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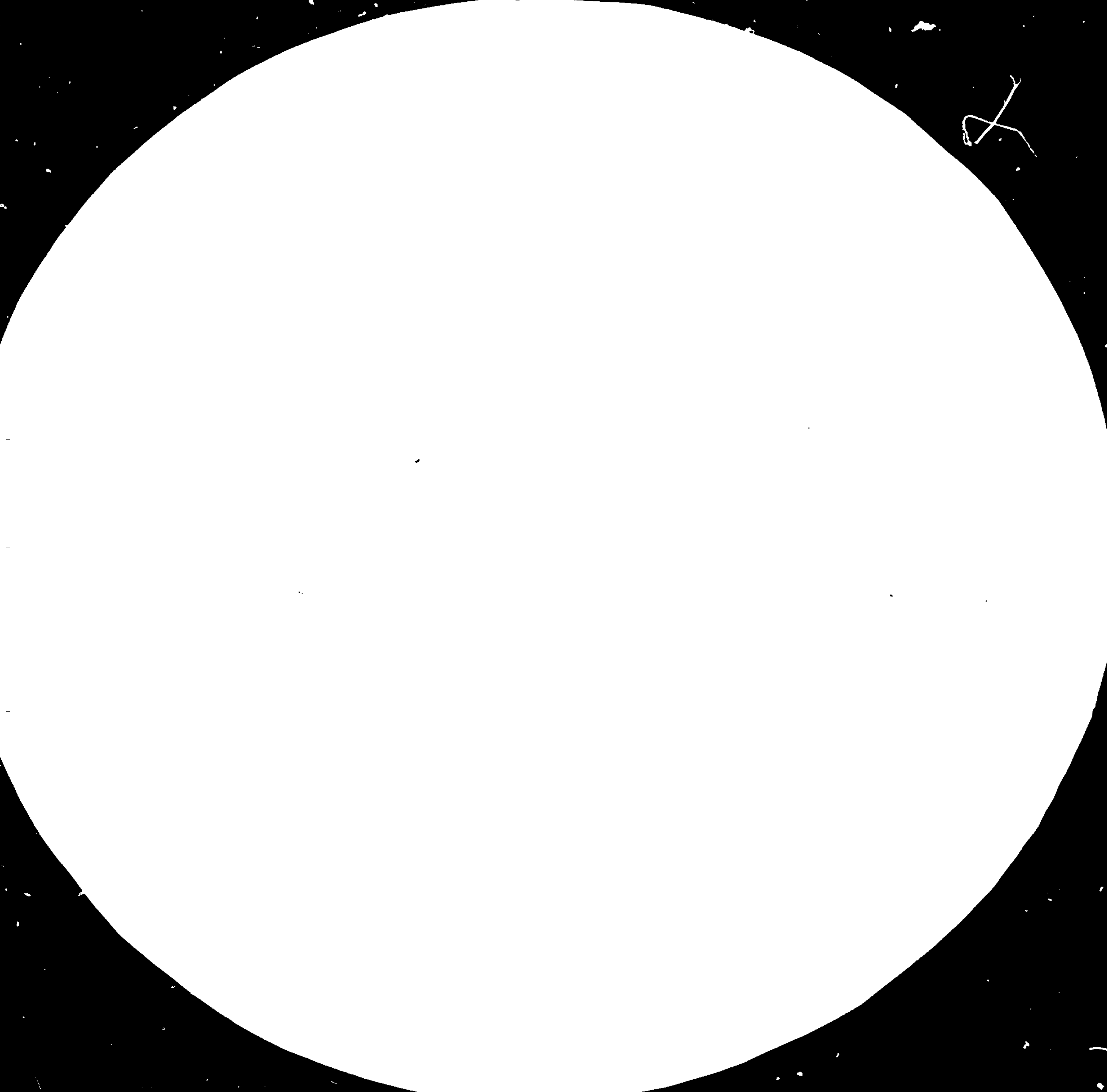

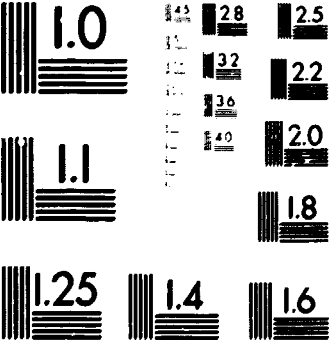

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ELECTRICAL MEASUREMENTS, PROCESS CONTROL AND ELECTROMAGNETIC INTERACTIONS IN ALUMINIUM ELECTROLYSIS

L. Tikasz

3007

ALUTERV-FKI
BUDAPEST
1984

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ELECTRICAL MEASUREMENTS,PROCESS CONTROL AND ELECTROMAGNETIC INTERACTIONS IN ALUMINIUM ELECTROLYSIS

Edited by
L.Tikasz

Co-authors:
J.Horvath
J.Pocze
G.Szina
M.Zaymus

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Budapest, August, 1984.

Laszlo TIKASZ

CONTENTS

PART I.

PART II.

APPENDIX

FIGURES

TABLES

SUMMARY

The main objective of this work is to give a general view on the problem of electrical measurements, process control and electromagnetic interactions in aluminium electrolysis. Theoretical background as well as actual measurements are discussed. This volume is, accordingly, divided into two parts.

Part I

THEORETICAL BACKGROUND

0.1 Electrical Parameters of a Cell

It is the electrical parameters that can be measured continuously and reliably, so that one should rely on them as much as possible. The main fields of their use are :

-determination of the total cell voltagecomponents (voltage losses in the anode, cathode and the bath)

-qualifying and testing carbonaceous materials and current carrying parts

-supervising the whole process, especially the results of work routines

-cell failures detecting

The relating measurements and calculations support the potroom personnel in their daily work.

0.2 Process Control

Automatic control is a powerful tool to run the process in a prescribed way.By its assistance, the power and material consumption as well as human interference can be reduce. The development of a control system involves:

-preliminary experiments

-identification procedures

-control methods

-realisations

Outlines of theoretical background, with abundant examples of practical applications in aluminium electrolysis are discussed. This method is supposed to be close to how a metallurgist thinks. The most widely used method, resistance control, is demonstrated in details. Optimal and hierarchical systems are outlined. The principles discussed here are important for both retrofitting activities and a construction of new smelting capacities.

0.3 Electromagnetic Interactions

This section discusses the significant effects of electromagnetic interactions on the process of electrolysis. Magnetic field is generated inside and in the vicinity of the cell due to the high intensity current. The interaction of magnetic induction and current generates magnetic forces, resulting in hydrodinamic fluctuation in the cell.

There are different cell constructions and smelter arrangements, having different magnetic characteristics From this point of view,it is also important to study the possible bus-bar arrangements.

The fluctuation of the molten metal, caused by magnetic forces, may lead, beside technological problems, decreased current efficiency.

Different methods have been developed to take the magnetic induction in the melt, the metal fluctuation velocity and the metal surface distorsion.

Computer programs have been developed to calculate the potential field and current distribution of reduction cells.These programs belong to larger systems, modeling electrolytic cells in a complex way,including magnetic,hydrodinamic and thermal effects.

Part II

LABORATORY AND PLANT MEASUREMENTS

0.4 Safety Instructions

The measurements described in this part are dangerous by nature. The objective of this section is to emphasize the importance of abiding the rules, instructions and preventive measures relating to a certain laboratory or plant.

0.5 Electrical Measurements

Several groups of measurements are detailed here :

-measurements relating to the cathode (current distribution, total voltage drop, voltage drop components)

-measurements relating to the anode (current distribution and voltage loss in the anode)

-current carrying parts and carbonaceous materials (specific resistance of anode and cathode blocks, baked paste samples , steel parts; specific resistance as a function of temperature and time)

-supervising of work routines (anode adjustment, alumina feeding, metal tapping, stub pulling, etc.)

-cell failure detecting (analog recordings of voltage or resistance, instruments for express testing)

0.6 Identification, Simulation

On the basis of the electrical measurements discussed in the previous Chapter, simulation methods are demonstrated here.

Simulation is the first step of modeling a control method or testing an estimation algorithm. The base of simulation, typical generation of signals and necessary software routines are outlined. Following these suggestions, a wery usaful program package can be established.

Calculation of anode voltage drop in a Soederberg cell is demonstrated. Calculations were made on a desc-top computer.

0.7 Electromagnetic Measurements and Calculations

Magnetic induction measurement in the melt needs specific equipment. The following examples of applications are detailed:
-measurements in the melt
-measurements in the air outside the cell

Calculations concerning the stable operation of the cell are made on the basis of the technological parameters and the components of the magnetic fiel.

Appendix

Basic devices are listed in the Chapters in Part II. Still, it is advantageous to recount the basic instrumentation of an electrical measuring team.

INTRODUCTION

or how to use this book

Our aim is to help metallurgists and potroom personnel in their everyday work. Electric and electromagnetic problems and process control methods discussed here are of a great importance in aluminium electrolysis. Both the theoretical background and the actual measurements are discussed.

For didactic reasons, this book is divided into two complementary parts. Part I. discusses the theoretical background. Actual measurements are discussed in Part II. Their sequence follows the arrangements of Part I. Each test method and measurement is described in the same structure: principles, equipment and personnel, procedure and evaluation. It is advantageous to refer to the actual measurements when studying the theoretical Chapters and vica versa.

The Authors hope their effort will help the UNIDO in its noble work.

1. ELECTRICAL PARAMETERS OF A CELL

1.1 Components of Cell Voltage

The total cell voltage is the sum of electrochemical and ohmic voltage drops as shown on Figure 1. :

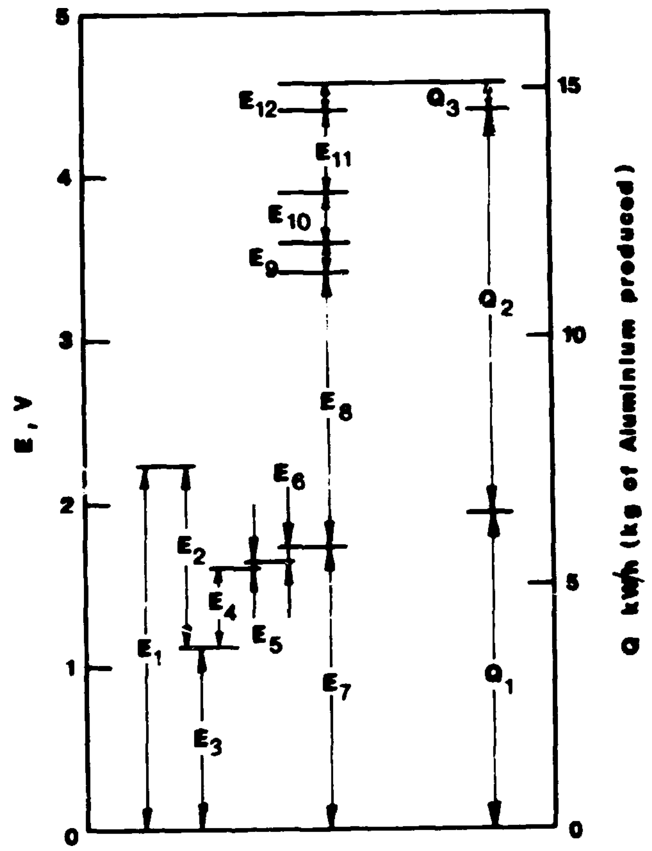


Figure 1.

COMPONENTS OF THE CELL VOLTAGE

/Haupin,1/

E1 : decomposition of alumina

E2 : depolarization by carbon

E3 : equilibrium potential

E4 : anode reaction overvoltage

E5 : anodic concentration overvoltage

E6 : cathodic overvoltage

E7 : cemf of cell
E8 : electrolyte voltage drop
E9 : electrolyte bubble voltage
E10: anode voltage drop
E11: cathode voltage drop
E12: external voltage drop
Q1 : enthalpy to produce aluminium+CO and CO2
Q2 : cell heat losses
Q3 : bus heat losses

The right-hand side of Figure 1. shows how the electric energy represented by the voltages on the left is consumed. Both scales refer to a current efficiency of 90% ./1/

It is the electrical parameters that can be measured continuously and reliably, so one should rely on them as much as possible. This chapter discusses real-plant measurements of the total cell voltage and the components of cell voltage listed above.

Total cell voltage

Traditionally, a voltmeter is connected to every single cell. There are different modes of connection:
-using one wire from the anode bar and one from the cathode bar
-generating reference points at both ends of the cell with resistances

The voltmeter measures cell voltage during normal operation as well as during anode effect. Usually,the meter consists of two devices, one operating in the range of 2-6 V and the other between 10-50 V. The measured value alters with the fluctuation of the line current. Additional information is thus needed whether the measurement is acceptable or not:line current is displayed at a central point in the potroom, or a low-current alarm is installed. Another way is the use of what is often called "normalised cell voltage", which is, nevertheless, of a resistance character.

External voltage drop

The external voltage drop includes losses on external electrical conductors. It is measured with simple contact tips. Its value ranges 0.1 to 0.2 V.

Anodic voltage drop

This represents the voltage drop on the anode including its connection stubs and the anode-stub contact. Its value ranges from 0.25 to 0.3 V with prebaked anodes and from 0.45 to 0.55 V with Soederberg ones.

One would expect uniform voltage drop on the anode surface. However, the anode bottom is not an equipotential surface, either in prebaked or in Soederberg cells. Chapter 3 demonstrates some aspects of this phenomenon. With the aid of a probe, the potential of different spots of the anode bottom vs. a fixed point can be mapped. With Soederberg cells, the voltage loss between the anode bar and the upper point of the baked anode paste is considered as anode drop. Another way is to insert and bake probes into the anode paste;these may be insulated ones or simple aluminium wires and give possibilities to scan different levels.

Voltage drop is raraly measured in stubs. This would require specially drilled stubs and small probes.

Losses between stub and carbon are mainly calculated or estimated from the previous measurements.

Cathode voltage drop

The components of cathode voltage drop and the problems and methods of its measuring are similar to those of the anode voltage drop. Its values range from 0.45 to 0.55 V.

The total cathode voltage drop is usually measured between the molten metal and a certain point of the cathode collector bars.

Measuring in the collector bars would require special preparations. Selected steel bars should be drilled in advance, they have to be built into the cathode when assembling the cell.With the aid of a small probe, the voltage drop may be scanned along the collector bar.

Losses between the bars and the carbonaceous materials are mainly calculated from these measurements.

Electrolyte voltage drop

Electrolyte voltage drop is partly due to the electric resistance of the electrolyte and partly to the presence of bubbles;there is, however, no actually separating these components. Measurements based on special probes may be mentioned. Calculations from geometrical and electrochemical data are used for actual evaluations. The bubble free part of the e.v.d. amounts to about 1.6 V and bubbles add a further 0.2 V or so.

Cemf of the cell

Theoretical or purely electrochemical determination of the components of the counter electromotive force is beyond the scope of the present paper. Instead of calculations, a linear extrapolation of the cell voltage to zero current is mainly used for the purpose of process control. Cemf is often calculated on the basis of multi-step current decreasing measurements.Theoretical value of cemf is about 1.8 V ; the extrapolation method gives a value of about 1.65 V.

1.2 Aspects of Test Methods

Materials and elements discussed

In aluminium electrolysis, several carbonaceous materials and current carrying parts have to be checked regularly :

- -prebaked anode block
- -primary anode paste
- -baked anode paste
- -cathode blocks
- -ramming mix
- -aluminium busbar elements
- -anode clamps
- -steel stubs
- -steel cathode bars
- -anode and cathode flexibles
- -contacts between the connecting elements

These are examined from an electrician's point of view. The properties of the molten bath aren't discussed here.

Reviews of different test methods usually start with some systematization. A possible classification, problems and test methods are given here; detailed descriptions of some measurements is in Chapter 5.

The test methods may be classified by the parameters checked, the technological aspects and the character of examination.

Parameters checked

Voltage losses, current distribution and specific resistance of different materials or elements are the electric parameters to be measured. Actual sets of these parameters may be considered as snapshots of the technological situation. In industrial practice, it is their dependence on time, temperature and place that gives relevant information about the technological problems.

The aim of voltage loss measurement is to test bus bars, steel stubs and contacts between the connecting elements. Current distributions characterize the states of the assembled anode and cathode. Raw materials and structural parts are mainly characterized by the specific resistance.

Technological aspects

From a technological point of view, one may select tests before assembling a cell, tests meanwhile assembling a cell and tests during operation.

Preliminary tests are necessary to select the anode and cathode blocks of similar properties, to avoid the use of fault elements. Tests menawhile assembling the cell involve systematical checking of rodding, cathode bar fixing, contact losses and cathode lining. Actual technological state is supervised during operation. This is detailed in Chapter 1.3 and 1.4 .

Character of tests

The examinations may be checked without deterioration of the elements, tests on samples taken out from the elements and examinations on specially prepared models.

A typical example of checking without deterioration is the measurements of specific resistance by eddy current. An instrument working on this phenomenon provides quick and reliable checking of carbon blocks. Standardized samples from carbon blocks or different pastes and mixes are tested in laboratories. Several methods of specific resistance measurement are outlined in Chapter 6. When effecting a new development, preliminary modeling is always useful; new filler materials, new composition of pastes, steel bars of new geometry, altered arrangement of anode stubs, etc can be mentioned. Models are mainly small physical representations; wide-spread application of computer models is under progress.

Test methods of different types of carbonaceaus materials are similar as is the case with the test methods of bus bars. That allows the use of one special instrument for different examination. /2,3/

Temperature measurements

The problem of temperature measurements is usually discussed in connection with energy and heat balances. They should, however, be mentioned here as well, due to their close relation to the electric measurements. Usually, the electrician is the person responsible for adequate preparations. Thermo-couples, thermo-resistors, heat flux meters, infra-red sensors, all have low-level electrical outputs. Transmitting and collecting these signals require great care. Electric measurements are regularly completed uith temperature measurements.

1.3 Analysis of Operational Data

There is no continuous method to measure current efficiency, alumina content of the bath, thermal state and other important parameters relating the electrolysis. This leaves us the electric measurements to rely upon. Components of the cell voltage discussed earlier give important information about the process. Analysis of total cell voltage alterations seems to be a useful method. Moreover, not only the cell voltage, but the line current and the calculated resistance have to be considered. Calculated resistance is a widely used parameter; detailed discussion of what it actually covers is done in Ch.3. /4,5/

Data acquisition

Data acquisition in aluminium plants is rather complicated. The instruments have to be selected carefully. Due to the difficulties set by the strong magnetic field, the extremely high temperature, the high common-mode voltages and the additive noises, correct data acquisition requires special preparations.

Decoupling of the valuable signals from the high common-mode voltages is usually the first problem. It can be solved with isolating elements. These provide true galvanic isolation between input and output and between either or both of these and the power supply. These protect people, equipment and signals from the effects of dc, ac or transient high voltage. There is a variety of form. Isolation amplifiers of voltage-in to voltage-out are easy-to-use components. In aluminium industry, isolation amplifiers designed for more than 1000 V CMV from input to output are in use. This limit may be significantly higher when multiplexing signals of different origin is inavoidable.

It is advantageous to establish what is called a measuring room where the different signals are led. Proper cabling is required. The standard instruments should only be connected after the isolation units. Basic devices are multi-channel tape recorders, multi-channel analog recorders, voltmeters, A/D converters and a desc-top computer. Detailed list of generally used instruments are given in Appendix.

Robust built of the devices is important, particularly of those used in potrooms. Shielding, covering or other different preventive measures may be necessary. Long-term measurements are common; reliability of the devices, that is, the main time between failures, have to be the best possible.

Operations examined

The regularly checked work routines are alumina feeding, anode adjustment, metal tapping, block changing or stub pulling and effect handling. There are technological situations of great importance which have to be supported with electric measurements; introduction of new developments or of new materials may be mentioned. In these cases, there is need for developing special measuring routines. Close co-operation is necessary between metallurgists and electrical experts to prepare an examination perfectly. The evaluation of data is also a collective work.

Anode adjustment

Alumina concentration in the bath can be traced by the resistance vs. time functions. Figure 2. demonstrates a cell being in preparation for an anode effect. The resistance rises until the alumina feeding where a sharp break appears.

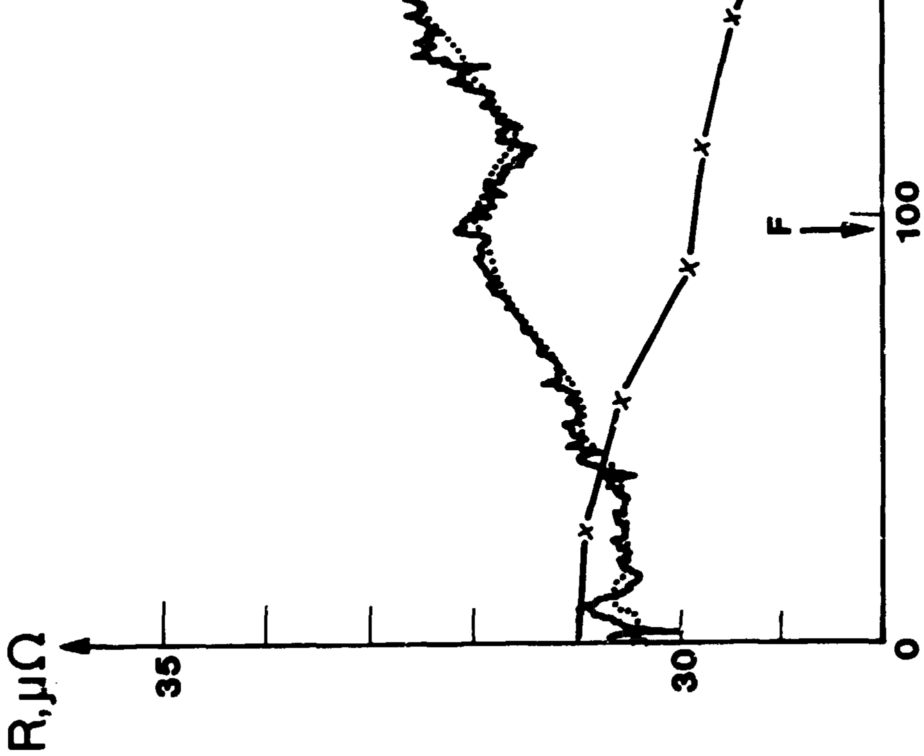
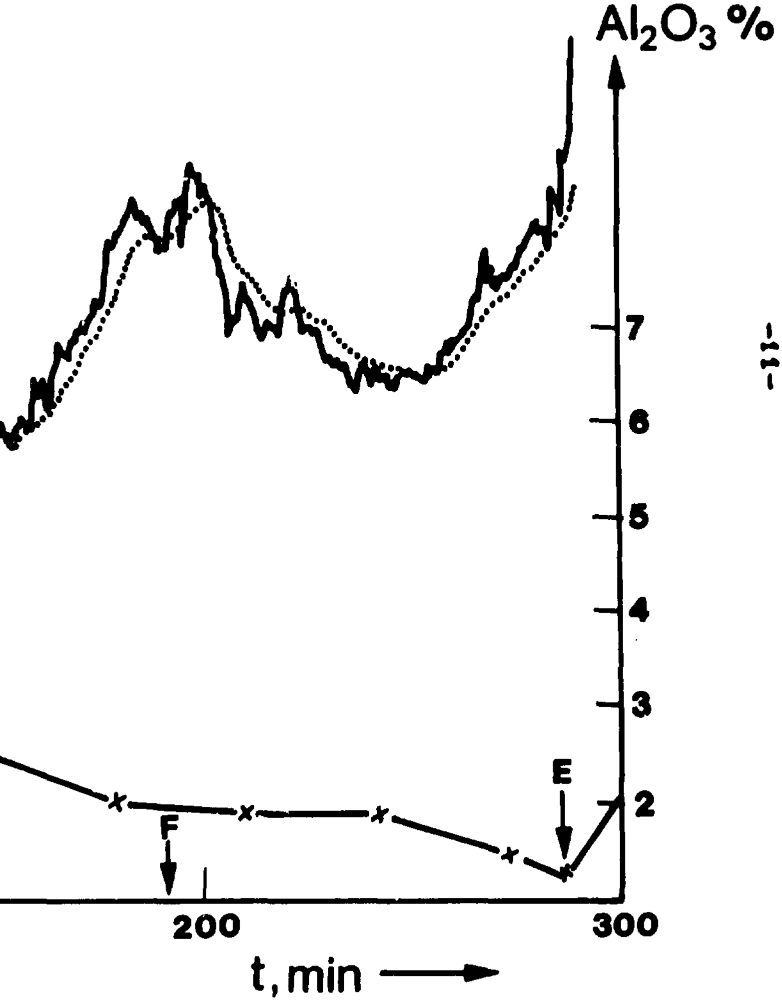


Figure 2.

RESISTANCE AND ALUMINA CONTENT FUNCTIONS

According to the alumina solution, the resistance decreases, then, after a minimum value, rises again. Anode effect occures at about 2%. From a technological point of view, the detecting


Al$_2$O$_3$ %
7
6
5
4
3
2
E
F
200
300
t, min

of these minimum values is of a great importance. In case of an overfeeded cell, the resistance function is nearly constant and sludge in the melt is presumable.

There are several types of anode adjustments such as adjustments for resistance control, movig meanwhile tapping or meanwhile anode bar slipping. Measurements during a long period of time are discussed in Section 5.2. Results, in connection with resistance control, are detailed in Chapter 3. Tapping procedures are given below.

Anode movement

It is advantageous to complete the resistance measurements with anode movement monitoring.

