges of the overflow drains using the changes of the gray scale values. After cell center line(s) have been located, the current distributor bar between two adjacent cells can be located using the upper and lower cell center lines. When the current distributor bar has been positioned, the cell in the thermal image has been located in vertical direction. To locate the cell in the horizontal direction the algorithm tries to find the cell edge.

After cell has been positioned both vertically and horizontally in the image the locations of the cathode bars are determined (the short vertical lines in the Figure 5). At the same time the cathodes are numbered (1...31) starting from the end of the cell where the overflow drain is situated. The cathode numbering is necessary in order to find out the exact location(s) of the short-circuited cathode(s) in a cell. The short-circuited cathodes are searched along the determined lines (upper and lower inspection lines) using thresholding. These inspection lines are determined after cell positioning using the previously obtained lines, cell center line and current distributor bar locations. The threshold value is not a fixed constant value. It is updated from the image information for every image.

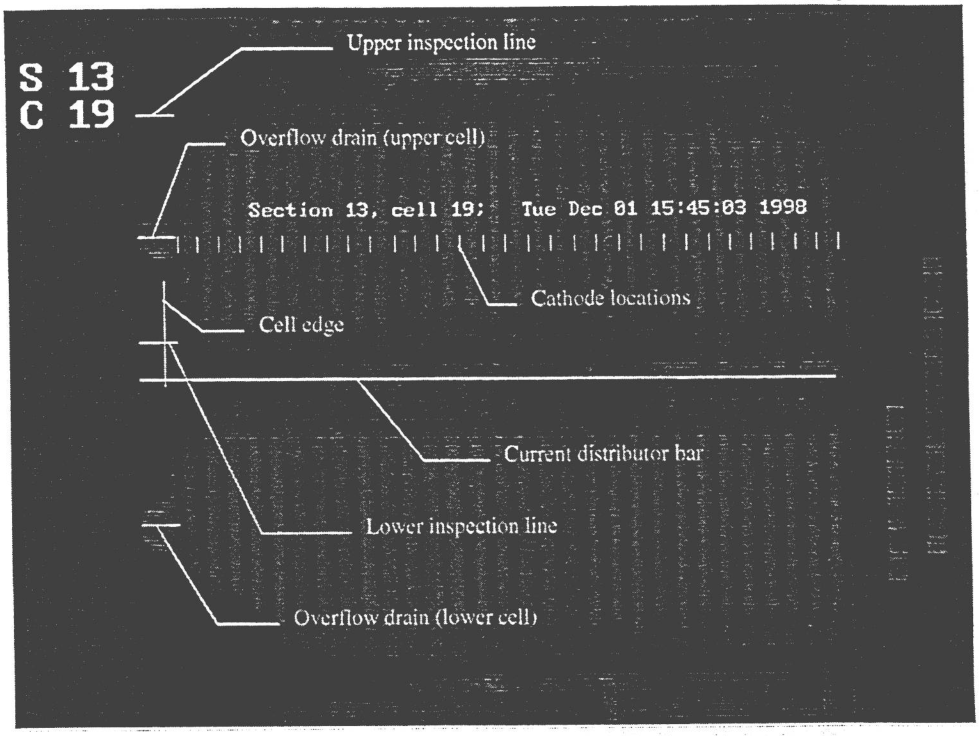

Figure 5. An example of processed thermal image of the electrolytic cells with the inspection results printed on it

The thermal image of the electrolytic cell is the one that can be seen also in the display during the inspection procedure. The section and cell numbers, date and time information and the numbers of the short-circuited cathodes are printed in the image. The same information is also saved as a record in a file to be printed after inspection procedure and data transferring. An example of how the information of the inspected cell is printed on the paper is shown in the Figure 6. On the left are the section and cell identification numbers (section 1, cell 16). The "<" -sign means the overflow drain. The short-circuited cathodes are placed on the line according to their cathode numbers.

```
...
S1C15  <l                                                    l
S1C16  <l              7  8                   19             l
S1C17  <l                                                    l
...
```

Figure 6. An example of the results printed on the paper

In the example image shown in the Figure 7a three short-circuited cathodes (cathodes 7, 8 and 19) are detected according to the detection algorithm. In the Figure 7b a line profile of the gray scale values along the lower inspection line in the Figure 7a is described. According to the line profile in the Figure 7b the short-circuited cathodes in the figure 7a are clearly warmer than the cathodes in a normal condition. Both the upper and lower inspection lines in the image have to inspected because the hot cathode bar ends may also be on the other side of the cell due to different current direction in a section. The positioning of the cell, locating and numbering the cathodes and thresholding together yield the information about the state of each cathode in a cell. The results are printed in the image as in the Figure 7a.