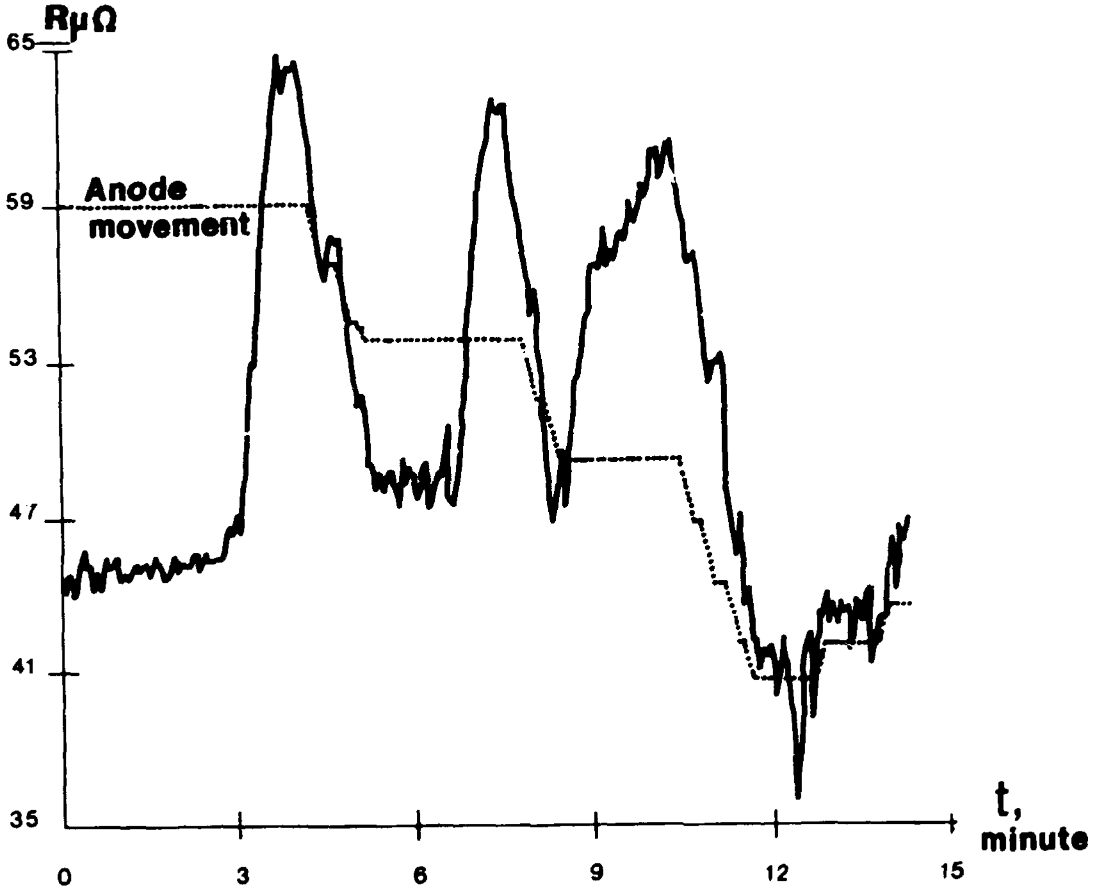


Figure 3.

RESISTANCE AND ANODE POSITION FUNCTIONS DURING METAL TAPPING

The thermal state of a cell can be estimated on the basis of the tapped metal, the anode movement and the resistance alteration. Figure 3. shows the typical functions of a metal tapping on a Soederberg cell.

Stub changing

The stub changing or the anode block replacement are great disturbances in the cell's life. The actual increase and its decay characterise the whole anode. The resistance function in a stub changing period can be seen on Figure 4.

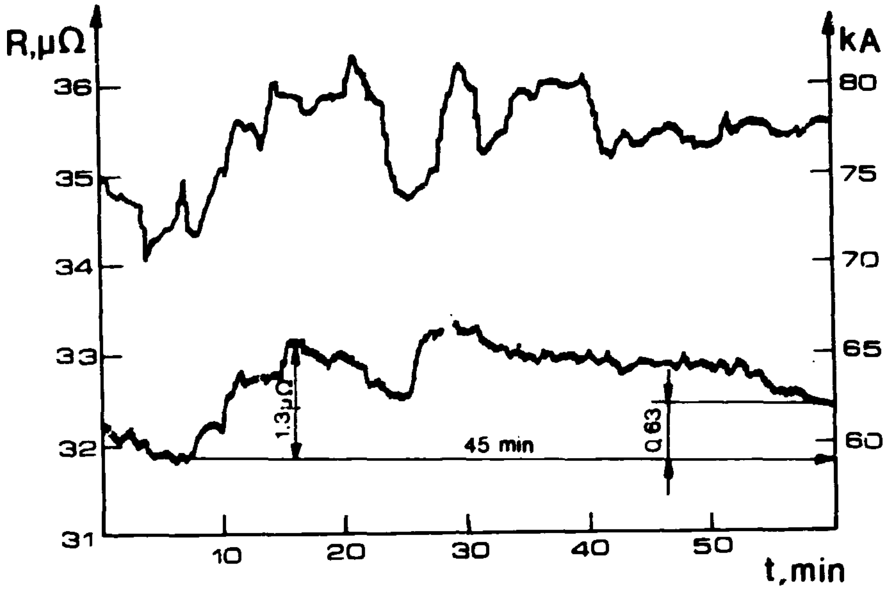


Figure 4.

CELL RESISTANCE FUNCTION DURING STUB PULLING

Anode effect

First, one can measure and evaluate the resistance rise before effect. Then, the behaviour during effect can be examined. Next, the effect quenching can be checked. After all, the whole effect canbe characterised. The anode effect measurement is demonstrated in Section 5.5.

1.4 Detecting Cell Failures

There are several possibilities to detect cell failures on the basis of the electrical measurements mentioned earlier.

In the cathode, voltage drops and current distribution alterations indicate the cathode condition during the life of the cell. The voltage drop rises in accordance with the cell age. Current distribution measurements are useful to detect damaged cathode blocks or direct contact between molten metal and cathode bar.

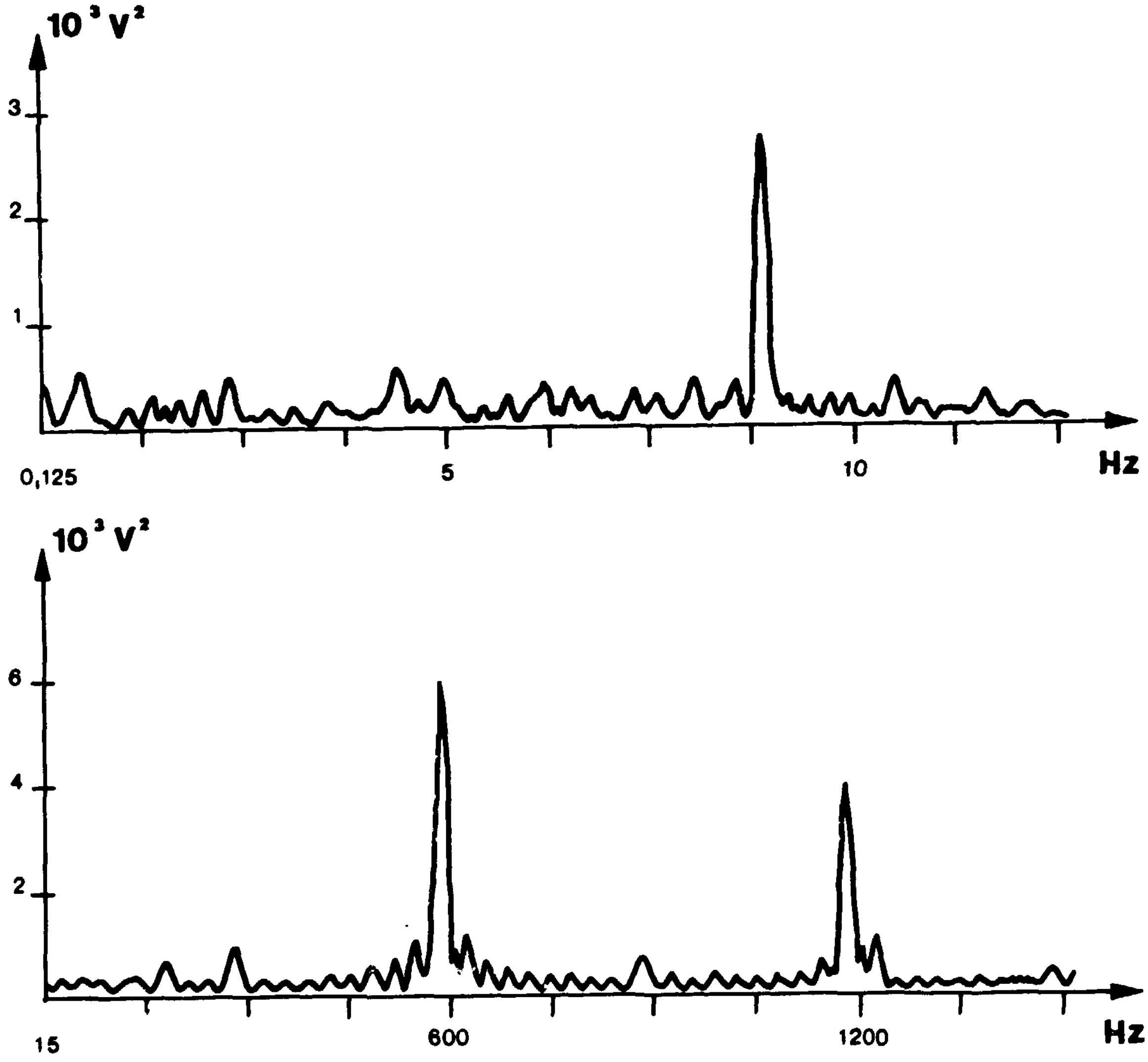


Figure 5.

POWER DENSITY FUNCTIONS OF A WELL OPERATING CELL

In the anode, current distribution measurements may indicate faulty blocks or faulty baked stubs. Uneven current-load distots the magnetic field and magnetic forces distorts the metal surface.

It may be useful to involve the voltage measurements into the scope of cell failure detection. Voltage noises are of a great importance. Typical noise of a well operating cell, as described by the power density function, can be seen on Figure 5.

Noises can be classified as waving, pulsating and fluctuating ones. Several types are demonstrated on Figure 6.

Waving

The appearance of the waving noises indicate hydrodynamic instability of the melt. The circulation and fluctuation of the melt change the actual anode-cathode distance and resulting a waving cell voltage.

Fluctuating

Fluctuations characterise the thermal state of a cell. The relatively warm cell has noises of small amplitude. In case of a relatively cool cell, fluctuations are larger, the cell is called "noisy".

Pulsating

Pulsating cell voltage can be recognised when the cell has certain anode-bottom problems. Temporary anode-cathode short circuits cause sharp falls in the otherwise normal cell voltage.

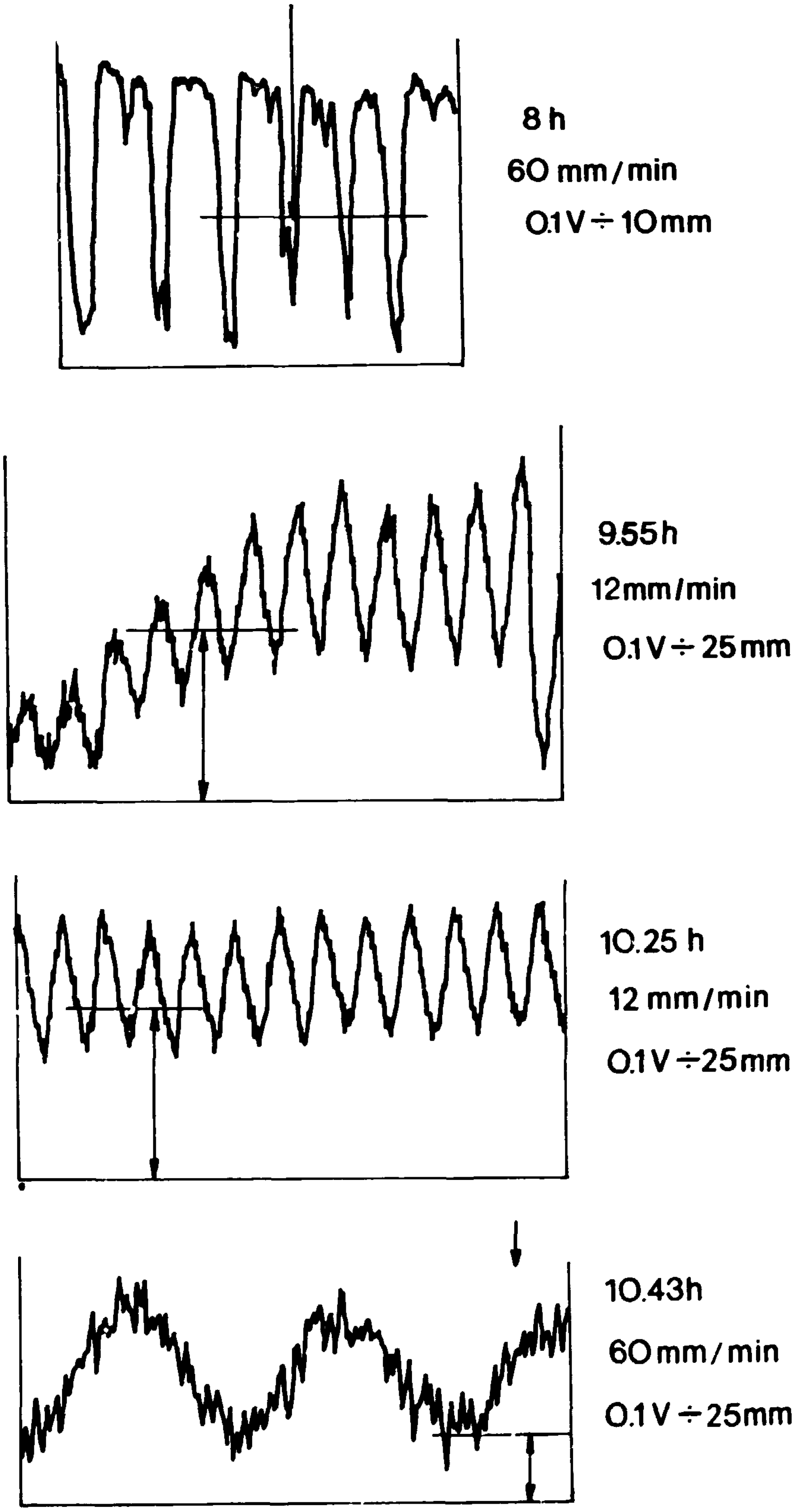


Figure 6.

SEVERAL TYPES OF CELL NOISES

In case of unstable serial current, calculated resistance is better to detect cell failures than cell voltage. Thisfilters off the alterations of current origin, that do not relate the cell itself. Analog recordings of current, voltage and resistance signals are suitable for the potroom personnel. However, computer control requires special algorithms. Discrete Fast Fourier Transformation subroutines are widely used for these purposes. An example of digital analysis is given in Section 5.5. /6,7/

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2 PROCESS CONTROL

2 1 Preliminary Experiments

Identification, that is, establishing a mathematical model of the process experimentally, is the first step towards process control. However, knowing the process in advance plays an important role in the design of experiments./1/. A really efficient experiment is only possible if the process and its disturbances are known wery vell. Even if black box techniques have to be used for identification, it is necessary to consider the nature of the process when designing the experiments. These experiments should be performed under conditions as close to real ones as possible. /2.3/

In many cases, preliminary experiments are necessary to accumulate information for the proper design of experiments. Such experiments can be just data-logging under normal condition. For example, the basic U(t),I(t),R(t) functions and correlation functions, mentioned in Ch.1., can be considered.

The experiments should provide the major time constants,the permitted input amplitude, presence of nonlinearities, time variacion of the process, noise level etc. From a practical point of view, the most important questions are : choice of variables, natural excitation, sampling rate and experiment length.

Choice of variables

Generally,the word "input" refers to variables that can be set and the word "output" refers to variables that can be measured and related to the phenomena of interest. For a sophisticated control algorithm, Table 1. demonstrates one possible choice.

Measurements (Outputs)	Controls (Inputs)
1.Resistance	1.Tapping of aluminium
2.Percentage of dissolved alumina	2.Supply of alumina by crustbreaking the side
3.Percentage of fluoride	3.Supply of alumina in the center of the pot
4.Temperature in the bath	4.Supply of aluminum fluoride
5.Temperature in the carbon side blocks	5.Changing of anode carbons
6.Aluminium height	6.Anode adjustment
7.Bath height	7.Amperage
8.Interpolar distance	8.Anode effect (control to the model)
9.Thickness of the side freeze in the bath level	
10.Thickness of the side freeze in the aluminium level	

Table 1.

MEASUREMENTS AND CONTROLS FOR AN ELECTROLYSIS CELL

/Gran,4/

As to several practical applications, cell voltage and line current are the only parameters measured continuously. Some data are taken from laboratory analysis as additional information. Others are calculated or estimated. Methods of interference are anode adjustment and supply of alumina. The remaining posssibilities are fixed for a longer period of time.

Natural excitation

In many cases,operational disturbances can be used to study the process. Alteration of the serial current, anode replacement and other technological events give a good opportunity for identification. On the other hand, the nature of unwanted noises can also be determined, that is, appropriate filters can be selected; digital pre- and postfilterings are widely used.

Sampling rate

Characteristics of the process and of the disturbances influence the choice of sampling rate. It is hard to find the actual process characteristics over several decades in a frequency range with only one experiment made. It is necessary to carry out several experiments to cover the frequency range of interest. When studying the cell voltages noise, in order to establish a cell failure detecting routine, the sampling rate is more than 10 Hz. For long-term behaviour description, half-minute averages are used.

Experiment length

Since the accuracy of identification depends on the experiment length, the latter should be as long as possible. On the other hand, the experiment should be shortenough to avoid the influence of possible extra disturbances. Furthermore, the recording devices may limit the number of data, and also, the more the data the larger the cost of analysis. A rule of thumb is that the experiment should take as much time as at least ten times the major time constant. Typical lengths are minutes for cell failure analysis, hours for checking the alumina consumption and days for studying the effects of a certain working routine.

2.2 Identification Methods

The complexity of the model should be considered at an early stage of the identification. One must decide on the proper type of model for application:

static - dynamic
linear - nonlinear
time invariant - time varying
deterministic - stochastic
lumped - distributed
time domain - frequency domain
parametric - nonparametric

During the identification, the choice of model structure may have to be reconsidered in order to get an acceptable model. A wrong structure may give misleading results. The assumption on the structure should be checked.

One usual way, to model a process, is to build a model from purely physical and chemical laws. However, models often turn out to be very complex and too complicated for practical purposes. Thus, some approximation and simplification is inavoidable. The cell voltage isn't derived from the correct electrochemical reactions, from the equlibrium potential and the overvoltages. Instead of a correct cell resistance, a derived value called calculated resistance is generally used. Dynamics that are not important for a specific application are neglected. If it is possible, linearization is used between well determined limits. This makes it easiar to use the model.

The most frequent methods for identification are correlation analysis, parameter estimation, frequency and step response analysis and a wide choice of adaptive methods. Let's follow a traditional solution step by step. /5/

It may be of interest to check the feasibility of the generally used cell voltage description for real-plant measurements :

$$U(t) = U_p + I(t) \cdot R \tag{2.1}$$

Here, U_p is the sum of the equilibrium potential and the overvoltages extrapolated to I=0. Figure 7. shows the recorded U(t) and I(t) functions. The statistical properties have to be determined first. Table 2. shows the mean value and the standard deviation of one series of cell voltage and line current data in different periods.

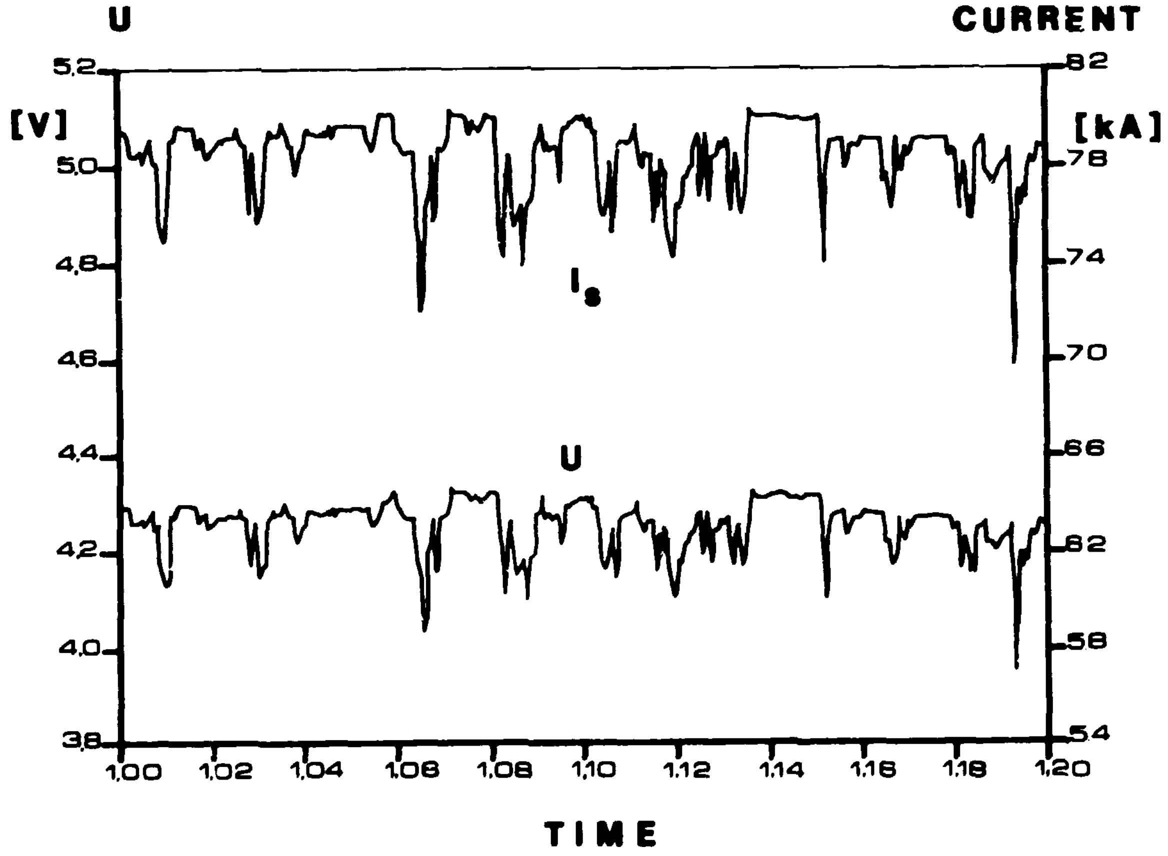

Figure 7.

REAL-PLANT RECORDINGS,U(t),I(t) /Vajta,5/

Time minute	M(I) KA	D(I) KA	M(U) V	D(U) V
0-200	78.15	2.437	4.24	0.088
201-400	77.74	2.823	4.17	0.086
401-600	77.72	2.738	4.18	0.103
601-800	77.47	2.580	4.40	0.119
801-1000	76.99	3.010	4.22	0.109
1001-1200	78.5	1.525	4.25	0.054
1201-1400	77.32	2.051	4.25	0.074
1401-1600	76.79	2.295	4.19	0.141
1601-1800	77.52	2.060	4.15	0.106

Table 2.

MEAN VALUES AND STANDARD DEVIATIONS

OF I(t) AND U(t)

/Vajta,5/

If (2.1) describes the behaviour of the cell correctly in the minutes-hours time range, the correlation coefficient should be 1. The correlation coefficient is calculated continuously from the previous ten measurements. The result can be seen on Figure 8. The correlation between the cell voltage and the line current disappears during technological interactions, but the connection is apparent elsewhere.

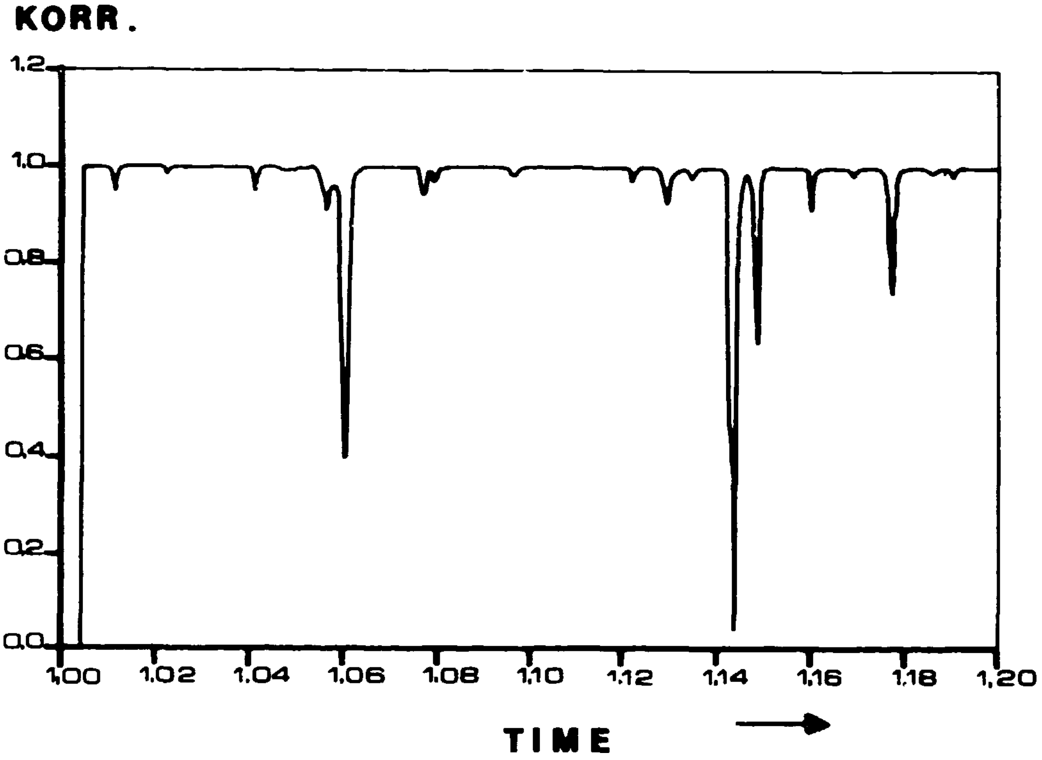

Figure 8.

CORRELATION BETWEEN U(t) AND I(t)

/Vajta,5/

To decide whether a static model is acceptable (even if its parameters change in time) or certain L-C components have to be taken into account, it is necessary to examine the auto- and crosscorrelation functions of the signals. The functions are calculated by the equations (2.2 and 2.3) :

$$\varphi_{I,I}(k)=\frac{1}{N}\sum_{j=1}^{N} I_s(j)\cdot I_s(j+k) \qquad (2.2)$$

$$\varphi_{I,u}(k)=\frac{1}{N}\sum_{j=1}^{N} I_s(j)\cdot U_i(j+k) \qquad (2.3)$$

where $\varphi_{I,I}$ is the autocorrelation function of line current,   is the crosscorrelation function between the line current and cell voltage. K is the shifting value, here K=-64,...,0,...+64.

Typical examples can be seen on Figure 9. and Figure 10.

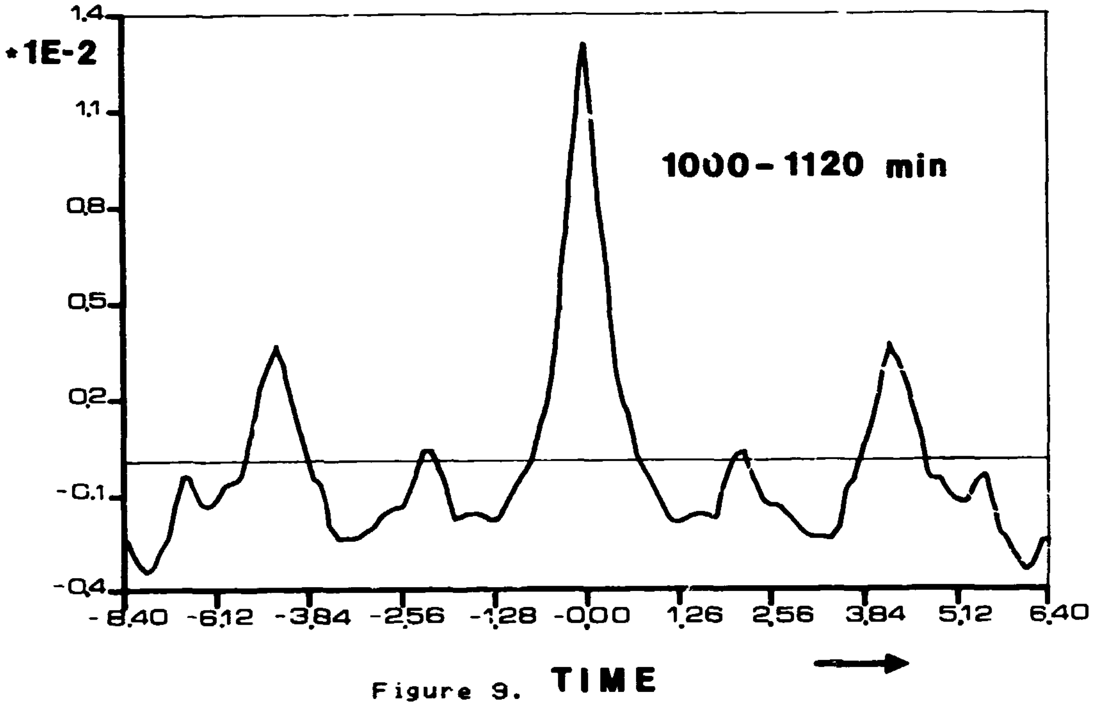

Figure 9.

AUTOCORRELATION FUNCTION OF LINE CURRENT /Vajta,5/

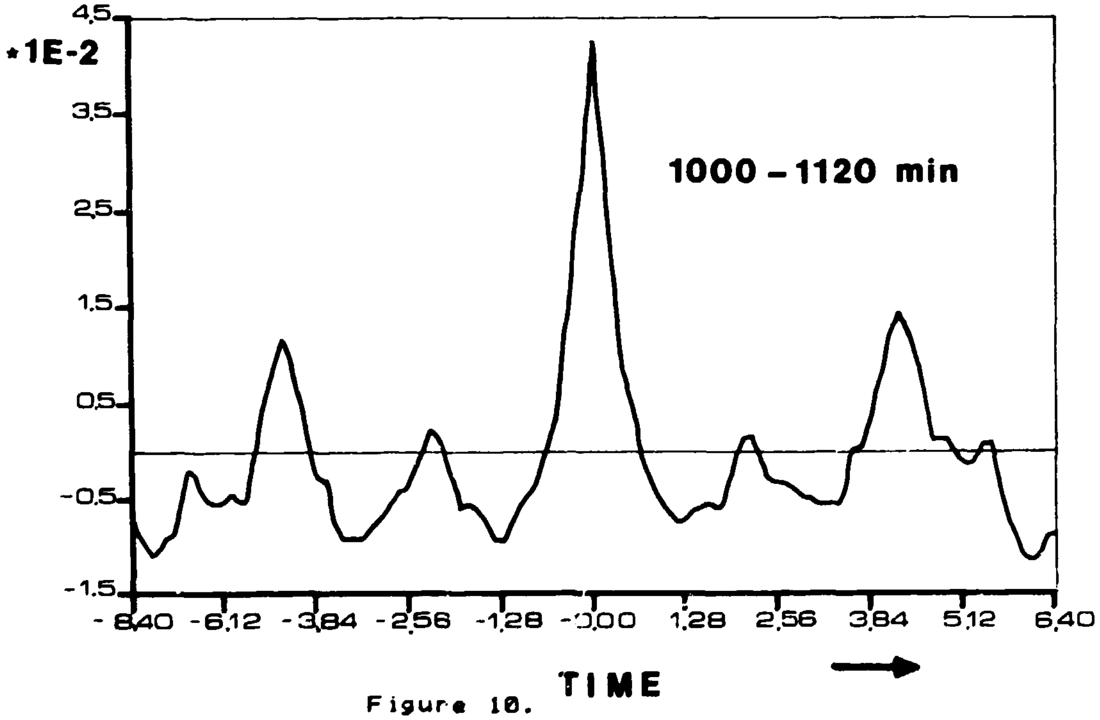

Figure 10.

CROSSCORRELATION FUNCTION BETWEEN LINE CURREN

AND CELL VOLTAGE /Vajta,5/

Numerical data are given in KA and V units. The shifting can be seen on the time axis. K=64 means a delay of 32 minutes. On the basis of these functions, the amplitudo-phase diagrams (BODE-diagrams) were determined by means of Discrete Fast Fourier Transformation (DFFT) of N=512 discrete measurements. Figure 11/a and 11/b demonstrate the results.

A series of experiment has to be done to identify the cell parameters. As a result of the investigation carried out, the simple static ohmic model seems to be fairly good for the purpose of process control.

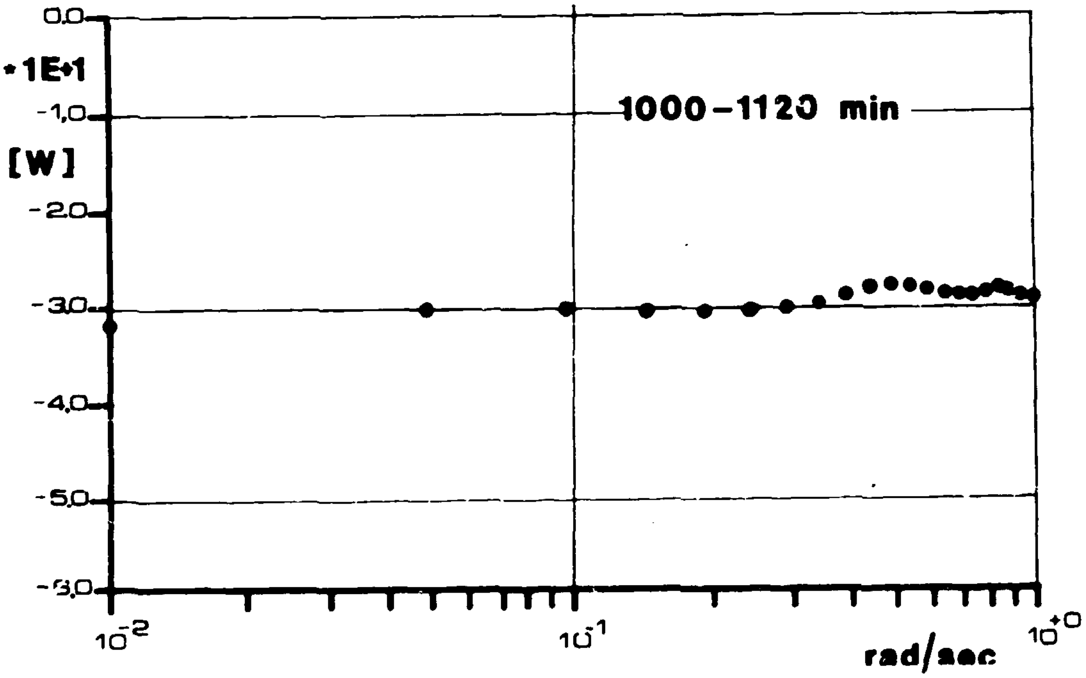

Figure 11/a

AMPLITUDO DIAGRAM

/Vajta,5/

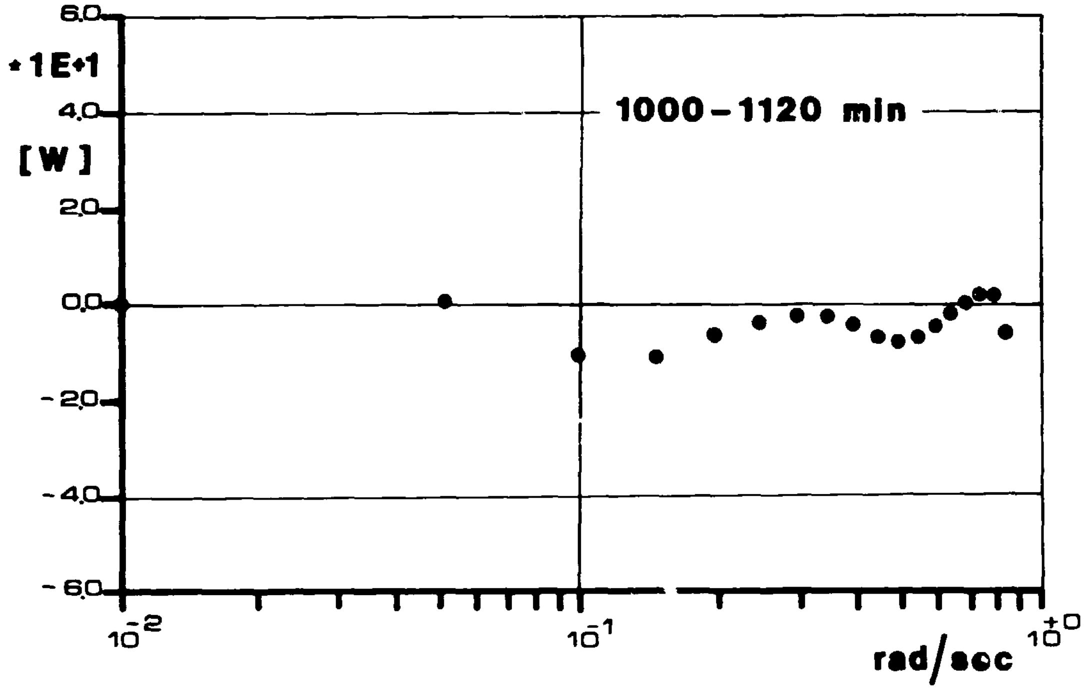

Figure 11/b

PHASE DIAGRAM

/Vajta,5/

Verification of a model

The problem of verifying a model is not exactly solved. It must be emphasized that no general verification can be made; it is possible only to ascertain that the model is suitable for specific purposes. Our ohmic model was checked in plant tests. This described the main alterations and technological interactions properly. As a result of long-term analysis, this model was accepted.

2.3 Control Methods

Basic concepts

The fundamental goal of a control system is to maintain prescribed conditions. The aim of a cell controller is to ensure an acceptable energy equilibrium of the electrolysis cell. *The aluminium reduction cell* is a very complex thermal system and it is advantageous to approximate gradually to what seem to be optimum conditions. Until now, resistance monitoring has proved to be the easiest way to control the cells, since it is the electrical signals that can be measured reliably and continuously. The method of traditional operation involved voltmeters at the cells and line current display in the potroom. The technological events were also scheduled and logged. These were the basis of a simple process control.

Conventional resistance regulation

Actually, resistance is a calculated one, and not the cell resistance itself. It is sometimes called pseudo-resistance. It is calculated :

$$R(t) = \frac{U(t) - Up}{I(t)} \qquad (2.4)$$

According to the potroom personnel's demand, a target resistance is set and the controller attempts to keep the process close to it. To avoid the too small interactions, a "no regulation area" is set on both sides of the target value. In the simplest case, anode adjustment is the only possibility of to control. The interference is proportional to the difference between the target resistance and the measured one. Too many consequtive single-direction adjustments are prohibited. Figure 12. illustrates the method.

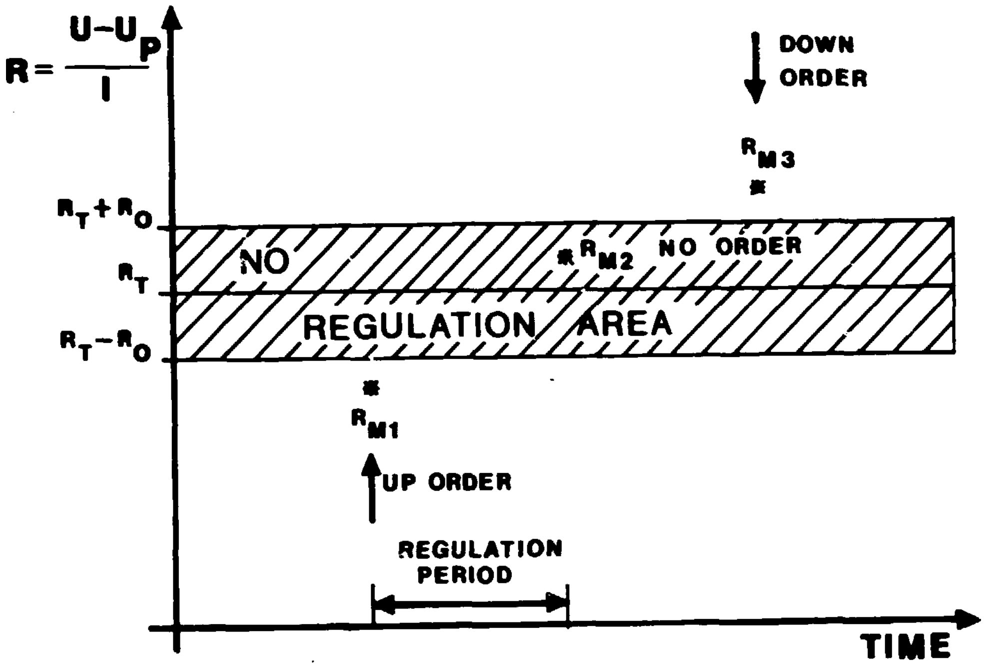

Figure 12.

CONVENTIONAL RESISTANCE REGULATION

Alumina feeding

Regulation of alumina feeding is one of the most important tasks. Old aluminium plants equipped with horizontal- and vertical stud Soederberg cells, usually do not have automatic feeders, so the alumina feeding can hardly be regulated precisely. Following the instructions of a controller strictly, acceptable results can be reached. However, scheduled work routine can never be attached so tightly to an automation system as the point feeding method. /6/

Figure 13. and 14. show the result of a simplified combination of anode adjustment and alumina feeding. An automatic feeder is supposed to work here, which adds equal amounts of alumina into the bath on instruction, but it is the rate of feeding that is controllable. If the cell operates with

automatic point feeder, the feeding has priority over the resistance regulation.

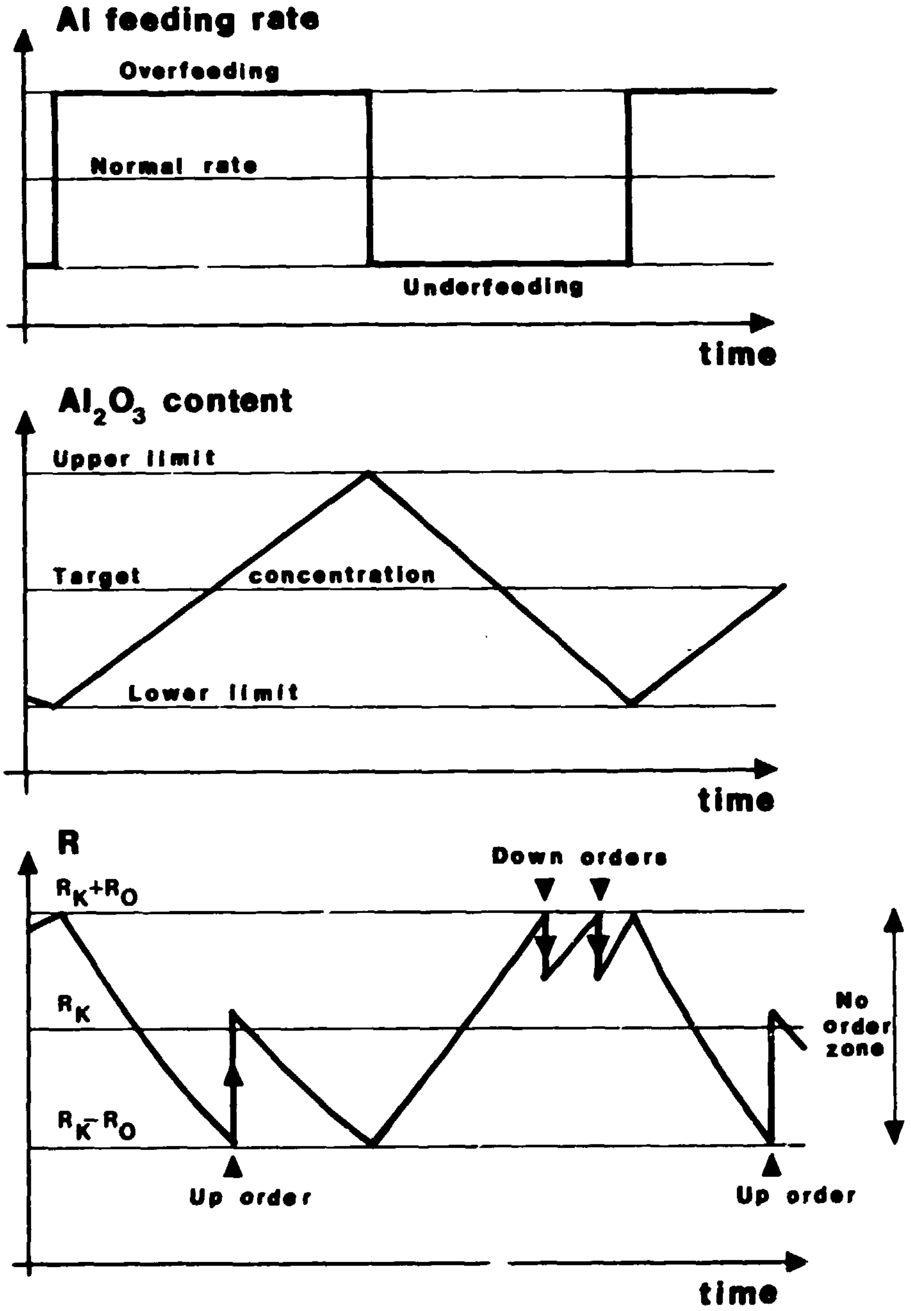

Figure 13.

RESISTANCE AND ALUMINA FEEDING CONTROL

/Reverdy,7/

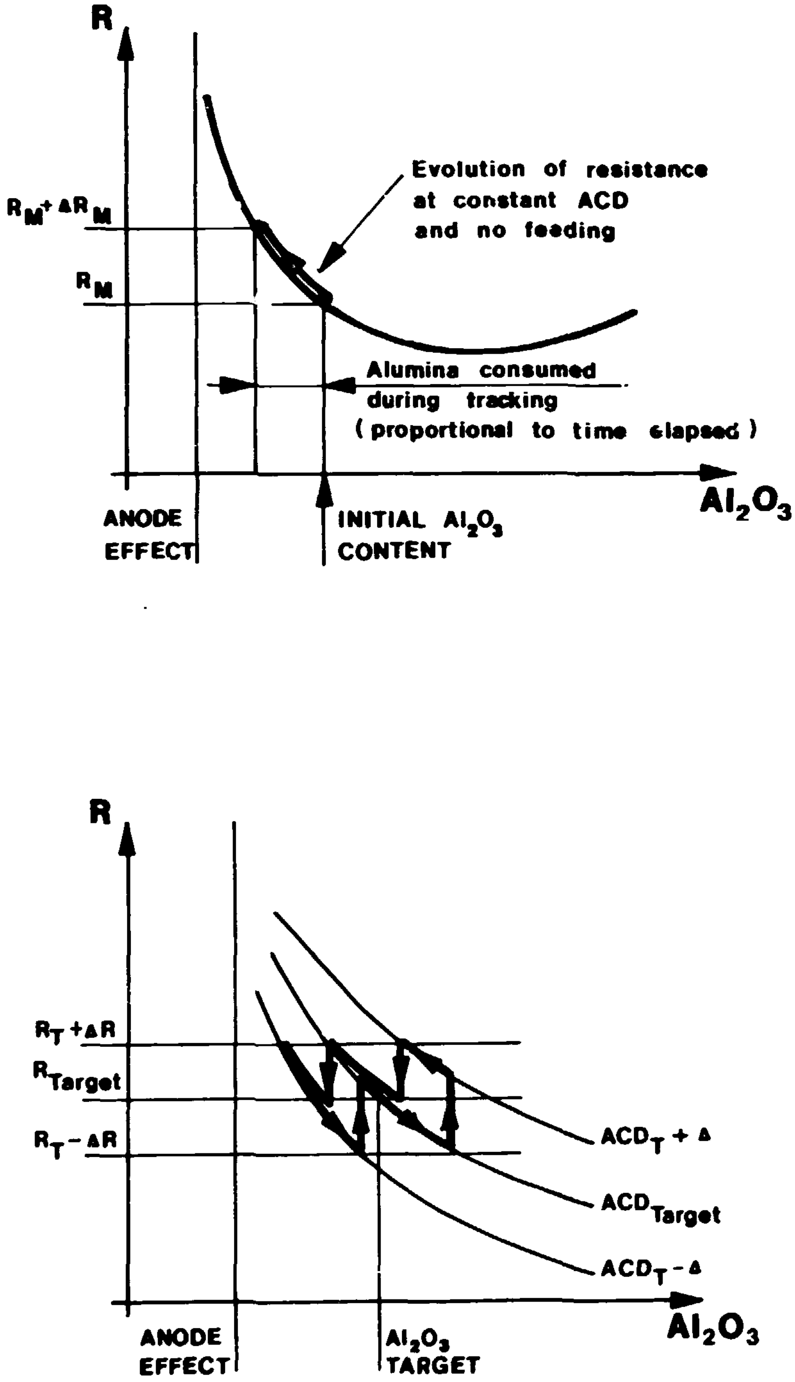

Figure 14.

RESULTS OF THE CONTROL METHOD

/Revardy,7/

Development of control algorithms

Basic control algorithms can't ensure reliable operation. Cell failure detecting routines must be developed. Usually, these short programs calculate the deviation of either the cell voltage or the resistance. If it reaches a value determined in advance, the cell is considered faulty, in table, shaky etc. In such cases, the controller tries to bring the cell back to normal conditions by means of special subroutines. Usually, this means first rising then lowering the anode step by step. The minimum task is to stop automatic control and signal to the potroom personnel. The block diagram of this system can be seen on Figure 15.

Advanced methods

A detailed mathemathical description requires a large number of variables; their relations are, in most cases, unknown or stochastic. Multivariable control algorithms should be used; most of the variables can only be estimated and not measured. The fundamental concept is that measurements should be used to adjust a mathematical model which is simulated on a computer and runs in real time. The estimates of the important variables of the process are thus generated. These estimated values of the state of the process provide the basis for control operations. This principle of the separation of tasks, estimation of process state variables and control of the process is widely used in practical applications. Figure 16. shows the scheme of how a multivariable controller operates. A possible choice of state variables is listed in Table 3.