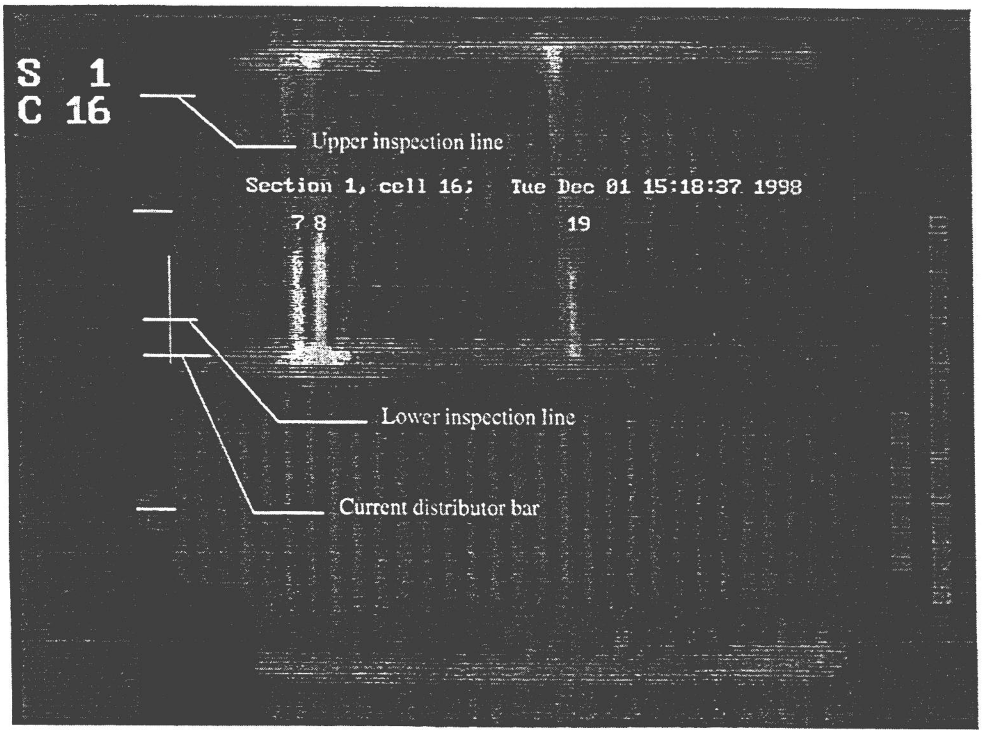

Figure 7a. An example of the electrolytic cell inspected by the proposed IR-based system

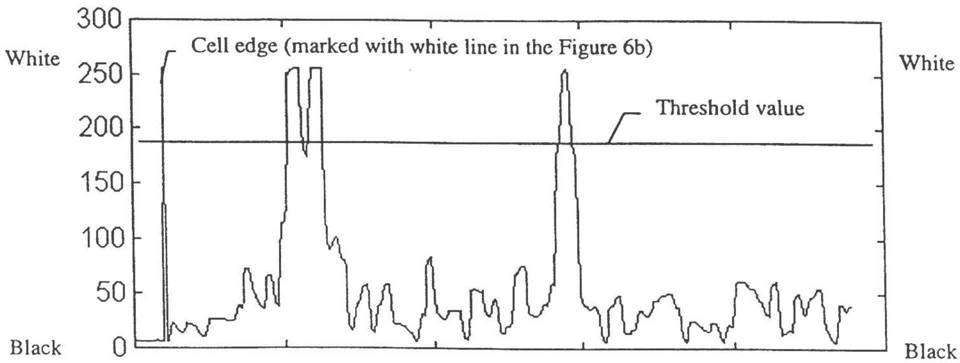

Figure 7b. Gray scale values along the lower inspection line (see Figure 7a)

5. SYSTEM TESTS

The system and its parts (devices and algorithm) separately have been tested in 1996-1997. The results of the algorithm tests have been reported in Mäkipää et al.[1]. The tests were run using images captured from video tape recordings. The test results indicated that the algorithm is applicable to interpret thermal images of the electrolytic cells. The whole system as described in this paper has been tested for several months during 1998. The tests took place in Outokumpu Harjavalta Metals Oy Copper Refinery, Pori, Finland[1]. The crane speed used during the tests was about 0.5 m/s.

In many electrolysis plants the electrolytic cells are covered with the plastic blanket for heat retention which makes it more difficult to use IR imaging for cell inspection. The blankets are harmful for the detection algorithm. It is not necessarily able to locate the cell and cathodes right in the thermal image. In some cases the covered cell can be inspected succesfully but usually the results are not reliable enough. During this test period the cell blankets were removed before the cell inspection.

The system tests were run by choosing certain sections of cells to be monitored over the test period. During the test period the electrolytic cells were inspected both with the proposed system and manually with the gaussmeter. The idea was to compare these two methods. First the chosen sections of cells were inspected with the proposed system and then the same procedure was done using the gaussmeter. The short-circuited cathodes measured by both methods were manually checked if they really were short-circuited or not. Totally hundreds of electrolytic cells were measured during the test period. Because of the large amount of data the results were summarized together. After the test period the cumulative sum of the measured short-circuits for all 31 cathodes were calculated. In the Figure 8 the results as a scaled summary cathode by cathode over the test period is presented. For example all measured short-circuits related to the cathode number 1 in all inspected cells are summarized. The third bar for every cathode means the checked amount of the short-circuits.