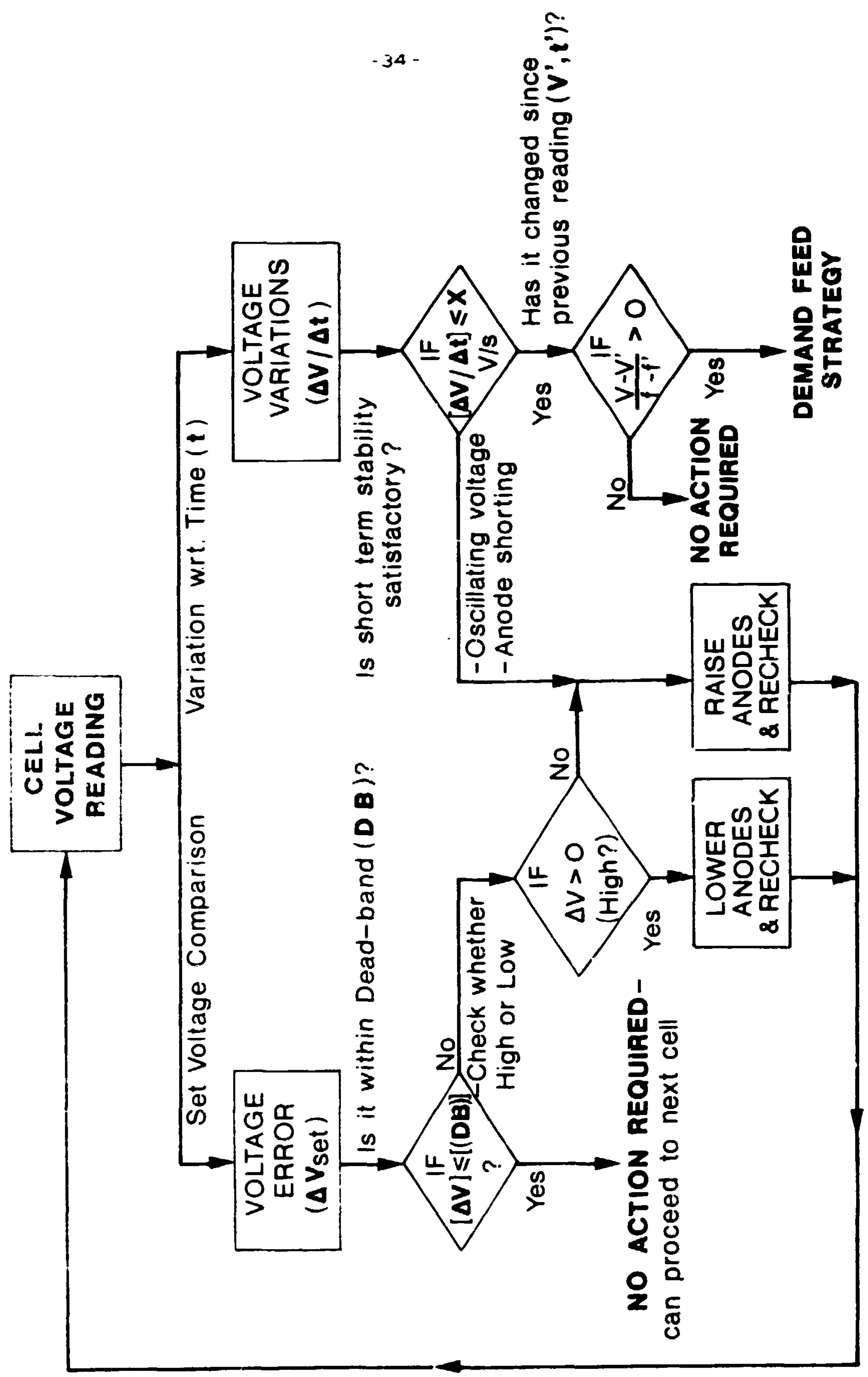

Figure 15.

LOGICAL DIAGRAM OF A CONTROLLER Grjotheim,8

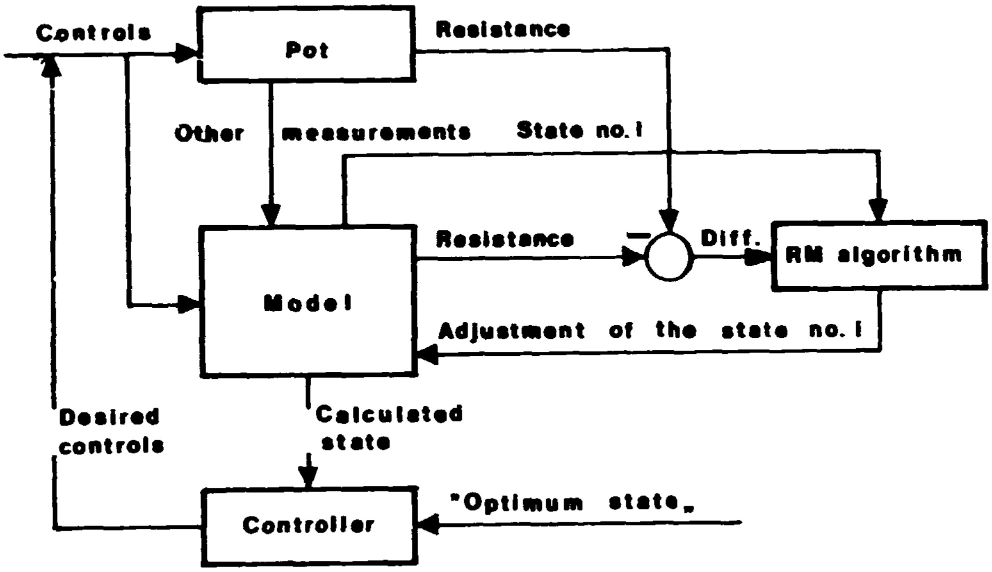

Figure 16.

SCHEME OF A MULTIVARIABLE CONTROL SYSTEM /Gran,4/

State variables

1.Mass of aluminium

2.Mass of bath

3.Mass of dissolved alumina in the bath

4.Mass of aluminium fluoride

5.Mass of the side freeze in the bath level

6.Mass of the side freeze in the aluminium level

7.Mass of undissolved alumina in the bath

8.Mass of undissolved alumina in the aluminium

9.Volume of frozen cryolite in the aluminium

10.Temperature in the bath

11.Temperature in the aluminium

12.Height of anode block

Table 3.

STATE VARIABLES FOR A MULTIVARIABLE CONTROL SYSTEM /Gran,4/

Optimum Control

The simple resistance control keeps the process at a prescribed target value. The question is how this value can be determined. The control method is generally considered an optimum one if it fulfills some special demand perfectly. Of course, demands may alter from time to time, depending on the working and economical conditions. Some typical demands are:

maintaining optimum process in the cell:

- working on optimum ACD
- working on minimum resistance
- current efficiency optimization
- minimizing material and power consumption

meeting market situations

- minimizing productioncost
- maximum outpot of metal
- reduced production

By assistance of resistance control, optimum operation can be approximated such as operation at a minimum resistance or working in the range of possible maximum current efficiency. The different areas can be seen on Figure 17.

Table 4. shows some parameters of real operation meeting different economic demands. This means that a really good method of process control can give reliable background for a dynamic market policy. Case 1 refers to operation under pressure for higher, and Case 2 for lower production output.

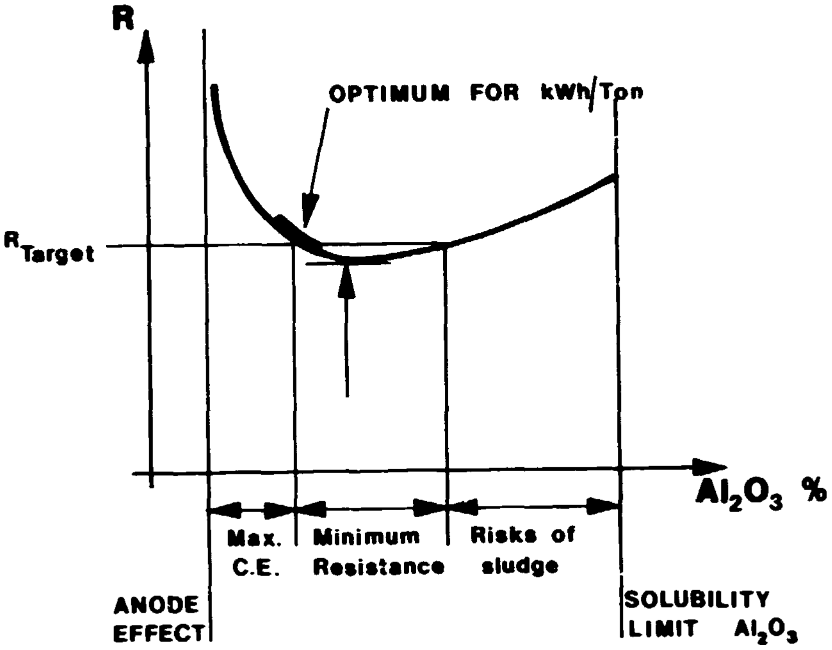

Figure 17.

CELL RESISTANCE AS FUNCTION OF AL2O3 CONTENT IN THE BATH

/Reverdy,7/

		Case 1	Case 2
Current	(KA)	107	97
Current efficiency	(%)	88.6	90.5
Pot voltage	(V)	4.17	4.08
Specific power consumption	(KWh/t)	14.020	13.430
Production	(t/y)	33,000	33,000
Variable cost (Case 2 as 100)		103	100

Table 4.

OPERATION PARAMETERS AT DIFFERENT ECONOMIC CONDITIONS

/Okada,9/

2.4 Digital Simulation

Digital simulation is an effective tool to really understand a process, to develop and test algorithms and to avoid most of the astonishing results of a new method at the first real-plant application. During the last decade, excellent simulation models have been developed at the leading aluminium producers. The models describe the thermal, electric and chemical behaviour of the cell. They are mainly used for designing, but a great deal of them are closely related to process control.

On Figure 18., the schematic structure of a simulation program package is demonstrated. The time behaviour of the cell voltage, electrolyte temperature, aluminum production and alumina concentration in the bath can be calculated using the input values, that is, serial current, anode position and alumina feeding rate.

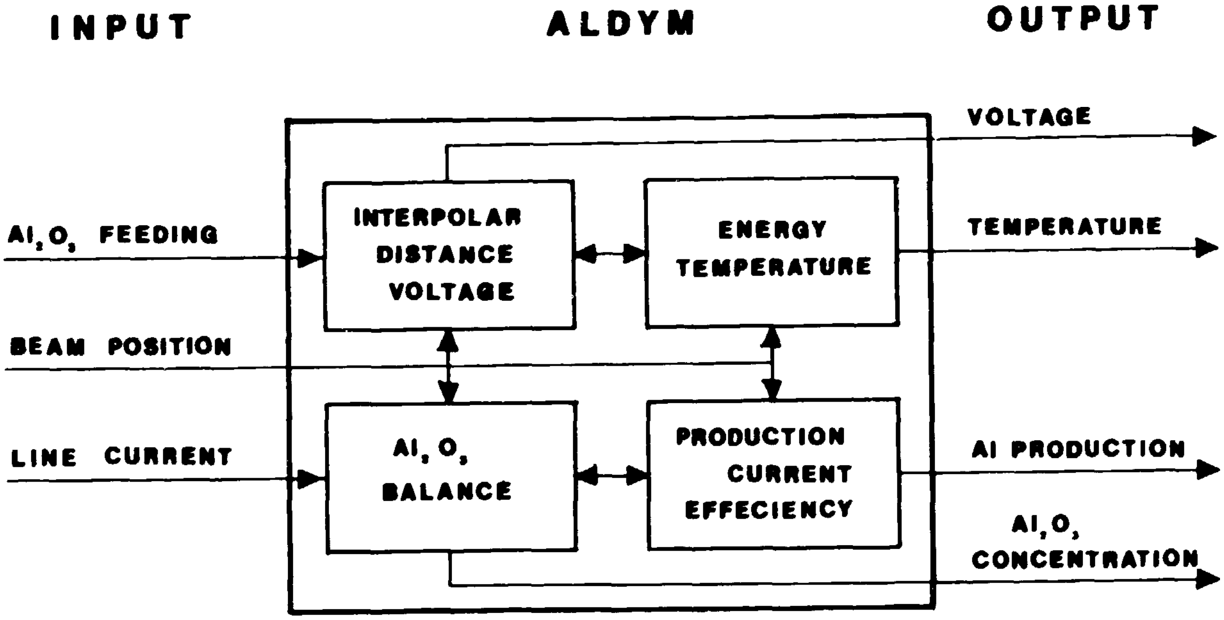

Figure 18.

SCHEMATIC STRUCTURE OF A SIMULATION PROGRAM /Etner,10/

The submodels are linked: the output of one submodel is the input of another and vica versa.

Let's consider a possible synthesis of the cell voltage. /11/ The simple resistance model in (2.1) can be divided into parts as:

$$U(t) = a_1 + a_2 \cdot \Delta i + a_3 \Delta p_a + a_4 \Delta \int_0^t p_t \, dt + a_5 \Delta t \quad (2.5)$$

where

$a_1 = Up$: apparent polarisation voltage (v)

$a_2 = \alpha \cdot \rho \frac{\delta_o}{A} + r$: total ohmic resistance (Ohm)

$a_3 = \alpha \, i_o \, \rho \frac{p}{A}$: voltage change due to anode movement $\left(\frac{V}{mm}\right)$

$a_4 = \alpha \, i_o \frac{\rho}{\rho_m A_m}$: voltage change due to metal tapping (V/kg)

$a_5 = \alpha \, i_o \, \rho \frac{\beta_a - \beta_m}{A}$: voltage change due to anode wear and metal production (V/hr)

In this approach, the choise and values of the variables are close to the traditional operation parameters. It is very important because the obtained results are easy to handle for the potroom personnel. On the basis of the identification results, the main parameters of this simulation model can be set. Line current, anode position, metal tapping and alumina feeding are generated and the output is the cell voltage. Figure 19. and 20. show the functions used.

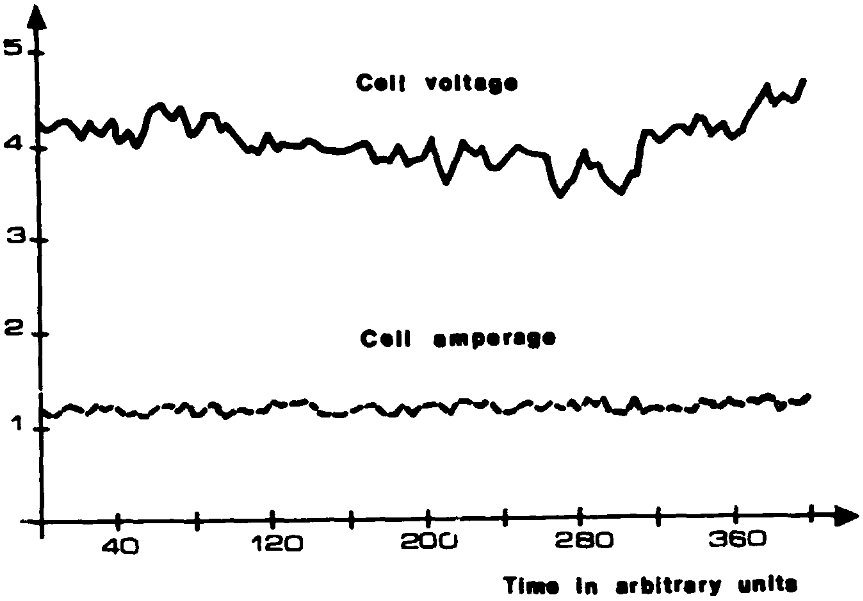

Figure 19.

SIMULATED LINE CURRENT AND CELL VOLTAGE

/Asbjornsen,11/

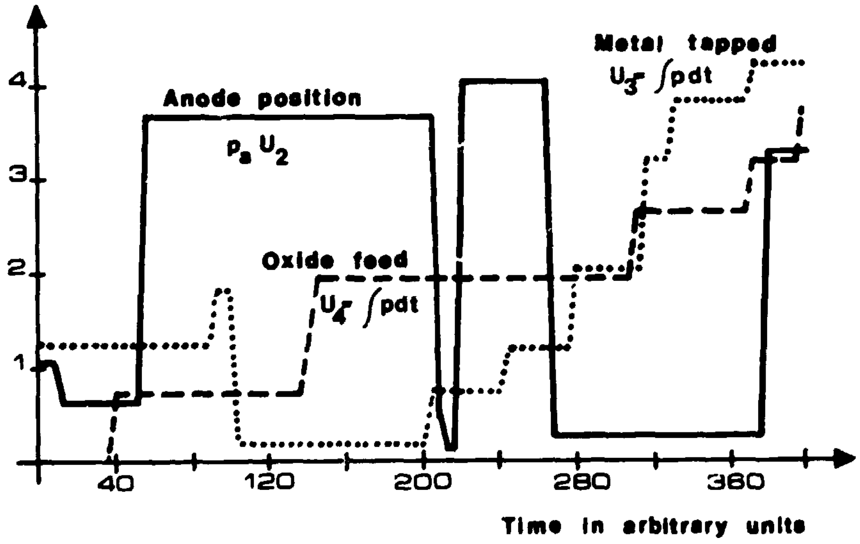

Figure 20.

SIMULATED WORKING ACTIONS

/Asbjornsen,11/

Using this model, several test calculations can be done, including the main parameters of the resistance model, and some prediction algorithms can be tested. The anode effect prediction is also a routine task of a control system. Different subroutines can be tried and tuned on this type of simulation models. There is no risk of disturbing the electrolysis itself; the digital simulation is worth time and money. The structure of an advanced simulation software is demonstrated on Table 5.

Input

Electrochemical,
physical and
geometrical data,
cell operating
parameters

Model for calculating the energy consumption	Model for optimizing a target function
Bottom voltage model Model of power losses from the pot Geometrical, physical, electro-chemical and electro-technical relationships	Optimum of the target function in non-linear dependence on a max. of 40 free variables

Output

Optimum energy
consumption,
optimized free
parameters, operating
results, operating
parameters,
pot geometry for
optimum conditions

Table 5.

STRUCTURE OF AN ADVANCED SIMULATION SOFTWARE /Bosshard,12/

2.5 Realisations

Early controllers

Until now, resistance monitoring has proved to be the easiest way to control the basic inputs of the process, but the industrial equipment has been developed substantially during the last decades. Early instruments were cabled logic systems with analog data handling. These special instruments were quite expensive and it was almost impossible to adjust them to a newly arising demand. Re-programming was sometimes more difficult than constructing a new instrument. Due to the wide-ranging application of the first digital computers, all types of tasks were tried to fulfil with one computer. That was the period of the integrated on-line/commercial computer installations. As the computers got cheaper and cheaper, the special computerised controllers appeared, providing the hardware background for the development of sophisticated process models, applying real-time adaptive algorithms and better control systems.

Industrial equipments

Nowadays, controllers based on microprocessors are used in the industrial applications. The control unit is located in the potroom, near the cell, and supports both the manual and automatic work routines. Built-in ROM memory stores different parts of the control program as well as the constants and the default values of parameters.

When this unit operates in a stand-alone mode, it provides all the functions needed for a normal operation. It measures cell voltage and line current, checks the possible errors (e.g. celll instability) and controls the necessary operations (anode replacement, starting of alumina feeding). Usually, it helps the staff in predicting the anode effects, displays the measured values. Sometimes it can follow the technologycal events (e.g. automatic anode adjustment during tapping).

The control unit has also got interfaces to other intelligent devices. It can change data with an upper level central unit. Through these connections, the parameters in RAM of the control unit can be set according to a target function. The potroom personnel can either check or modify the electrolysis. Proper man-machine connection is essential. Figure 21. shows the connections of a control unit.

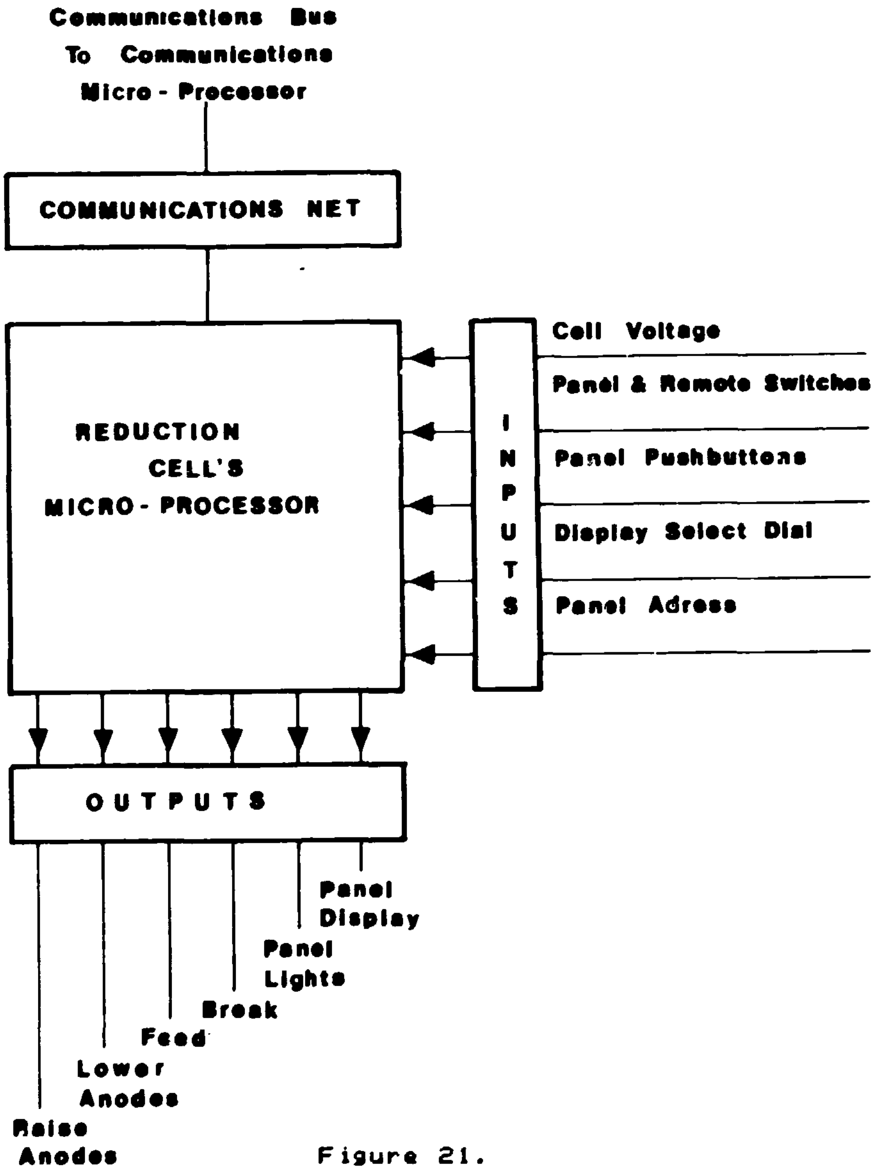

Figure 21.

CONNECTIONS OF A CELL CONTROL UNIT /Mohr,13/

Hierarchical control systems

Industrial application of computer based control systems induce the need for different interconnections. On the one hand,a technical manager may require to check separate cells, potrooms, lines or the whole plant. On the other hand, data acquisition, data management, digital control and supervisory functions have to be done. Table 6. demonstrates, how different functions may be distributed among single systems in the multicomputer systems.

Functions	Centralised system	Distribution	
		Horizontal	Vertical
Data acquisition	***	11111	1 N
Supervisory	***	.....	1.....N
Control	***	.....	1 N
Man-machine	***	NNNNN	1 N

Table 6.

DISTRIBUTION OF FUNCTIONS IN MULTICOMPUTER SYSTEMS

/Farber,14/

In plants,three- or four-level computerised control systems are general. It is an important task, therefore, to integrate the isolated stations into one common system. The resulting network is able to change data and allows tha sharing of instrumentation devices between different functions. The regular levels and the functions are:

Cell controller	-alumina feeding
	-voltage control
	-error detecting
	-anode effect termination
Potroom computer	-communication to and from the cell
	-line current signals to the cell
Line computer	-line load control
	-setpoint changes
	-short term data storage and report
Plant computer	-long term data storage
	-process control support tasks
	-software maintenance

Future trends

Plant operators run the system with multivariable, multiple loops, unpredictable material variations, etc. In time and with growing experience, the operators generate rules-of-thumb that help them deal with this complexity. These sets of rules are closely related to their plant and process. The main goal of the process control theory is to develop what one may call an expert system which is a computer-based model for problem solving. Expert systems are growing into a rapidly expanding area within the field of artifical intelligence. They differ from physical modeling because they attempt to model those aspects of a problem, for which the numerical representation could hardly be applicable; this is the case with unwanted events, like cell failures. The process supervisory systems of the future will be closer to the man than to the machine. /15/

The motivation for new developments in process automation systems is, usually, cost reduction. The semiconductor technology allows to replace expensive cables by powerful intelligent hardware modules. The cell controller units become more independent and, at the same time, more integrated to a distributed system as well.

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3. ELECTROMAGNETIC INTERACTIONS

3.1 Theoretical Background

High current intensity, common in aluminium electrolysis cells, results in a strong magnetic field inside and in the vicinity of the cell. The magnetic field has a serious impact on the bath and on the molten metal; the magnetic field, through its interaction with the electric currents, produces electromagnetic forces that affect both liquid layers. As a result, the interface between the molten bath and the aluminium layer gets distorted, the anode-cathode distance may uncontrolled. The melt fluctuates, thus promoting the reoxidation of the metal, and decreasing the current efficiency. /1/

The magnetic field is described by the Biot-Sawart's law. According to this basic rule of electricity, the magnetic field, at any P point, depends on the electric current and the geometric arrangement :

$$\bar{H}=\frac{I}{4\pi}\cdot\frac{\bar{dl}\ \bar{r_0}}{\bar{r}} \qquad (3.1)$$

where:

$\bar{dl}$: line-element of the conductor

$\bar{r_0}$: unit vector from P to dl

$\bar{r}$: distance between E and dl

The magnetic forces, described by the Lorentz equation, rise in the melt :

$$\bar{F} = I \cdot \bar{dl} \times \bar{B} \qquad (3.2)$$

where:

$\bar{dl}$: line element of the conductor

$\bar{B}$: magnetic induction

It is somewhat difficult to describe the magnetic behaviour of an electrolysis cell properly. There are several facts which have to be considered :

-complicated geometrical arrangement

-influence of extreme temperatures

-presence of ferromagnetic parts

This problem is usually approached through simplifications : the geometry is regarded simplified, the existence of ferromagnetic parts neglected, etc. Sophisticated computer models are needed for an adequate solution.

3.2 Construction

Aluminium smelters use different types of aluminium electrolysis cells,busbar and cell arrangement. These aspects have a serious impact on the current and potential distribution and the magnetic field pattern. /2,3/

Usual pot types are the horizontal and vertical stub Soederberg-anode cells and the prebaked-anode cells.

Cell arrangement in the smelter may be "end-to-end" or "side-by-side" systems.

Current busbar arrangements are "single-end-feed" or "double-end-feed" systems.

Cell types

It is in a few old smelters only that horizontal stub Soederberg cells are still in use. Current intensity of these smelters is rather low, under 100 KA. When working at such low intensities, the effect of the magnetic field on the operation of the cell is negligible.

Large numbers of vertical stub Soederberg series were built in the 1950-1960's. After twenty or more years in service, their thorough reconstruction was,in many cases, inavoidable to make the potlines competitive. Current intensification is part of the reconstruction; however, the magnetic field that the increased current generates results in a more substantial fluctuation and circulation of the molten layers. A tipical pattern of the magnetic induction distribution is shown on Figure 22. /4/

Prebaked anode cell has proved to be the most favourable construction since the 70's. It has advantageous technological parameters at high amperage. The magnetic field of a prebaked anode cell can be seen on Figure 23.

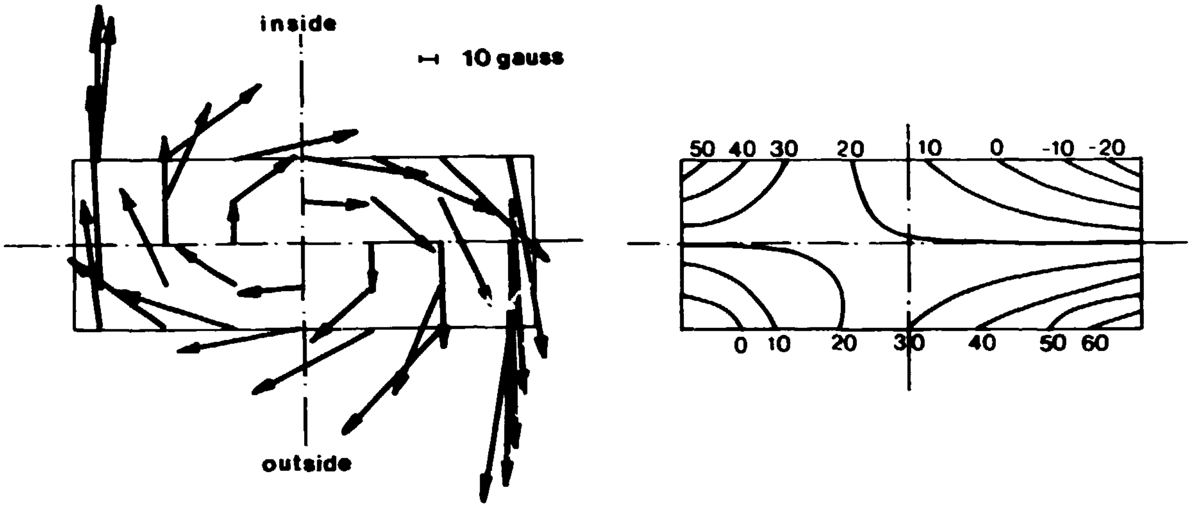

Figure 22.

MAGNETIC FIELD IN A SOEDERBERG CELL,

HORIZONTAL AND VERTICAL COMPONENTS OF THE FIELD

/Urata,4/

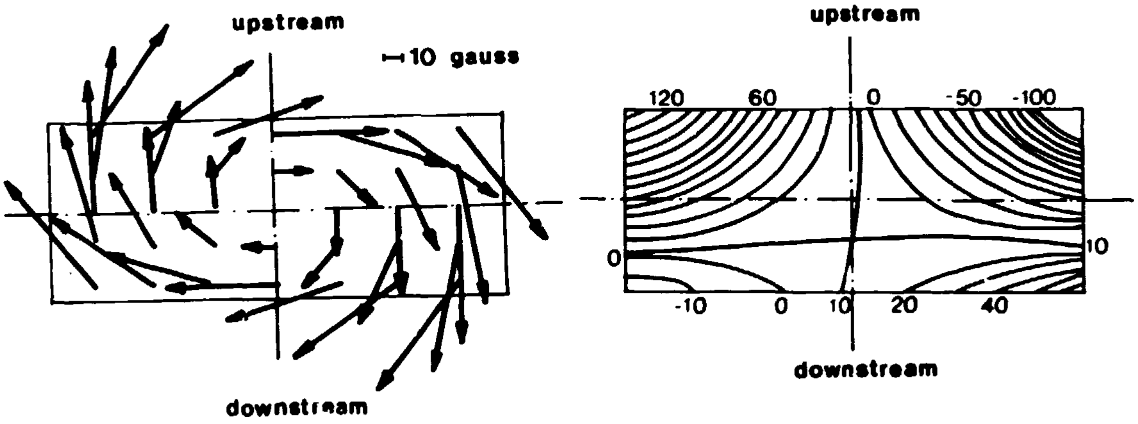

Figure 23.

MAGNETIC FIELD IN A PREBAKED CELL,

HORIZONTAL AND VERTICAL COMPONENTS OF THE FIELD

/Urata,4/

Cell arrangement

End-to-end layout is the simplest and most frequent system. The busbars are led, over risers, along the shortest way from the cathode of one cell to the anode of the next. This system is used for cells working at up to about 50KA; magnetic assymmetries make it unsuitable for larger cells. Figure 24. shows this busbar arrangement and the magnetic field pattern of a cell of this type. Side-by-side layout is used for series over about 100 KA. This provides better magnetic conditions than the end-to-end layout. See Figure 25.

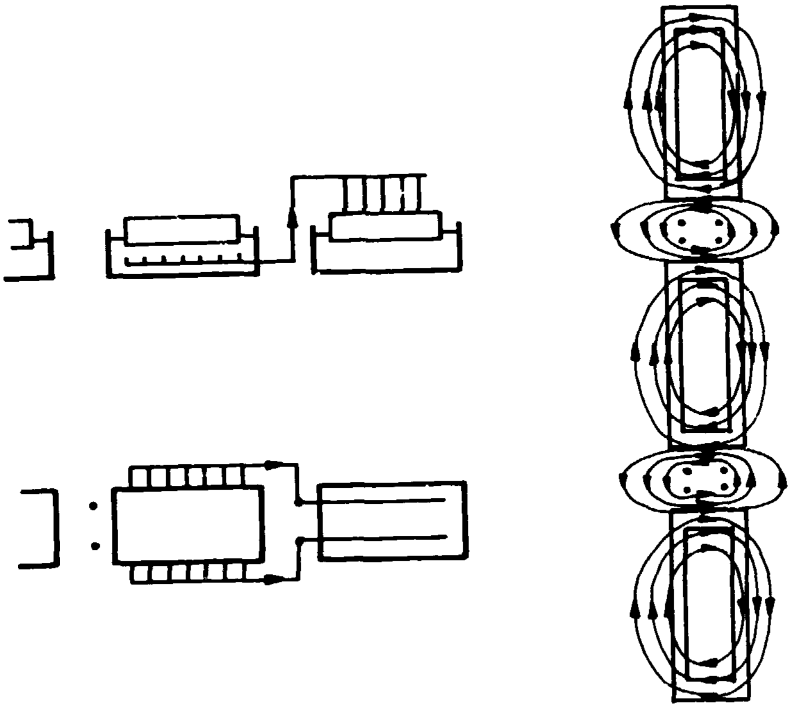

Figure 24.

END-TO-END CELL ARRANGEMENT

/Sele,3/

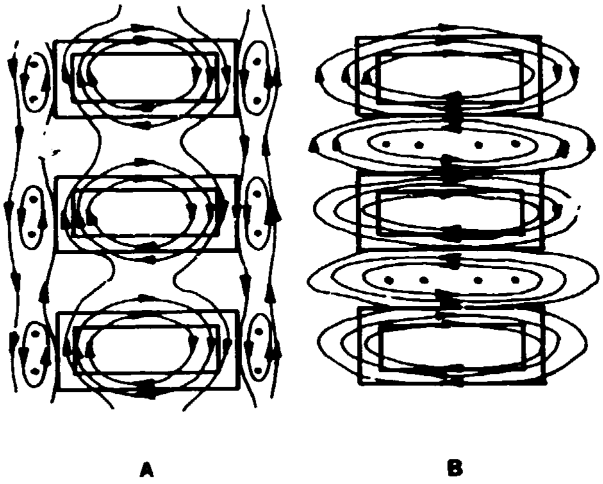

Figure 25.

SIDE-BY-SIDE CELL ARRANGEMENT

/Sele,3/

Busbar systems

As far as the magnetic conditions are concerned, the geometrical position of the busbars on and between the cells and the division of the current in the busbars are the main things to consider during design. There are a lot of varieties; typical ones will be introduced here.

Cells with single-end-feed system were developed first, but this conception was given up soon. The double-end-feed busbar system offers better magnetic conditions for larger cells, and is used extensively in existing potlines of the "end-to-end" type. Part of the cathode current from one cell is brought to risers at the far end of the following cell. As much as 50% of the line current is sometimes brought to the other end, but that is expensive and not neccessary for the magnetic conditions. 25-30% will normally be satisfactory (Figure 26.).

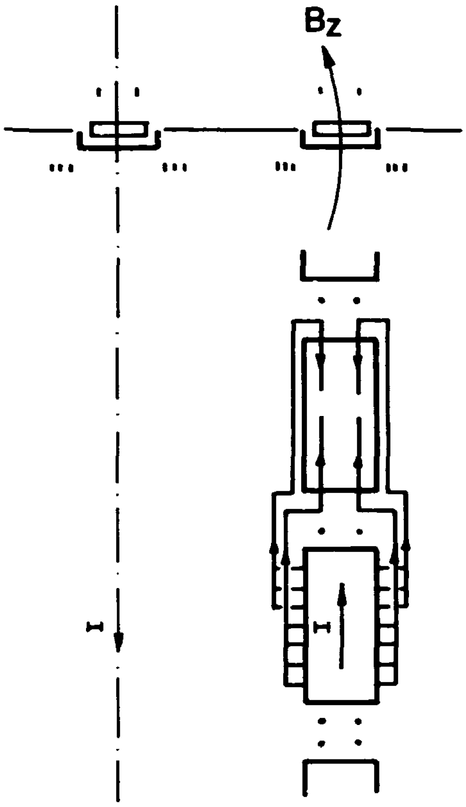

Figure 26.

DOUBLE-END-FEED BUSBAR ARRANGEMENT

/Sele,3/

There is one important magnetic problem which has not been solved by the above busbar system. The return current in the neighbouring cell-row generates a vertical magnetic field in the cells, and this field is left uncompensated on one side. Several methods can be used to compensate this magnetic field.

Recent series of about 200 kA and above are built with busbar systems similar to that shown in Figure 27. Actual industrial arrangements are usually patented.

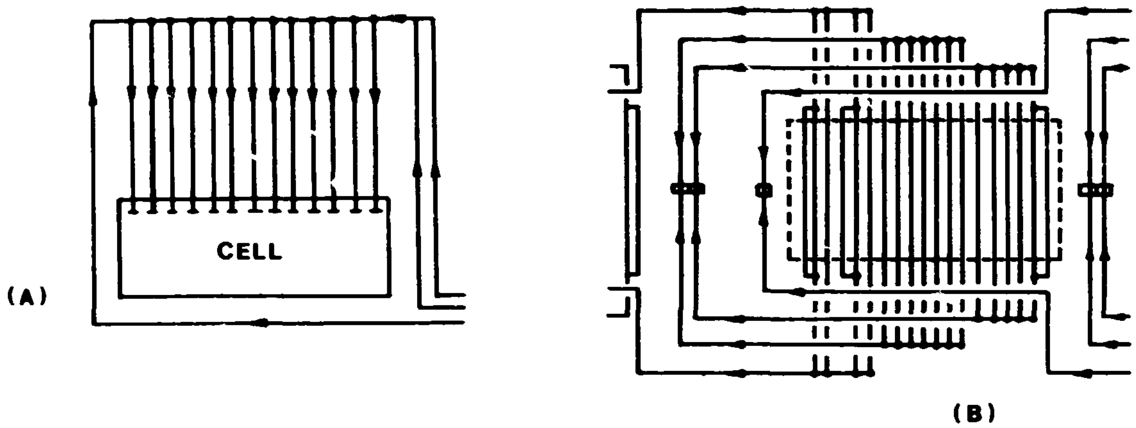

Figure 27.

BUSBAR ARRANGEMENT OF A CELL ABOUT 200KA,

(A) ANODE (B) CATHODE BUSBARS

/Sele,3/

3.3 Effects of the Magnetic Field on the Cell Operation

Behaviour of the melt can be described by the Navier-Stokes equation. The influence of the magnetic field described by the Lorentz law have to be considered. The general form of the Navier-Stokes equation is :

$$\rho \cdot \frac{d\bar{v}}{dt} = -\mathrm{grad}\, p + \bar{f}_g + \bar{f}_e + \bar{k} \qquad (3.3)$$

where

ρ : melt density
$\bar{v}$: melt velocity
p : pressure
$\bar{f}_g$: gravitation force density
$\bar{f}_e$: Lorentz's force density
$\bar{k}$: frictional force density

It is extremely complicated to solve this equation for the case of a real cell. Some phenomena of the technology is outlined here.

Static distorsion of the metal surface

The electromagnetic forces in the cells may distort the metal surface. This result in uneven anode consumption. This "hydrostatic" phenomenon depends mainly on the actual busbar system. Two typical distorsion pattern can be seen on Figure 28. and Figure 29. /5/

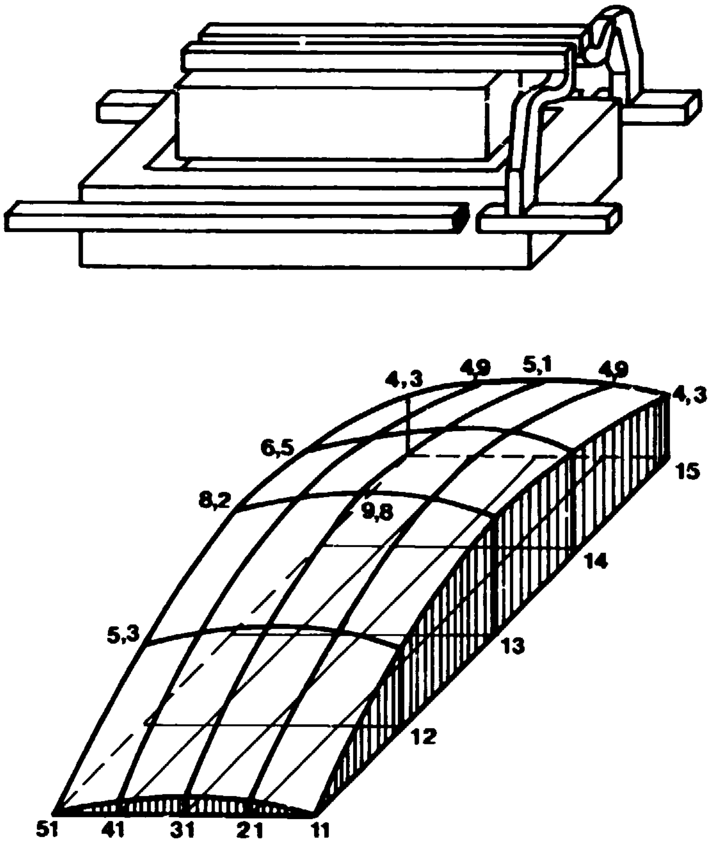

Figure 28.

STATIC DISTORSION OF THE METAL SURFACE I.

/Dogramadzi,5/

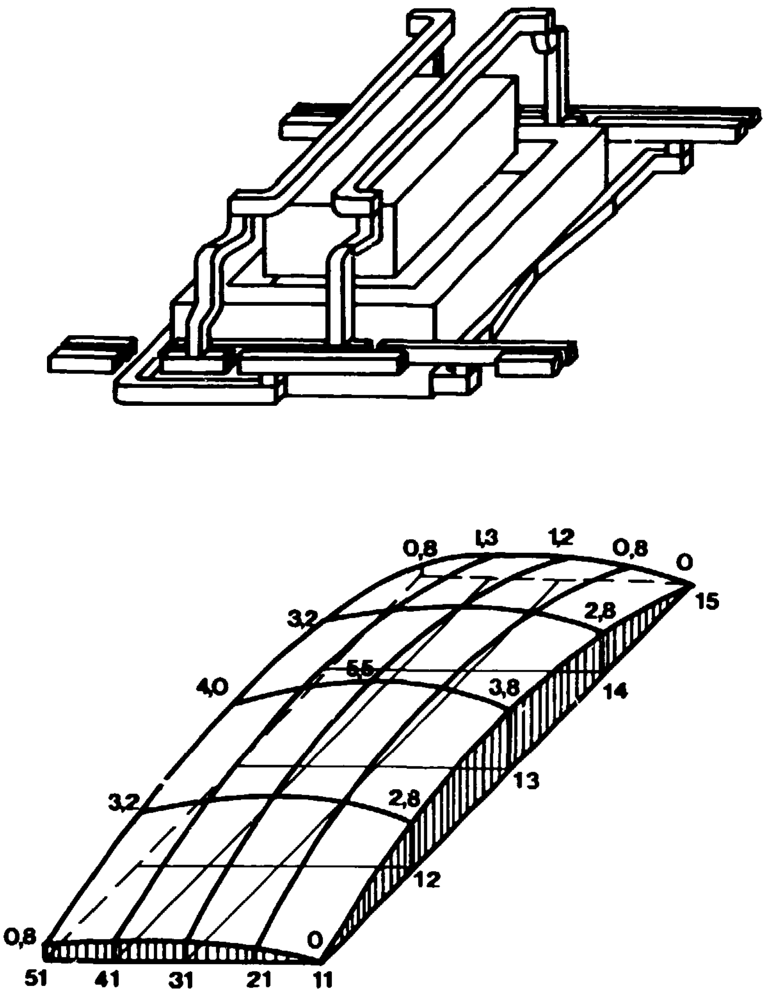

Figure 29.

STATIC DISTORSION OF THE METAL SURFACE II.

/Dogramadzi,5/

Metal circulation

In high amperage cells, strong circulation in the metal is often observed. This motion can erode the sidewall of the cell. The behaviour of different cells belongs basically to two types of motion : the four eddies symmetric motion (a) and the three eddies asymmetric motion (b). /6/. See Figure 30.

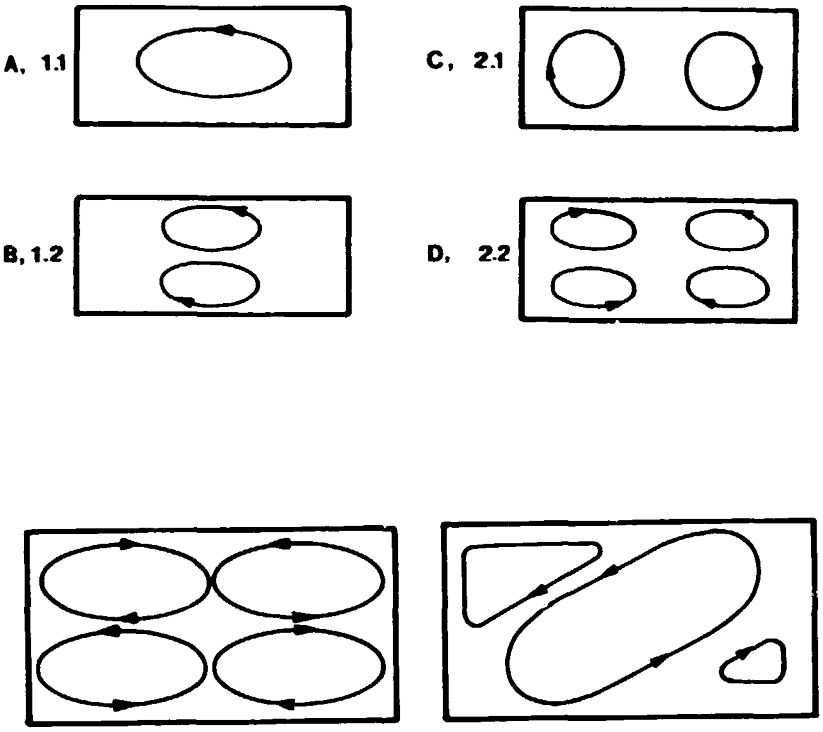

Figure 30.

METAL CIRCULATIONS

/blanc,6/

Metal oscillation

Surface oscillation of the liquid metal reduces the actual interpolar distance and, consequently, the current efficiency goes down. To suppress the oscillation and to stabilize the surface of the melt, the interpolar distance should be decreased /7/. Oscillations can occur in any types of cells : in a normal cell, in an abnormal cell and also in a cellnder externel interference. In a normal cell, the oscillation remains undetected, due to the relatively small amplitudes. In an abnormal or a disturbed cell, the oscillation can be detected through the behaviour of the cell resistance.

Some examples are given in Ch.7. Stability calculations are demonstrated in Ch.7.4.

3.4 Measuring methods

Measurements are usually made with Hall-detectors. Actual measurements are hindered by same difficulties, such as effects of the corrosive electrolyte or of the high temperature. To meet this difficulties, the measuring probe is protected against the agressive melt and it is cooled or isolated. Several methods are developed to solve these problems. /8/

A three-axis Hall-probe set, one probe for each co-ordinate, is inserted into a tube. The set is cooled with high-pressured air. Three non-ferromagnetic,stainless steel pipes are put into one another and the pressured air passes through them. Temperature of the probe should be kept under a limit during measurement (Figure 31.).

The effect of high temperature may also be eliminated by the isolation of the probe. First, a long graphite crucible is put in the molten aluminium. Its stand is fixed on the cathode shell. The crucible keeps the melt away from the probe. The probe is covered by a changeable heat insulator made of a cheramic material. The measuring period should not take more than 10 - 15 seconds. During this short time the temperature of the probe will not grow over the temperature limit. Another important parameter is the angle of the probe; this, as well as the temperature, has to be checked regularly. The arrangement of the device is shown on Figure 32. Real-plant measurements are give in Ch.7.

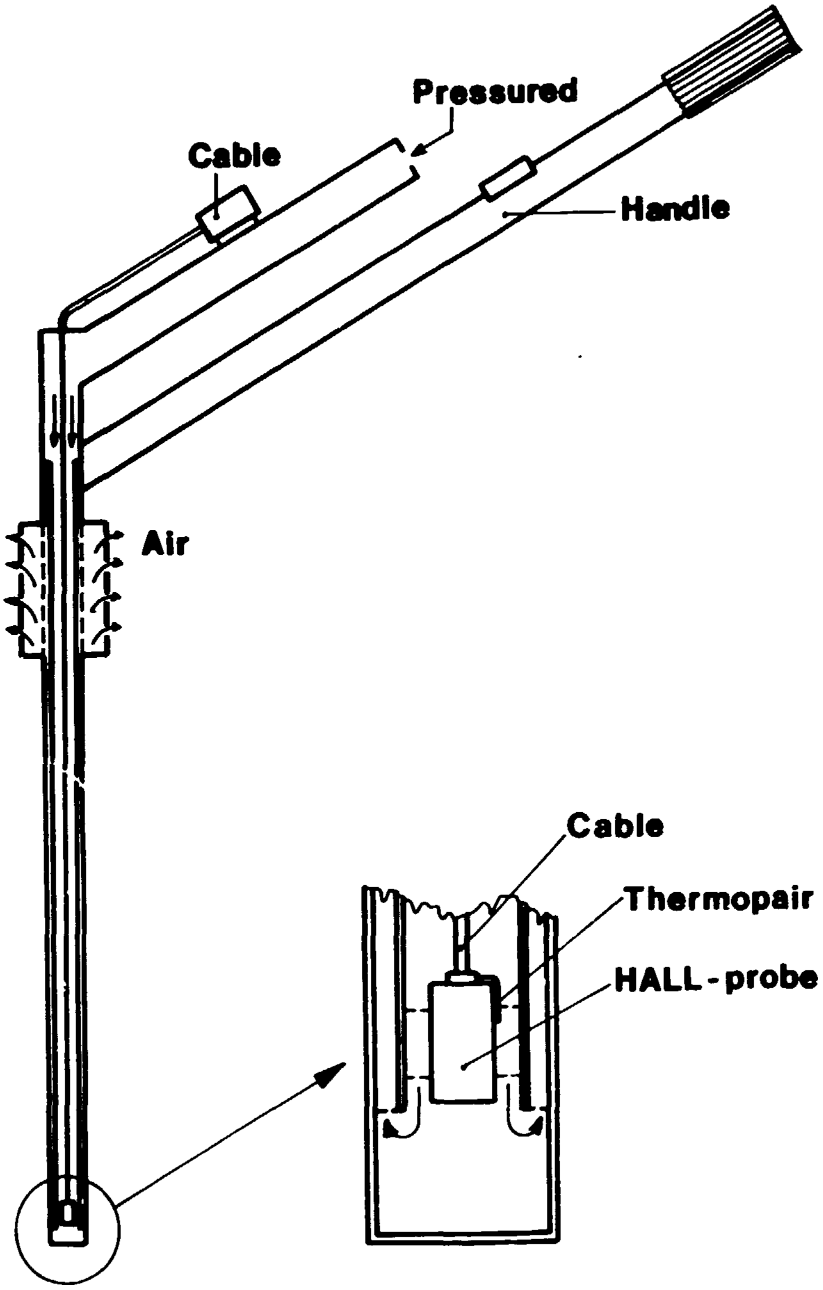

Figure 31.