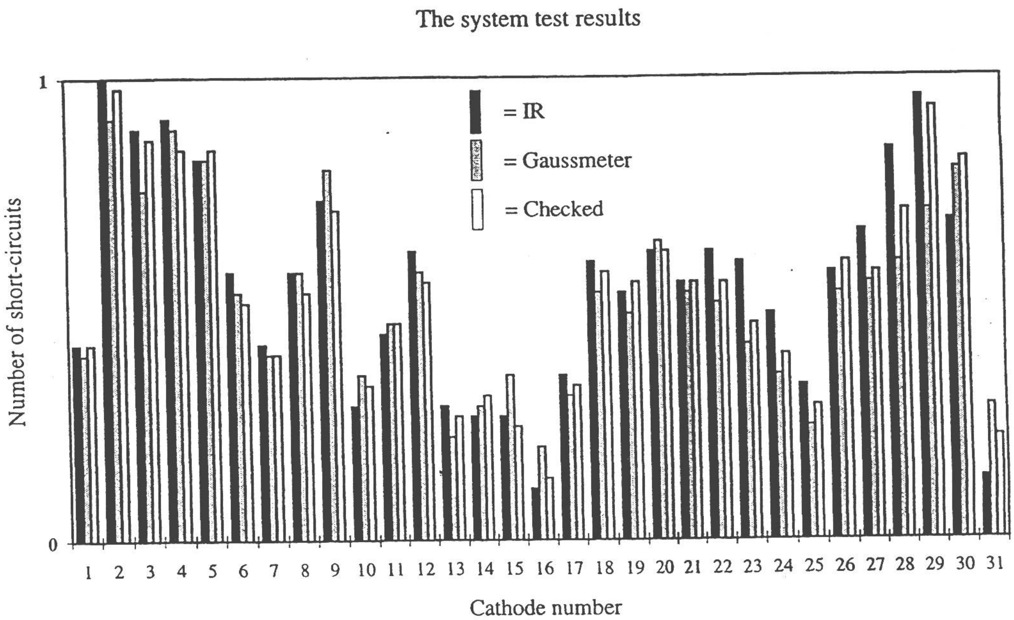

Figure 8. The results of the system tests, comparison between the proposed IR-based system and gaussmeter

According to the test results the short-circuited cathodes can be detected with the proposed system as reliably as with the currently used manual method. In some cases there are differences between the two methods. There are cases where the gaussmeter does not indicate a short-circuit as the proposed IR-based system and the other way round. It is possible that the hot cathode bar cannot be indicated as a short-circuit with the gaussmeter while in the thermal image it can be clearly detected. In some cases the cathode can be short-circuited but not warm or hot enough (sometimes it takes time to see short-circuit in a thermal image of the electrolytic cell) and can then be measured with gaussmeter but not with the proposed system. Bad contacts can make the cathode bar hot and to be interpreted as a short-circuit by the detection algorithm of the IR-based system. Also if the short-circuit is really severe and it is seen as very large white area in the thermal image of the electrolytic cell the adjacent cathode(s) with normal condition may be indicated as short-circuited cathodes by the detection algorithm.

The appropriate crane speed according to the tests is about 0.5-1 m/s. In this speed the quality of the grabbed thermal images of the electrolytic cells is good and the detection algorithm can be developed to inspect one cell in less than 1 second. With this speed it will take about 30 minutes to inspect the 700 electrolytic cells in the refinery.

6. CONCLUSIONS

Using an infrared camera combined with image processing algorithms to interpret thermal images of the electrolytic cells an effective method has been developed for the short-circuit detection in the copper electrorefining process. The advantage of the proposed system compared to the manual gaussmeter method is that measuring is always done according the same rules without having different interpretation for every image. Gaussmeters may differ from each other and personnel may interpret gaussmeter measurements differently. Infrared imaging makes it possible to measure all cathodes in the electrolytic cell remotely at the same time. Another benefit related to the proposed system is that the cell inspection results can be documented for later analysis. Using purely manual method it is not possible or at least it is not easy to gather cell inspection data concerning short-circuit detection.

The excessive walking on the electrodes may be one reason for the short-circuits. Using infrared imaging for the short-circuit detection walking on the electrodes can be decreased because of remote measurements and it helps personnel to concentrate on the cells where the short-circuits exist. The inspection results reports show the cells that personnel has to take care of. The electrolytic cells in the normal condition can be ignored.

The cell blankets disturb the automatic detection of the short-circuits. At the moment measurement with the proposed system has to be done without the cell blankets. Using a manual inspection method for example gaussmeter re-measurement immediately after correction of the short-circuited cathode can be done. After correction the electric current through the cathode bar and the magnetic field around the cathode bar becomes normal. Re-measurement immediately after corrections with the IR imaging is not possible because the temperature of the short-circuited cathode bar decreases slowly.

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