HALL-PROBE, COOLED WITH PRESSURED AIR

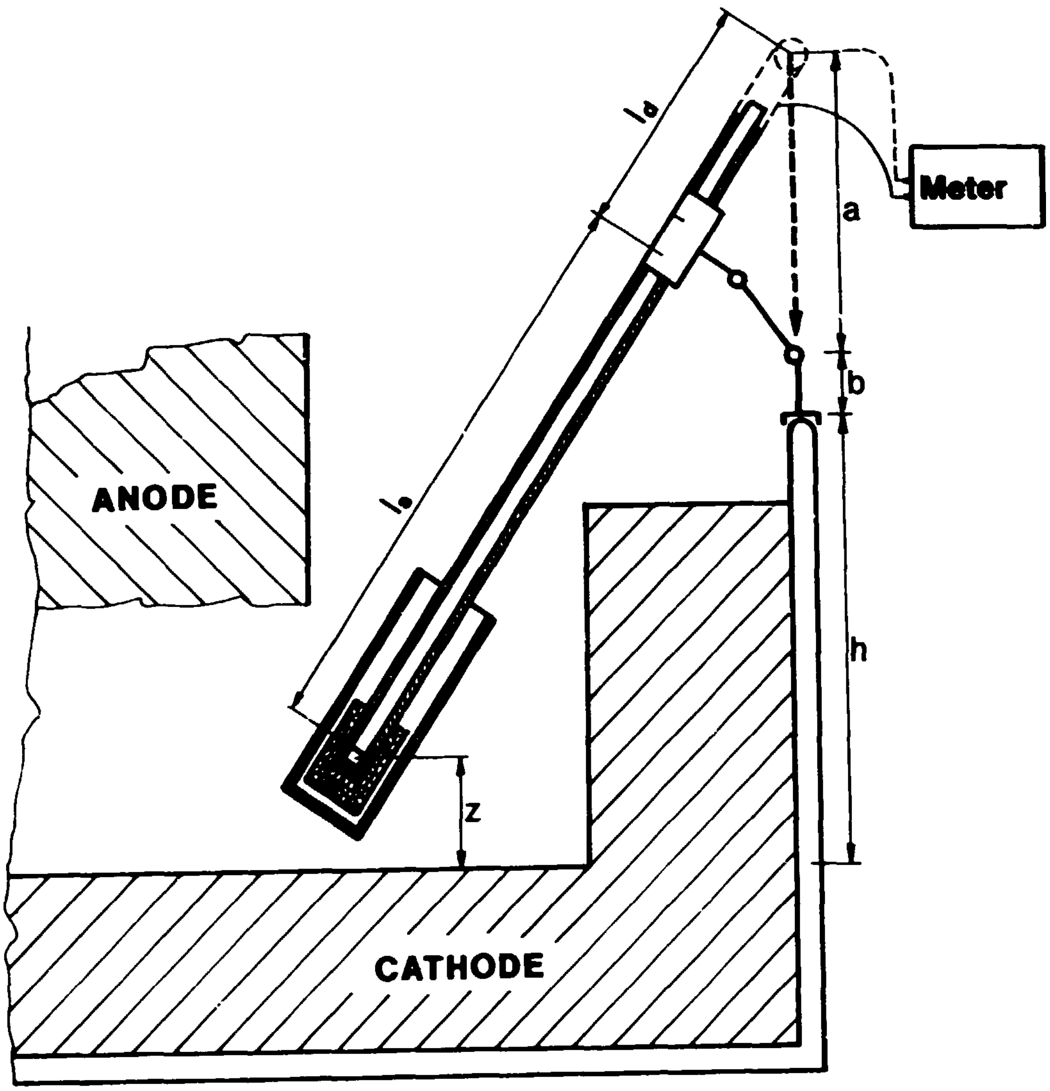

Figure 32.

THERMO-INSULATED HALL-PROBE

3.5 Calculation and Modeling

General aim of modeling

Several computer programs have been developed to calculate potential fields, current distributions and magnetic fields of the aluminium electrolysis cells. These programs usually belong to a large system which model the cell in a complex way including "hydrodinamic" and thermal effects.

Calculation of potential distribution

In the following parts of this section, some examples are given demonstrating possible applications of the theory. The computer model referred below was tested on a Soederbrg cell, but it is also suitable for calculation of prebaked anode cells. /9/

For the calculation of potential distribution, the following two-dimensional Laplace equation has to be solved:

$$\frac{\partial}{\partial x}\left(\gamma \cdot \frac{\partial \varphi}{\partial x}\right) + \frac{\partial}{\partial y}\left(\gamma \cdot \frac{\partial \varphi}{\partial y}\right) = 0 \qquad (3.4)$$

where

γ : temperature dependent conductivity of carbon
φ : the electrical potential

The temperature distribution of the cell was determined experimentally. Cathode bars were considered equipotential at each cross section. Potential drops along cathode bars were calculated with a three dimensional program. The resistive contact layers between the carbon and cathode bars and between the cathode blocks were also considered.

The surface layer between the contact layer and the carbon was described with the boundary condition :

$$\gamma_c \cdot \frac{\partial \varphi}{\partial n} = \gamma_R \cdot \frac{\partial \varphi}{\partial n} \qquad (3.5)$$

where

n : the normal to the boundary

γ_R : conductivity of the contact layer

γ_c : conductivity of the carbon

For the sidewalls of the cathode and for the frozen bath surface, the boundary conditions are :

$$\frac{\partial \varphi}{\partial n} = 0 \qquad (3.6)$$

Potential distribution is calculated with the finite difference method. The finite difference equations were solved by Gaussian elimination, using direct access backing storage. Figure 33. shows three cathodic blocks with a freeze above the one, on the right, at 900 C.

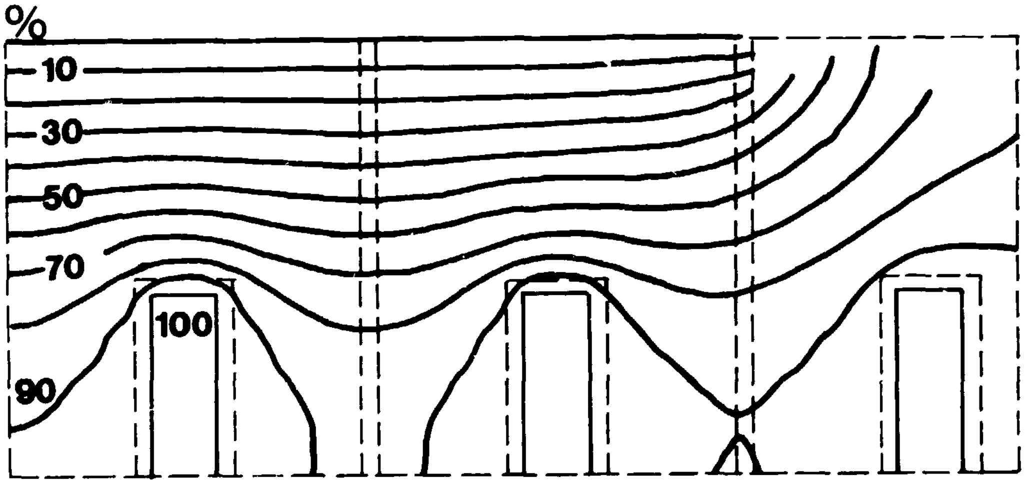

Figure 33.

EQUIPOTENTIAL LINES IIN THE CATHODE AT 900 C

/Koltai,3/

On Figure 34., the same blocks are shown at another cross-section at 700 C. The effect of the contact layer between respective cathode bars and carbon blocks is significant.

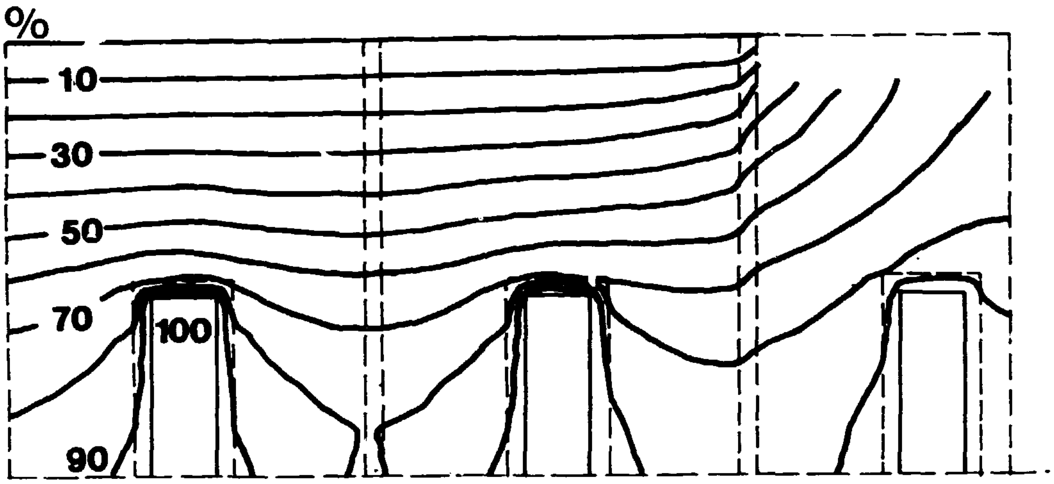

Figure 34.

EQUIPOTENTIAL LINES IN THE CATHODE AT 700 C

/Koltai,9/

For calculations of anodic currents, the three-dimensional Laplace equation has to be solved :

$$\frac{\partial}{\partial x}\left(\gamma \frac{\partial \varphi}{\partial x}\right) + \frac{\partial}{\partial y}\left(\gamma \frac{\partial \varphi}{\partial y}\right) + \frac{\partial}{\partial z}\left(\gamma \frac{\partial \varphi}{\partial z}\right) = 0 \qquad (3.7)$$

Solution of this equation was obtained with finite difference method on a non-uniform grid. The finite difference equations were solved iteratively by the strongly implicit procedure. The conductivity of the anodic bars was assumed to be of a finite value so the potential distribution of the anodic bars was also determined. On the bottom of the anode, constant current density was assumed. This assumption was necessary because the analysis was restricted to the anode only, excluding the electrolyte region. This is a good approximation because of the high resistivity of the electrolyte. /10,11/

Potential distribution of a Soederberg cell in a vertical cross-section is shown on Figure 35.

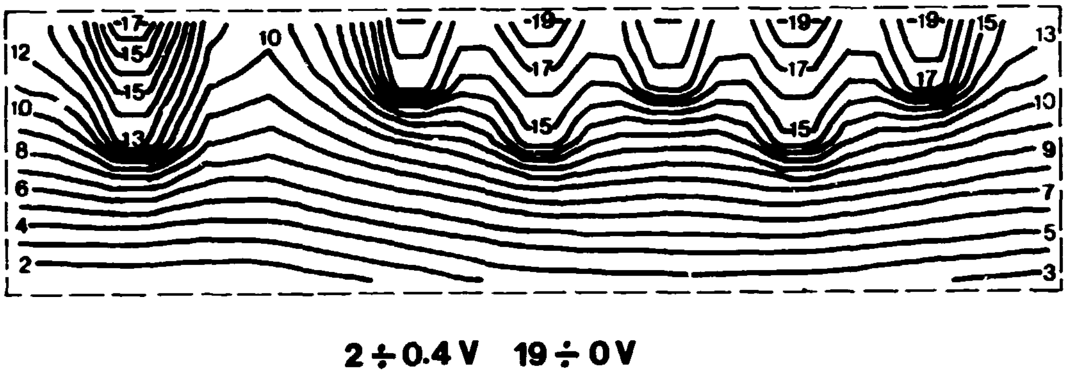

Figure 35.

EQUIPOTENTIAL LINES IN A SOEDERBERG ANODE

/Koltai,9/

Analysis was carried out in the conductive part of the anode. Through a series of analyses, an equivalent circuit of this region was determined. Then this circuit was completed with the resistances of the bars in the non-conductive part of the anode and the external bus system. The potential distribution on the bottom of the anode is shown on Figure 36. Apparently, the bottom of the anode is far from being equipotential.

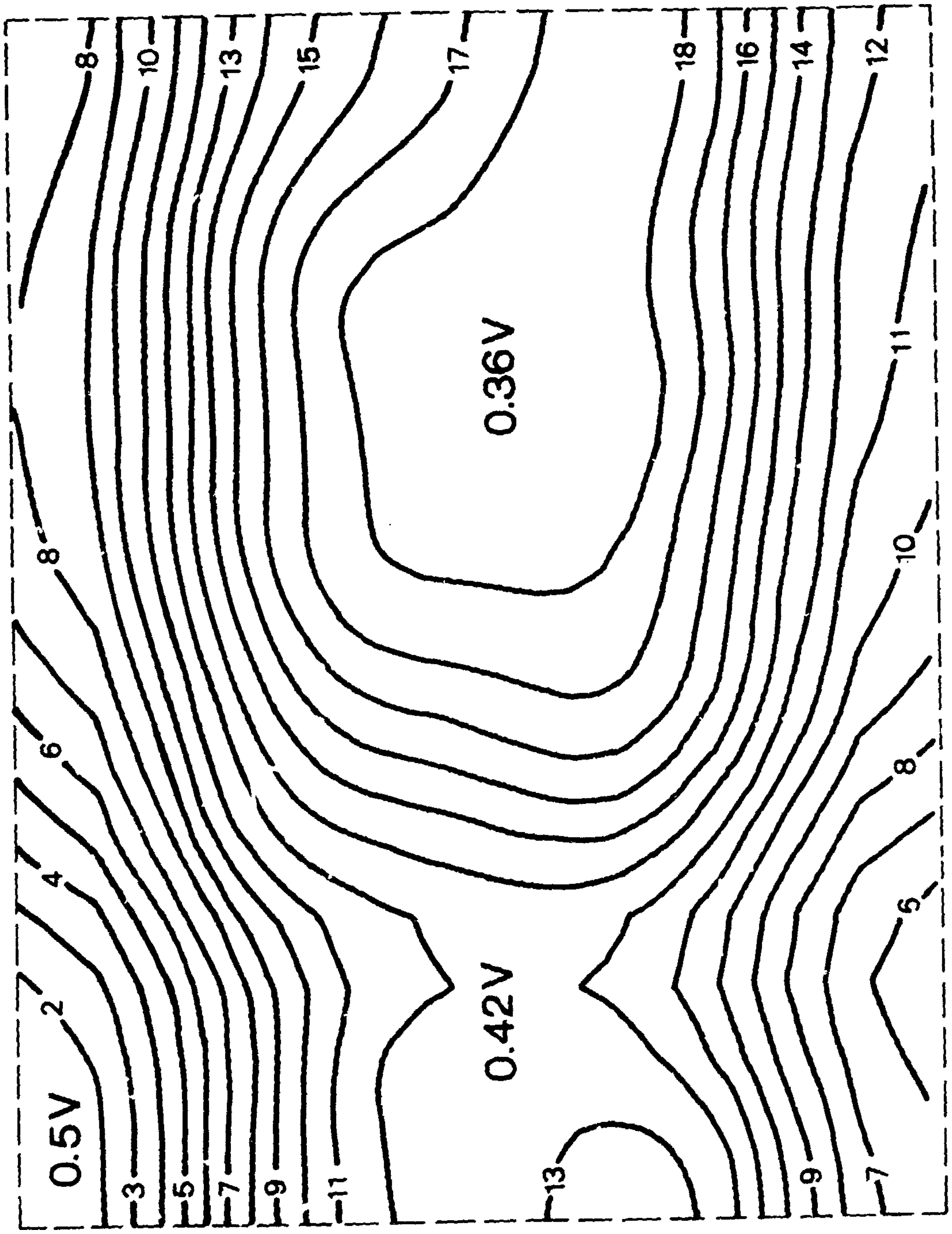

Figure 36.

EQUIPOTENTIAL LINES ON THE BOTTOM OF A SOEDERBERG ANODE

/Koltai,3/

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4. SAFETY INSTRUCTIONS

Measurements described in this Part are dangerous by nature; the dangers involve electric shocks, fire or other hazards. Safety rules, instructions and preventive measures must be imposed to prevent accidents. Observing these measures is obligatory. The measures described here are of a general nature. Differences between actual laboratory and potroom conditions render it inavoidable to carefully study and abide by local safety precautions.

General rules

1. Nobody can work alone in a laboratory with electric devices.
2. Personnel assigned to laboratory or plant measurements must be familiar with all the peculiarities of the work involved.
3. All personnel must be familiar with the places and the use of electric disconnectors, fire alarms and fire extinquishers and other alarm devices. In case of an emergency, everybody must act with the necessary competence.
4. All personnel must know when and how to use their protective gear.
5. A first-aid outfit, complete with all tools and materials necessary for first aid, must always be kept a well-indicated place.
6. In case of an injury, the person must receive immediate first aid according to the nature of his injury. After applying first aid, a doctor must be contacted.

Electric measurements

Voltages in the potroom may be extremely high. Use true galvanic isolation elements to decouple these potentials from the standard measuring devices.

For life protection, the use of isolating transformators is preferable to earthing.Use batteries for power supply in the potroom whenever it is possible.

Cables should be as short as possible. Use cables with strenghtened mechanical covering and with strenghtened electric isolation.

Do with all care when carrying long wires or conducting bars along the cells to avoid short-cuts between cells of different series.

Always be prepared for the appearance of electric sparks. Never panic.

Fire protection

It is compulsory to use face-guard, safety goggles, industrial gloves and laced boots when measurements require contacts with the melt. Handle hot measuring probes and crucibles with great care. Splashing electrolyte can cause dangerous injuries.

In case of fires, alarm the Fire Brigade and start to extinquish the fire immediately. Burning chemicals must be extinquished with substances according to their nature. Use carbon-dioxide, dry chemical or gas extinquishers. Newer use extinquishers on a burning man. Wrap him tightly into a blanket.

Fires of electric origin can only be extinquished after cutting off the current.

5. ELECTRICAL MEASUREMENTS

5.1 Measurements on the Cathode

5.1.1 Current distribution in the bus bar

Principles

One one hand, the line integral of the magnetic field force along a closed curve is proportional to the current passing through the surface bounded by the curve. On the other hand, the voltage induced in a wire which is bounded around a current carrying bar is proportional to the alteration of the current.

A multi-turn coil, called Rogowsky coil, is used for actual measurements. This closed, with a fast movement, around the current carrying part. To eliminate the influence of closing speed, integral value of the voltage pulse generated in the coil is displayed.

Instrument : Rogameter

- Range : 0.1 -10 KA
- Diameter of conductor : max. 20 mm
- Accuracy : +/- 5%
- Main sizes : 260 x 200 x 80 mm
- Weight : 4 Kp
- Power supply : four R14 batteries

Personnel : two technician, special training isn't required

Procedure, evaluation

Close the frame around the bar; current flowing through the bar can be read immediately. Log the measured values and the current levels carefully.

These measurements give useful information in case of a cell start-up as well as during normal operation. Evaluate the current distribution as function of the cell life.

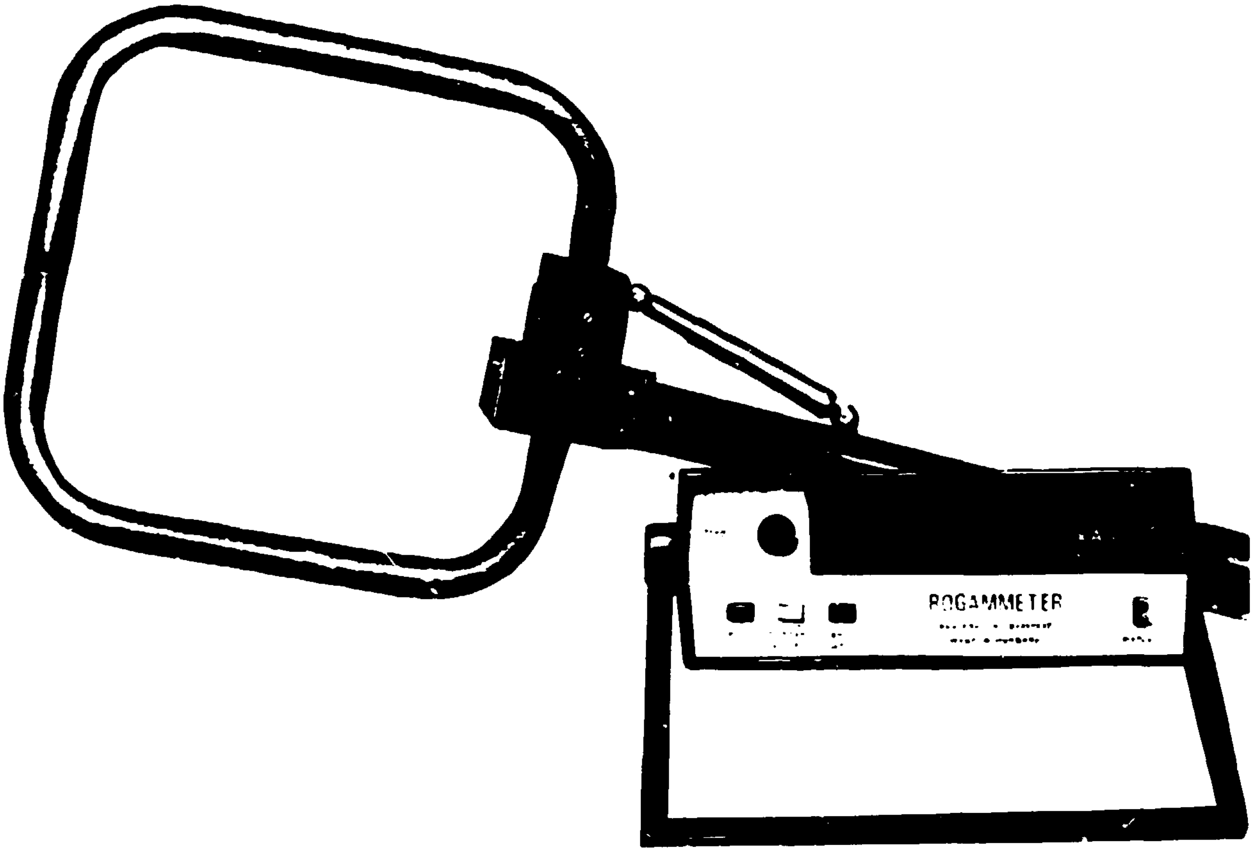


Figure 37.
ROGAMETER

Example

Current distribution in the cathode of a Soederbeg cell is demonstrated on Figure 38. Measurements were done in a pre heating period of a cell.

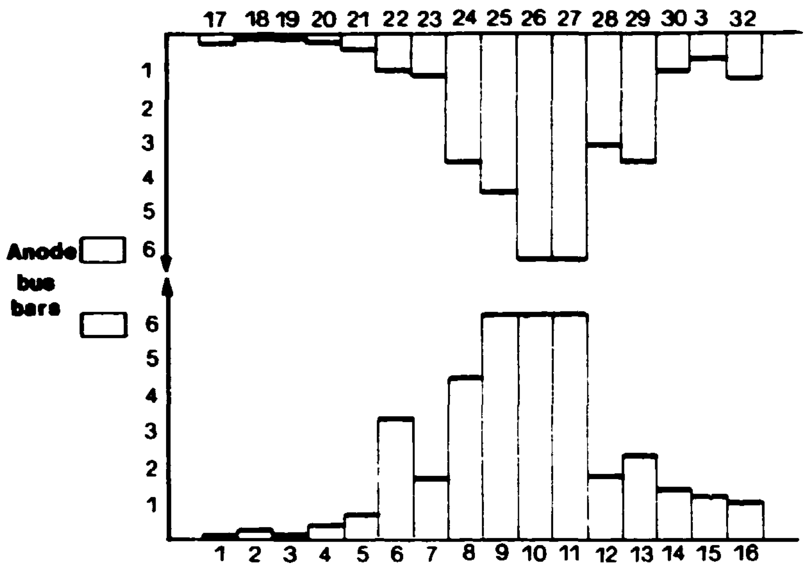


Figure 38.

CATHODE CURRENT DISTRIBUTION

5.1.2 Voltage Losses in Cathode Bars

Principles

Total cathode voltage drop is regularly measured during normal operation of a cell.But, it is difficult to determine its components. Losses in the bars are examined here.

A posible method is to use specially drilled bar. With the aid of a small probe, voltage drop along the bar can be scanned. Scheme of a drilled bar is shown on Figure 39. This bar have to be built into the cathode in advance. In practice, several drilled bars are used for scanning the whole cathode of the test cell. Different places and levels can be mapped. Addditional temperature measurements can be done in the holes. Results of a detailed examination are essential for evaluating both the construction and the operation. Verification of computer models need this kind of data, too.

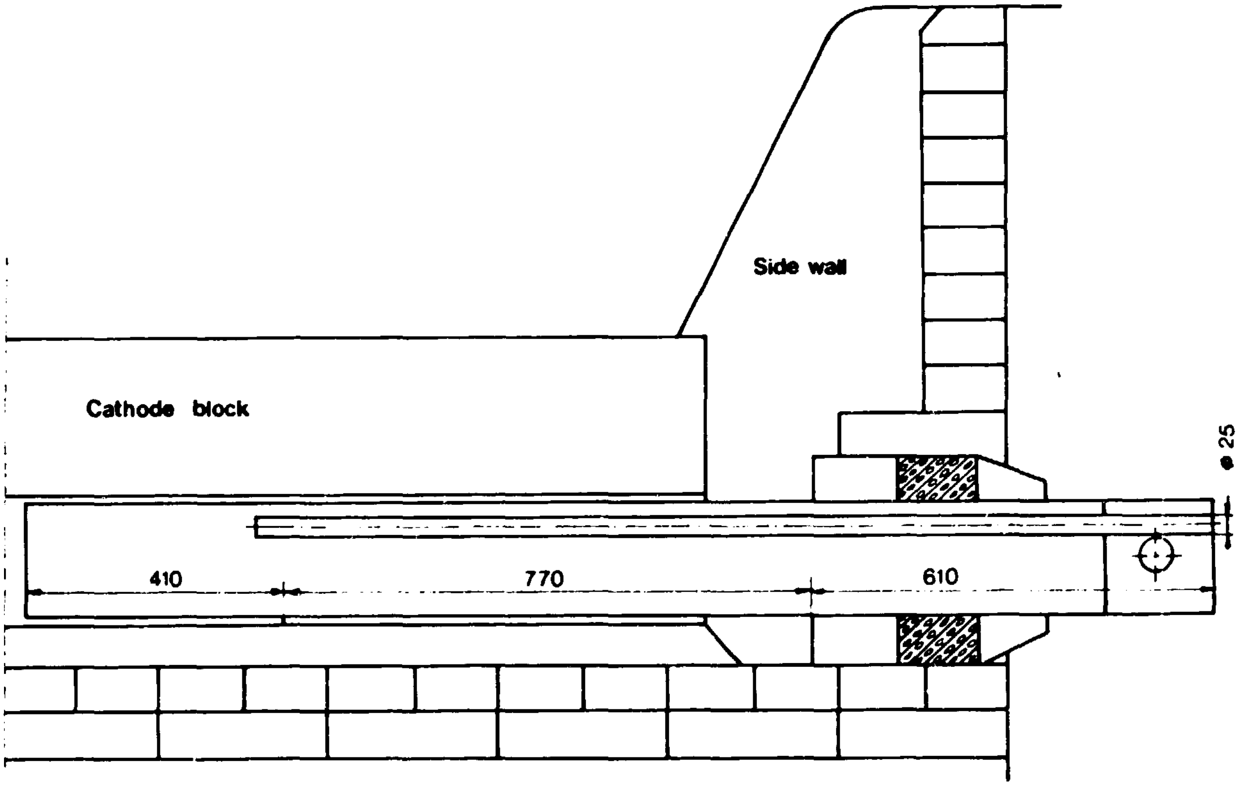


Figure 39. SCHEME OF DRILLED CATHODE BAR

Some mechanical problems may arise when drilling the bars. The geometrical deformation of the holes during operation have to be taken into account.

Instruments : small measuring probes
mV meters
thermo couples
Personnel : two technician

Procedure, evaluation

Measurements in the narrow holes have to be done with great care. Scan the voltag drop of a bar with the probe. Check the isolation of the probe's stem and the proper contact between the probe and the bar. Log the actual line current values regularly. A detailed, long-term examination which covers the whole life of the cell needs perfect data processing.

Evaluate the voltage loss distribution first inside one bar then between the bars. Analyse the voltage losses as functions of the cell life.

Example

Voltage drop and temperature distribution in two cathode bars are demonstrated on Figure 40. One bar was built in the middle and the other at the side of the cathode bottom. Measurements were done in the early life of the cell.

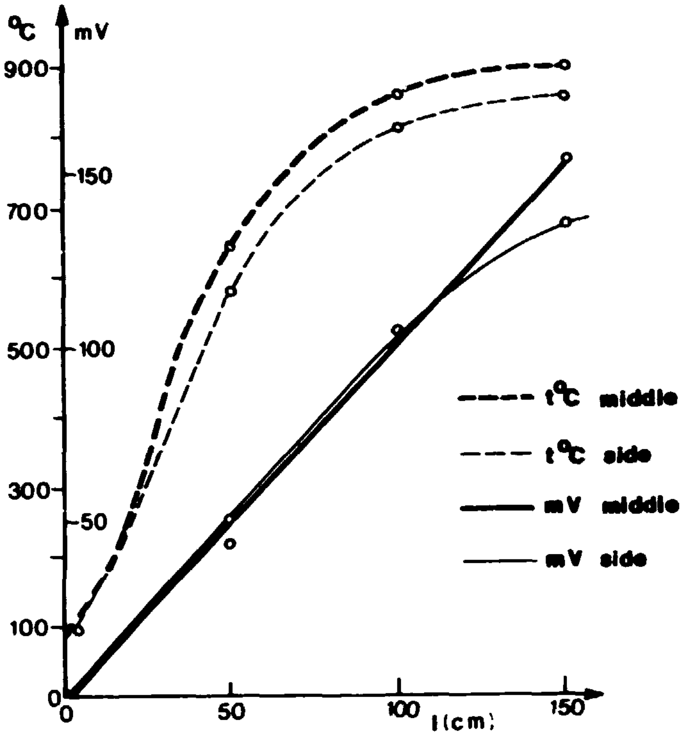


Figure 40.

VOLTAGE AND TEMPERATURE MEASUREMENTS IN A DRILLED BAR

5.2 Measurements on the Anode

5.2.1 Current distribution between anode stubs

Principles

Current distribution has a great importance using both types of anode. The actual distribution characterize the arrangement and the level of stubs or blocks.

Principle of the measurement is similar to the one mentioned at cathode current distribution, in Section 5.1.1.

Instrument : Rogameter

Personnel : two electrician

Procedure, evaluation

Close the frame around the selected stub and read the displayed results. Analyse the probability characteristics of the anode current distribution regarding its dependance of technological interaction.

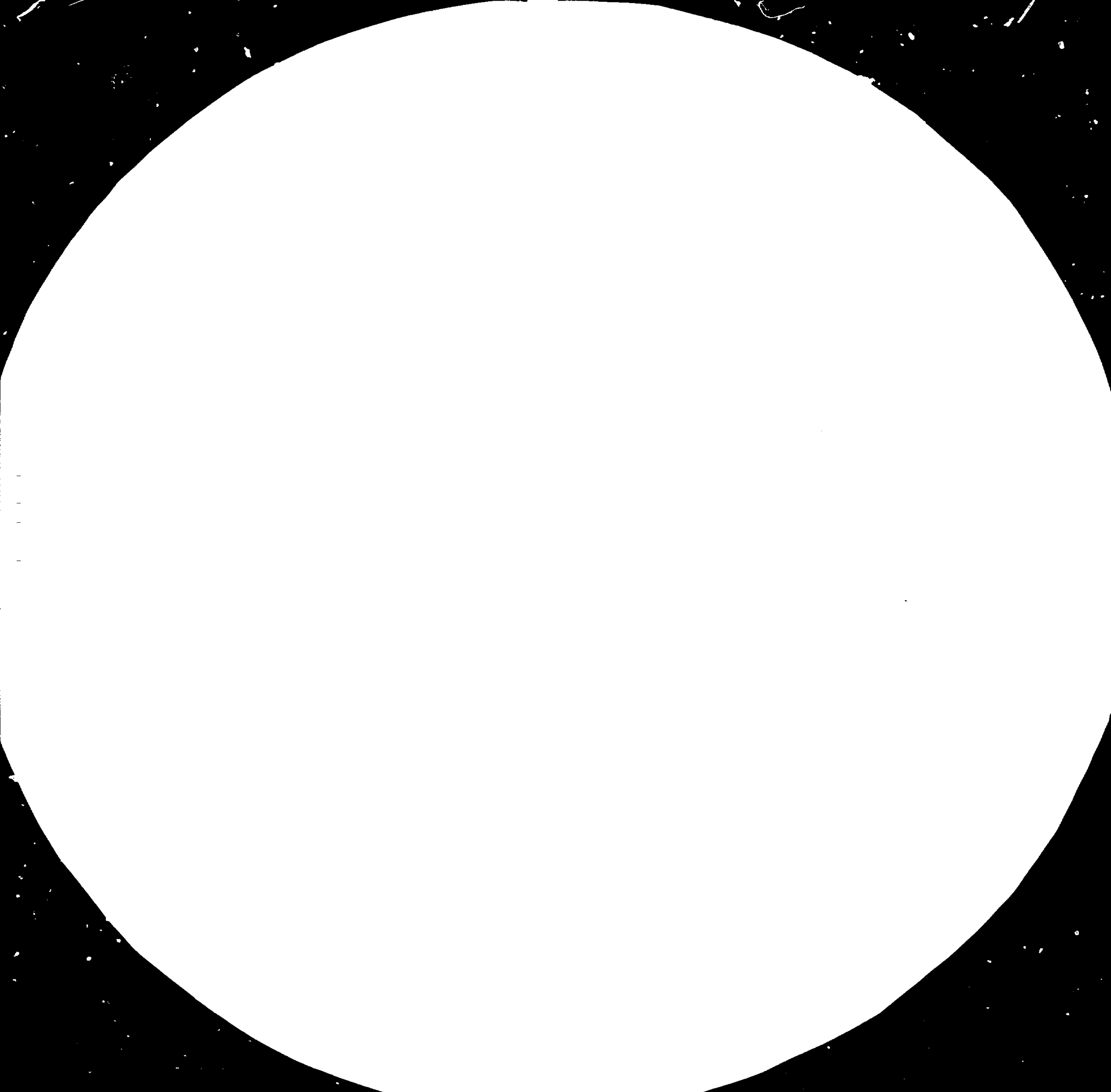
Example

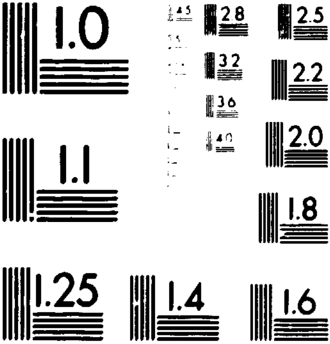
Current distribution of a prebaked cell is given in Table 7. It was measured in a normal operation period of a prebaked cell.

No. of blocks	Current		Std. deviation
	KA	%	KA
1	1.02	1.18	0.05
2	7.23	8.34	0.41
3	8.14	9.39	0.32
4	7.45	8.59	0.28
5	9.71	11.2	0.82
6	6.65	7.67	0.27
7	6.44	7.43	0.26
8	4.78	5.52	0.44
9	6.48	7.48	0.31
10	6.11	7.05	0.24
11	5.42	6.25	0.27
12	6.27	7.23	0.30
13	5.72	6.60	0.23
14	5.24	6.04	0.23

Table 7.

CURRENT DISTRIBUTION BETWEEN PREBAKED ANODE BLOCKS





MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS

STANDARD REFERENCE MATERIAL 1010a

(ANSI and ISO TEST CHART No. 2)

5.2.2 Measurement of Anode Movement

Principles

Anode adjustments are regular events in cell operation. There are many cases when the anode is moved. Alumina content of the molten bath changes with time and the changing cell resistance is compensated by rising or lowering the anode. This is a frequent control action made by manually or automatically. Anode have to be moved during metal tapping and the difference between anode consumption and metal production also needs anode adjustment.

These anode adjustments need fairly different measuring methods. Adjustments for resistance control are mainly estimated from the operation time of anode motors or from the appearing voltage change. Integrating the turns of anode motors with a special device, the metal tappings and the long-term alterations can be checked. Sometimes, manual measurement are necessary.

Long-term result of anode adjustments is examined here.

Instrument	: stand-alone anode movement meter, measures and stores the number of up and down orders as well as the summarised up and down movements separately
Personnel	: only for read stored data once a week

Procedure, evaluation

After assembling, the instrument operates in stand-alone mode. Supervise it and read data weekly. It is advantageous to use this measurement when a new feedind routine or new anode materials are introduced.

Evaluate the movements between the tappings. Analyse the correlation between the amount of tapped metal and the anode movement. Estimate the thermal state of the cell.

Example

Figure 41. shows the anode movement of a Soederberg cell for a month. It was recorded in the normal state of a Soederberg cell. Tappings (.....) and anode slipping (-----) are given.

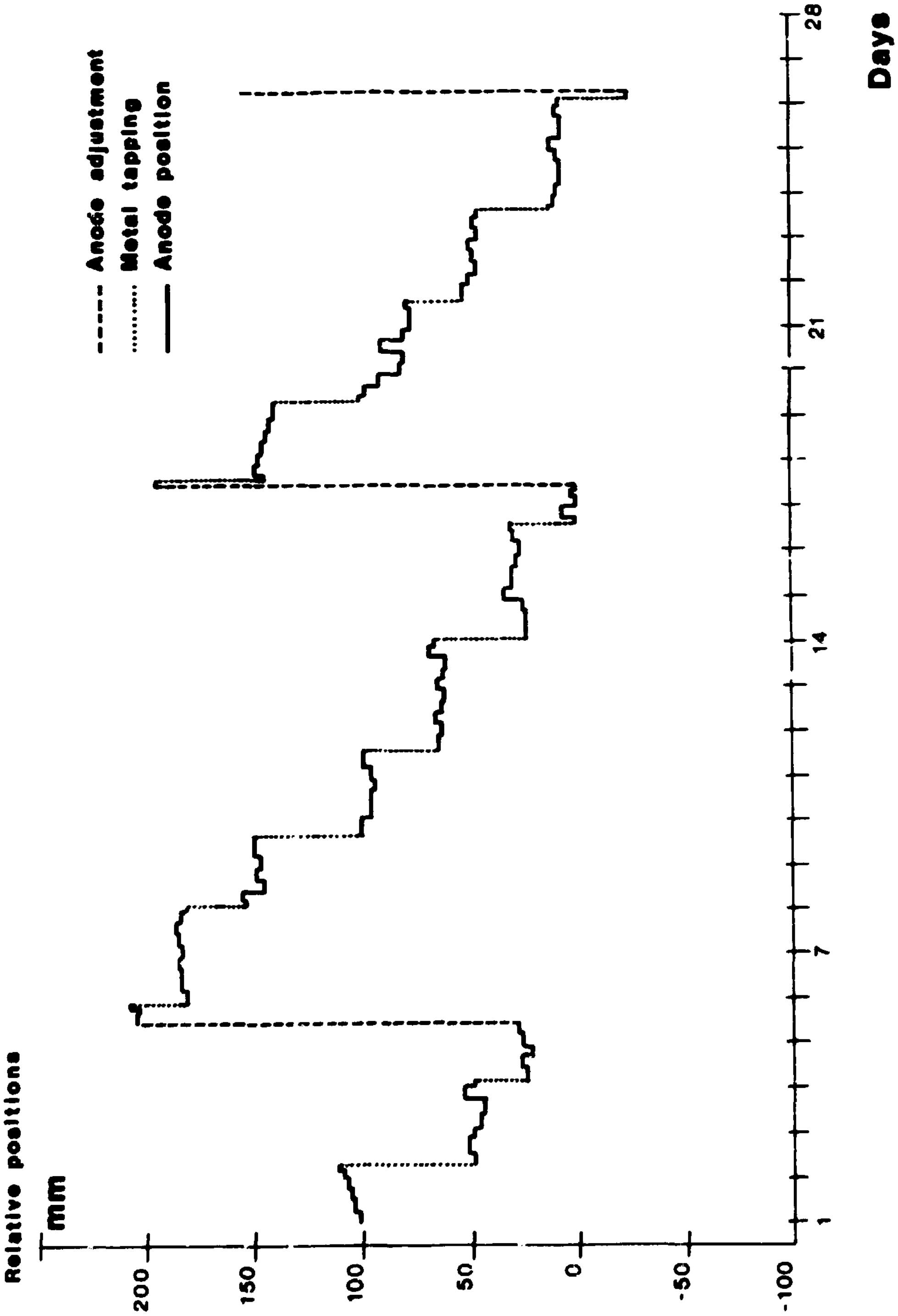


Figure 41. LONG-TERM ANODE MOVEMENT

5.3 Testing of Current Carrying Elements

5.3.1 Testing Pastes and Mixes

Principles

The electric properties of pastes and mixes change significantly during baking. The test methods should cover the whole process of baking. The determination of resistance is based on the well-known voltage and current measurements. A special resistance meter arrangement is necessary to test the pastes. The instrument contains a cylinder with removable, plunger-like contacts for current connections at both ends and with pins for voltage drop measurements. The cylinder is placed into a thermo-regulated furnace. With this instrument, both the resistance alteration during baking and the resistance of the baked paste can be determined.

Instrument :special resistance meter arrangement,
see Figure 42.
thermo-regulated furnace
stabilised power supply
ampermeter
high-accuracy voltmeter
Personnel : one technician

Procedure, evaluation

Put a paste or mix sample into the test cylinder. Prebake the sample as necessary. Place it into the measuring device and fix the current contacts on the plungers and the voltage contacts on the pins.

Heat up the furnace according to the existing baking profile. Measure and log the current and voltage data.

Prepare and compare the resistance vs. temperature diagrams of the different pastes and mixes.

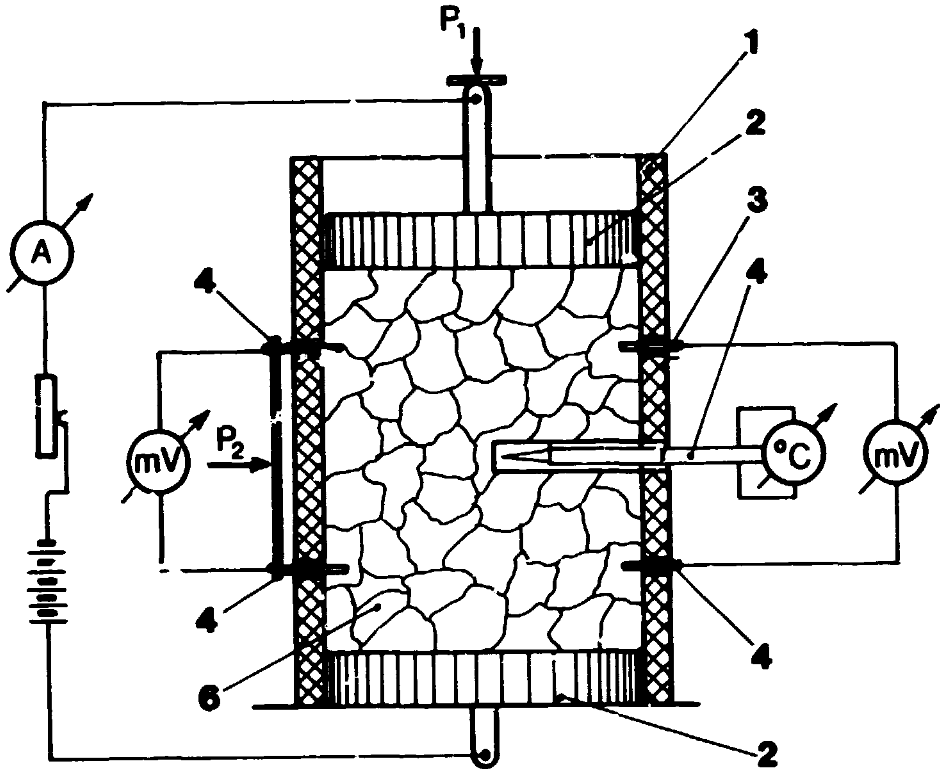


Figure 42.

RESISTANCE METER FOR PASTES

Example

Table 7. demonstrates the measured specific resitance values meanwhile burning for a ramming mix. On Table 8., the measured data for a cathode block sample can be seen.

T(C)		T(C)	
150	25000	635	366
200	18750	710	382
250	11860	820	65
350	5510	930	47
430	3270	1010	41
500	2610	after baking:	
550	1560	20	59

Table 8/A

SPECIFIC RESISTANCE VS. TEMPERATURE DATA FOR A RAMMING MIX

T(C)		T(C)	
20	69.7	610	58.3
215	64.0	710	56.7
310	62.8	810	55.6
450	60.2	910	54.7
525	59.1	1000	54.2

Table 8/B

SPECIFIC RESISTANCE VS. TEMPERATURE DATA FOR A CATHODE BLOCK SAMPLE

5.3.2 Test of Cathode Bar Fixing

Principles

The quality of cathode bar fixing is characterised by the voltage drop or the resistance between the cathode block and the steel bar.

When developing a new fixing procedure, a new ramming mix or a modified bar geometry, it is advantageous to test them in advance. The new development can be tested by the assistance of a small model. This should represent the real arrangement as well as possible. Figure 43.
hows a segment of a cathode block model. The measuring pins are marked.

The standard fixing procedure should be followed by regular resistance measurements. The faulty blocks can be selected, that is, the cathode life may be extended.

A new cathode block fixing is tested below.

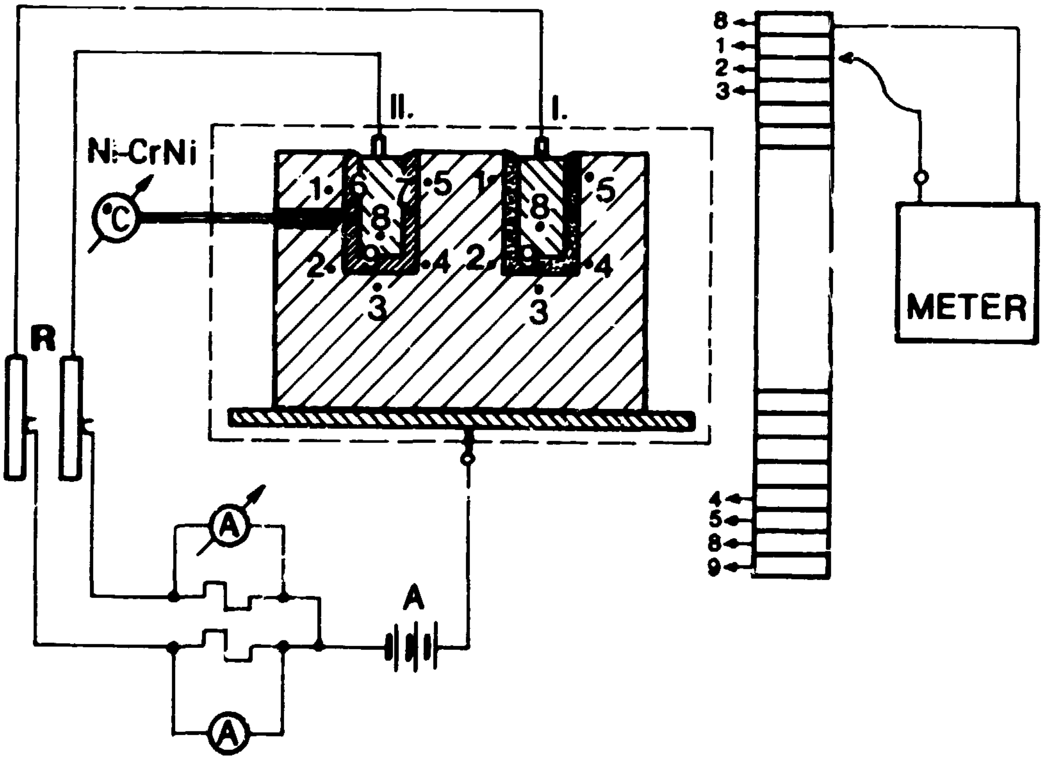


Figure 43. TESTING OF CATHODE BAR FIXING

Instruments :micro-ohm meter
stabilised power supply
ampermeter
high-accuracy voltmeter
thermo-regulated furnace
Personnel : one technician

Procedure, evaluation

Prepare an adequate model of the examined cathode fixing. Check the resitance at selected points during assembling.

Put the model into the furnace and bake it according to the cell start up procedure. Measure the resistance continuously.

The actual cathode block should be similar to the one under operation. Test it again.

Draw a diagram representing the relation between temperature and resistance. Compare the characteristics of different fixing arrangements.

Example

Table 9. demonstrates the measured resitance values for different fixing methods.

Fixing	Resistance		
	500 C	700 C	900 C
Ramming mix (15 mm gap)	14.2	16.5	13.0
Ramming mix (5 mm gap)	11.0	13.5	17.5
Cast iron (10 mm gap)	3.2	7.3	11.3

Table 9.

RESISTANCE DATA OF DIFFERENT FIXING METHODS

5.3.3 Eddy Current Based Measurements

Principles

The specific resistance of anode or cathode blocks can be checked using small samples taken from the blocks. It is preferable to use quick, non-deteriorating methods in industrial practice.

A device called Carbotest has been developed for this purpose. Its operation is based on the eddy current phenomenon. A contact measuring coil, exited by a.c., is placed on the carbon surface. The magnetic field of the coil generates eddy currents in the carbon; the latters change the original electric properties of the coil according to the carbon properties. This device provides quick and reliable checking of natural and synthetic carbonaceous materials.

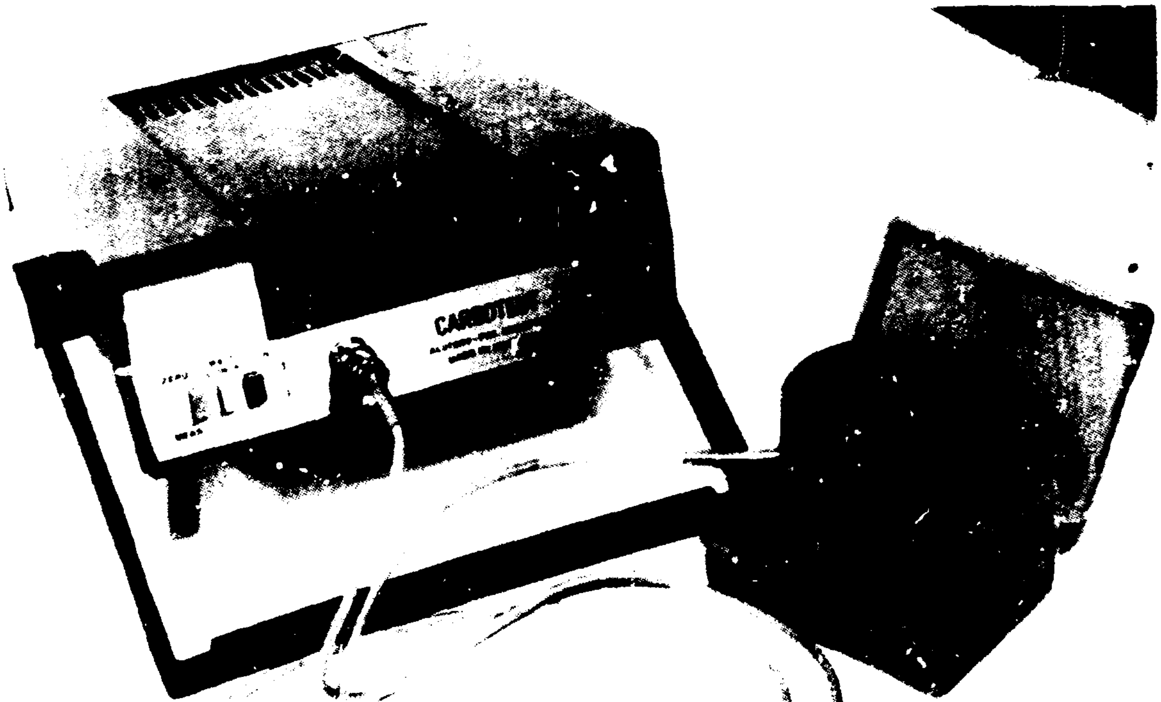


Figure 44. CARBOTEST

Instrument :Carbotest, see Figure 44.

Range	: 15-120
Accuracy	: +/- 5%
Main sizes	: 260 x 200 x 80 mm
Weight	: 2 Kp
Power supply	: four R14 batteries

Personnel : one technician

Procedure, evaluation

Put the measuring coil onto the surface of the carbon block. Read and log the displayed values.

Scan the whole surface and evaluate the homogenity of the block in the direction of various axes.

Select and group the blocks of similar properties for one cell.

Example

Table 10. demonstrates the measured resitance values for cathode blocks of different origin.

Types	Specific resistance
I.	45.5
II.	77.4
III.	73.1
IV.	56.2
V.	46.8
VI.	86.8
VII.	52.3

Table 10.

SPECIFIC RESISTANCE OF DIFFERENT CATHODE BLOCKS

5.4 Measurements in the Molten Bath

5.4.1 Metal Surface Distorsion

Principles

In case of uncompensated magnetic forces, the surface of the molten metal gets distorted. Static distorsion or intensive metal waving may appear.

With the aid of a measuring probe, the voltage drop between the molten metal and the electrolyte can be detected. The metal surface around the anode as well as the waving at a certain point can be scanned. The proper detection needs non-corrosive measuring pins. Measuring between the probe and an electrode put into the molten metal seems to be reliable. The angle and the level of the probe should be measured precisely; a special stand was developed for this purpose.

Instrument	: measuring and reference probes with wolfram pin stand for reliable level determination voltmeter analog recorder
Personnel	: three technicians

Procedure, evaluation

Prepare the measuring places and determine the reference level. Put the reference and the measuring probe into the molten metal.

Rise the measuring probe slowly and measure the voltage between the probes continuously. Read and log the level and the angle data when any time a sharp jump appears in the voltago.

Map the surface distortion around the anode. Check the amplitude of the waving at several randomly selected points and at the corners.

Example

Figure 45. demonstrates the measured surface distorsion in a Soederberg cell.

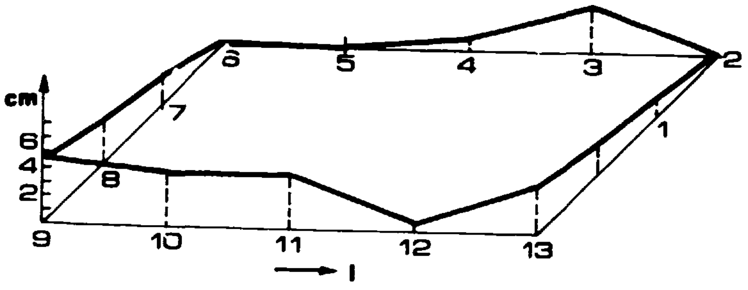


Figure 45.

STATIC SURFACE DISTORSION

5.4.2 Alumina Concentration

Principles

The alumina content of the electrolyte is one of the most important parameters of the process. It is usually determined by laboratory analysis. On-the-spot test of alumina concentration may often be necessary.

Current-voltage relations of the graphite and the molten electrolyte provide the basis to this. The critical current density depends on the alumina concentrattion; the latter is proportional to the maximum current. Based on this phenomenon, a device called Aluminatest has been developed for real-plant measurements.

Voltage rising step-by-step is led through the measuring probe immersed into the electrolyte. Current data are detected and stored, and an electronic device calculates the alumina concentration from the maximum current.

Instrument : Aluminatest with measuring probes,see Figure 46.
batteries
Personnel : two technicians

Procedure, evaluation

Break the crust and prepare the measuring spot. Put the probe into the electrolyte and wait until it warms up.

Start the program then read and log the displayed values. Detect the changing of alumina concentration in connection with the feeding routin.

Remove the probe from the melt and clean it. Repeat the steps at an other cell.

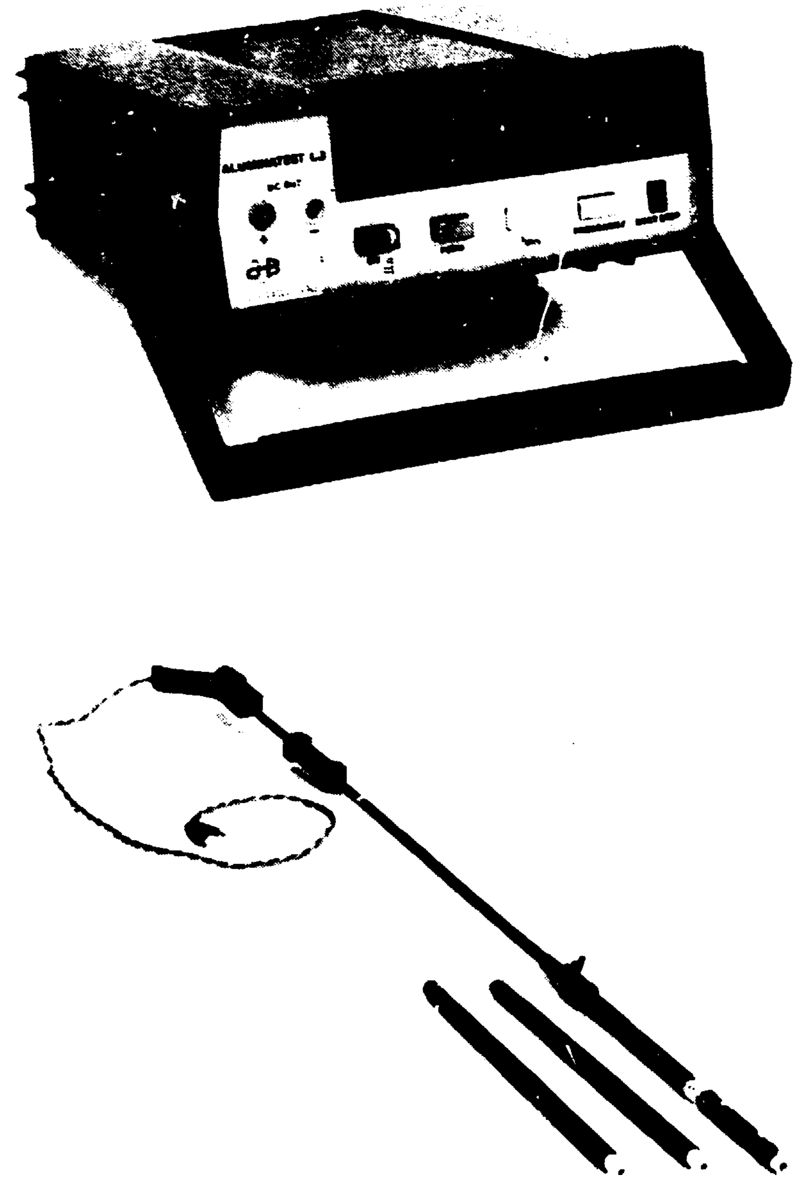


Figure 46.

ALUMINATEST AND THE MEASURING PROBES

Example

Alumina concentration shown on Figure 2. was measured by Aluminatest.

5.5 Control of Operation Conditions

5.5.1 Anode Effect Properties

Principles

Anode effects are regular events during normal operation. At a low alumina concentration of about 2%, the produced gases of isolating properties start to cover the anode surface. The result is a sharp increase in cell voltage.

From a metallurgist's point of wiev, the rising slope of the cell voltage before anode effect is important. Another information about the process is the character of the cell voltage during anode effect.

Based on a desc-top computer controlled data acquisition system, several measurements can be made. Cell voltage and line current data can continuously be measured and stored. Voltage, current and resistance functions can be displayed. In case of an anode effect, a new measuring routin is started. After quenching the anode effect, the main data, such as average voltage, type and duration of the effect, etc, are determined.

Instrument : desc-top computer
isolating unit
multiplexer
A/D converter
printer
plotter
Personnel : one technician

Procedure, evaluation

Supposing that the necessary programs are developed and checked and, moreover, the instruments are properly interconnected, there is no need for trained staff. User-friendly programs help the operator in his work. Events and results are displayed and printed automatically.

Example

Figure 47. shows the resistance vs. time function of a cell when anode effect starts. The anode effect duration can be seen on Figure 48.

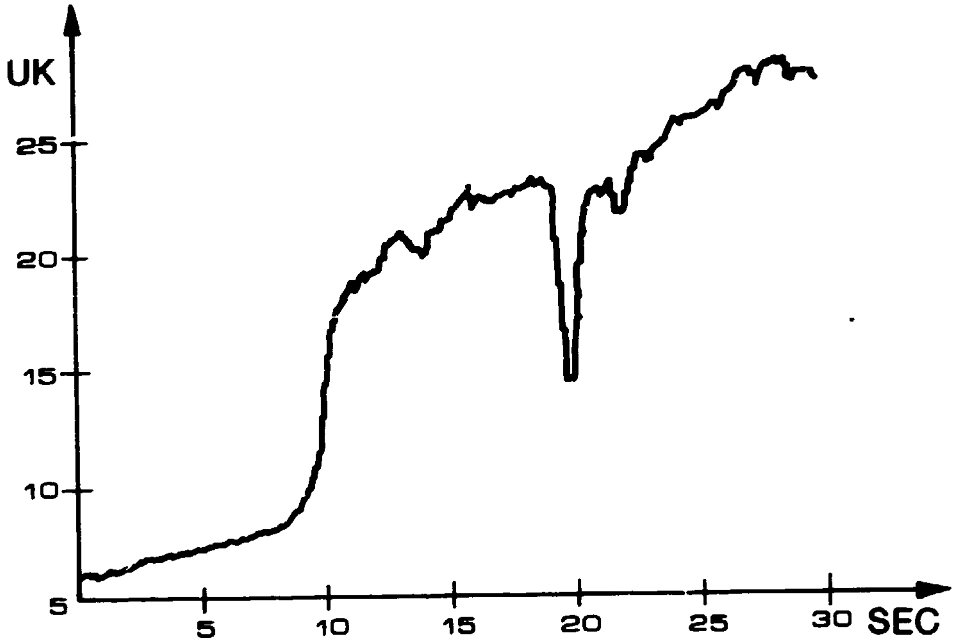


Figure 47. ANODE EFFECT STARTING

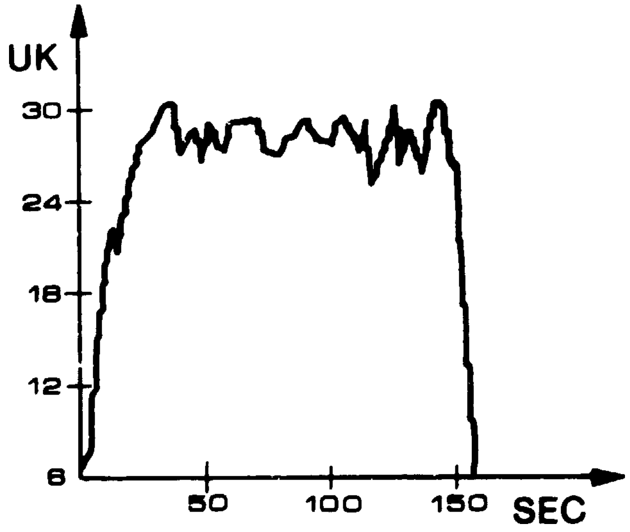


Figure 48. ANODE EFFECT DURATION

5.5.2 Analysis of Cell Noises

Principles

Noises of the cell voltage or the calculated resistance bear information about the process itself. The graphs drawn by analog recorders are excellent for visual analysis. Nevertheless, there is need for numeric evaluation.

Noises could be classified as waves, fluctuation and pulsation. These ,as shown in Section 1.4., indicate the waving melt, gas bubbles in the electrolyte and the anode bottom conditions.

Based on a computer-controlled data acquisition system, noise analysis can be performed. Cell voltage and line current data can continuously be measured and stored. The calculated values are: average, standard deviation, auto- and cross correlation functions, power density functions. Fourier analysis can be made, using DFFT algorithms.

By the assistance of these values, fast real-time subroutines can be developed and run on cell controllers.

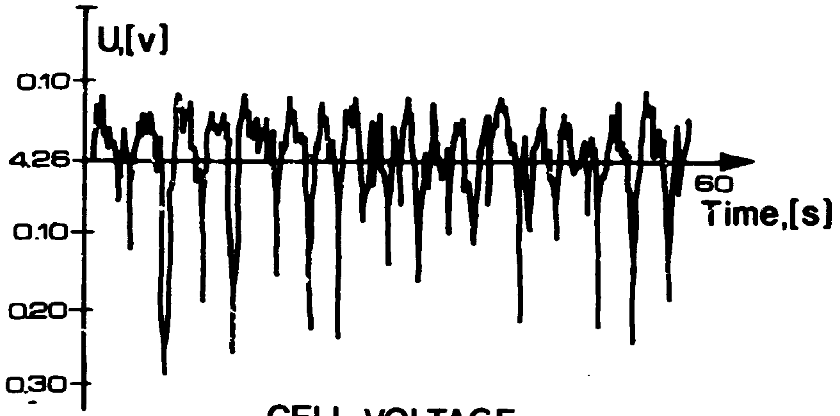
Instrument : desc-top computer
isolating unit
multiplexer
A/D converter
printer
plotter
Personnel : one technician

Procedure, evaluation

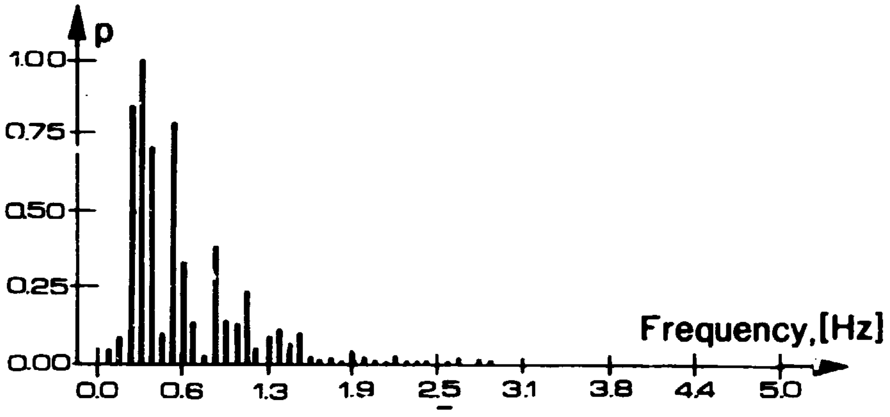
As in Section 5.5.1.

Example

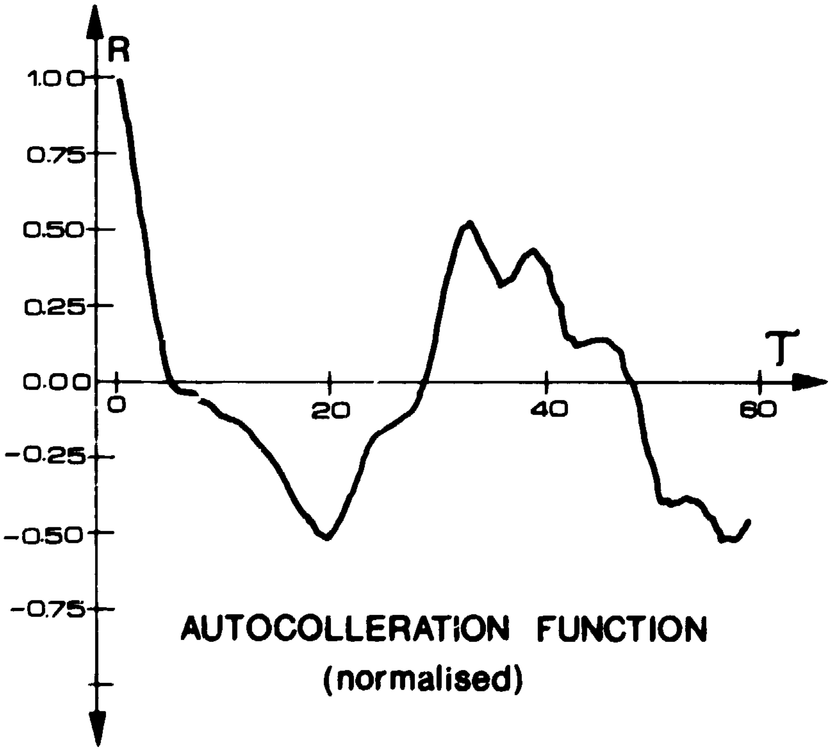
Figure 49. shows the cell voltage as a function of time, the normalised power density function and the auto correlation function for a shaky cell with troublesome anode.



CELL VOLTAGE



POWER SPECTRUM (normalised)



AUTOCOLLERATION FUNCTION
(normalised)

Figure 49. CELL OF ANODE BOTTOM PROBLEM

6. IDENTIFICATION AND MODELING

Identification and modeling are the most important parts of all preparations for process control. Its importance makes it inavoidable that, meanwhile sticking to the usual three-parted structure of "Principles - Experimental - Example", it be explained in more detail.

Unfortunately, any real demonstration of computer models can only be made on a computer. Nevertheless, the structure of a real CAD system is given below; the general subroutines are listed and an actual model for anode voltage drop calculations is detailed.

6.1 Structure of a CAD System

The Computer Aided Design is an effective way of problem solving in general. It involves a unified, modular library of programs. A general organization of an interactive program system is given in Figure 50.

The structure consists of two program packages; the first contains the subroutines for reducing the model order and the second tests the obtained approximations.

The link between the user specifications and the various sets of modules is carried out by means of the Main program and the Choice routin. In the Main program, the original model structure, the approximation degree and specifications for the reduced model can be given.

The Reduction routines are followed by Simulation ones. The results of the different calculations steps can be Displayed and Plotted. Evaluating the results, the designer can modify the model and can continue the procedure.

The structure of this system seems to be applicable for identification, modeling and simulation study in aluminium electrolysis as well.

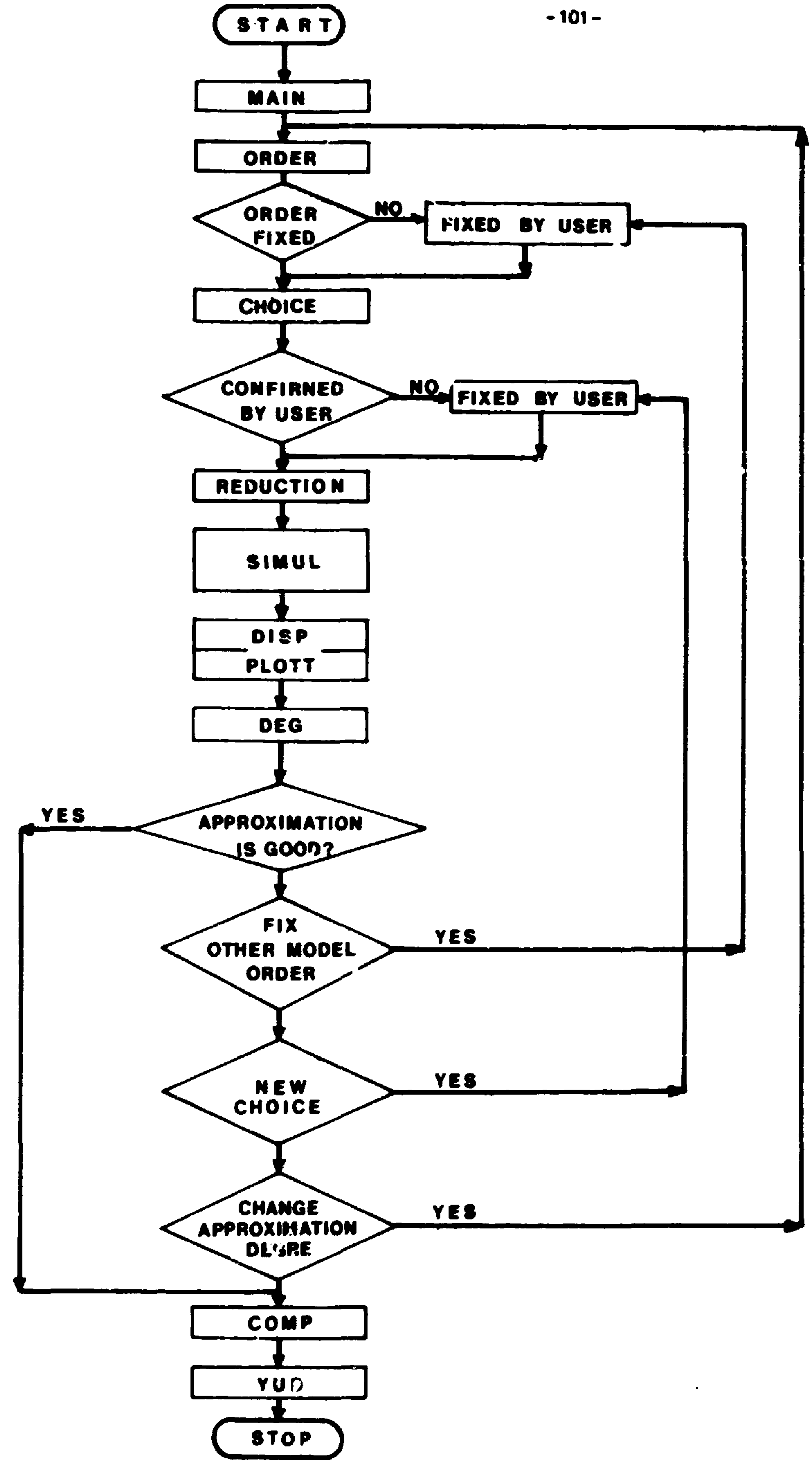


Figure 50. A CAD PROGRAM PACKAGE /Fortuna,1/

6.2 Typical Software Routines

There are program routines which are generally used in computer applications. These form a library and the user may select the necessary ones and link them. The subroutines may vary according to the actual computers, but their character and task are similar.

Program language

The programs are usually written on a high-level language; this helps understanding and modifying. Special simulation languages, sometimes called simulation processors, are developed.

Demands

The whole system should be user-friendly. The interactive problem solution speeds up work, supports the constructor to concentrate on his task itself. The subroutines should be documented exactly, so that error detecting and continuous development be easy.

Input and output

Input and output service routines are the links between man and machine. User's specifications have to be observed. The output may have several formats. Graphic display handling and a plotter are necessary.

Data handling

Data handling should, as a rule, be the best possible. Its choice depends on the actual operating system. Checking and creation of datasets are usually supported by a supervisor. The amount of data may be different with each tasks. Still, numeric calculations require large operating storage capacity.

Pre-processing routines

Pre-processing routines involve data acquisition, digital filters, harmonic analysis and spectral analysis (power spectrum, amplitude spectrum, phase and amplitude tratransfer functions, auto- and cross correlation functions, etc.)

Generation of simulated data

This involves function generation, including sine, pulse, step, ramp and higher degrees, and noise generation, including uniform white noise and gaussian white noise.

Analysis of the model

The analysis requires pole-zero calculation, conversion of discrete model into continuous ones, Bode and Nyquist routines and parameter estimation algorithms.

Literature:

1. L.Fortuna-A.Gallo:

An Interactive Program Package for Linear System Reduction

Preeprints, Vol. VIII. pp.185-189.

IFAC, 9th World Congress, Budapest, 1984.

6.3 Anode Voltage Drop Model

In this Section an anode voltage drop model for vertical stub Soederberg cells is presented. This model is based on a physical approximation. The following groups of parameters are:

Electric and geometric parameters

(i) anode current density
(ii) elecrtric properties of the baked paste
(iii) cross-section of the anode stubs
(iv) number of the stubs
(v) distance between stub and anode bottom
(vi) number of stub levels
(vii) distance between stub levels
(viii) distribution of the stubs

Thermal properties

(i) temperature distribution inside the anode
(ii) profile of the isothermic layers
(iii) temperature of the anode top
(iv) place of the 400 C isothermal layer (baking)
(v) ratio between the amount of heat generated in the anode and convected from the melt
(vi) heat-flux in the anode
(vii) thermal conductivities of carbonaceous materials during use

Technological aspects and cost factors

(i) quality of the raw materials
(ii) cost of a new stub, cost of renewal
(iii) cost of stub pulling

(iv) amount of gases released from the anode
(v) mechanization conditions
(vi) specific anode paste consumption

The anode voltage drop describes the anode quality; it is an important element in eiither voltage balance or thermal calculations. In the industrial practice, it is a measured data. What with the surface of the anode bottom being far from equipotential, several measurements have to be made and their average accepted as anode voltage drop. It seems to be useful to calculate the voltage drop in order to get more precise data. The calculations presented below are used in real examinations.

Preliminary assumptions

(i) rate of the current flowing through a certain stub is a function of the distance between the bottom of the stub and the 650 C isothermal layer
(ii) the anode paste starts to conduct at the 650 C isothermal layer
(iii) the current distribution around the stub can be mathematicallly approached by an ellipse-shape; the latter is determined by the length of the stub in the conducting layer and by the radius of the area supplied
(iv) the surface of the supplied area is proportional to the current passing through the stub
(v) the real current distribution accords to the geometric arrangement

(vi) there is only vertical heat flow
(vii) the arrangement of the stubs is ideal, meets the temperature distribution of the central line
(viii) the amount of heat, conducted by a stub, is independent of the actual current load
(ix) the anode voltage drop is considered as the ratio of the power loss inside the anode and of the line current

The sequence of calculations

(i) thermal distribution in the anode
(ii) power loss inside the stub
(iii) power loss in the contact layer between steel and carbon
(iv) power loss in the carbon
(v) total power loss
(vi) determination of the anode voltage drop

Structure of the computer program

(i) input of geometrical, thermal and specific data
(ii) calculation of the heat-flux at the anode top
(iii) calculation of the thermal distribution
(iv) calculation of the anode level
(v) current load in the stubs of different levels
(vi) power loss in the anode
(vii) voltage drop in the anode
(viii) checking the specific power loss in different stub levels
(ix) printing the results
(x) start of a new calculation

Application of the results

With the aid of this model, the following extexaminations can be made:

- (i) calculation of the anode voltage loss for any structure
- (ii) checking voltage losses for a modified stub level distribution
- (iii) calculate the current-load alteration of the stubs between stub pullings
- (iv) calculate the voltage rise after a pulling procedure

Figure 51. demonstrates the results of a detailed calculation.

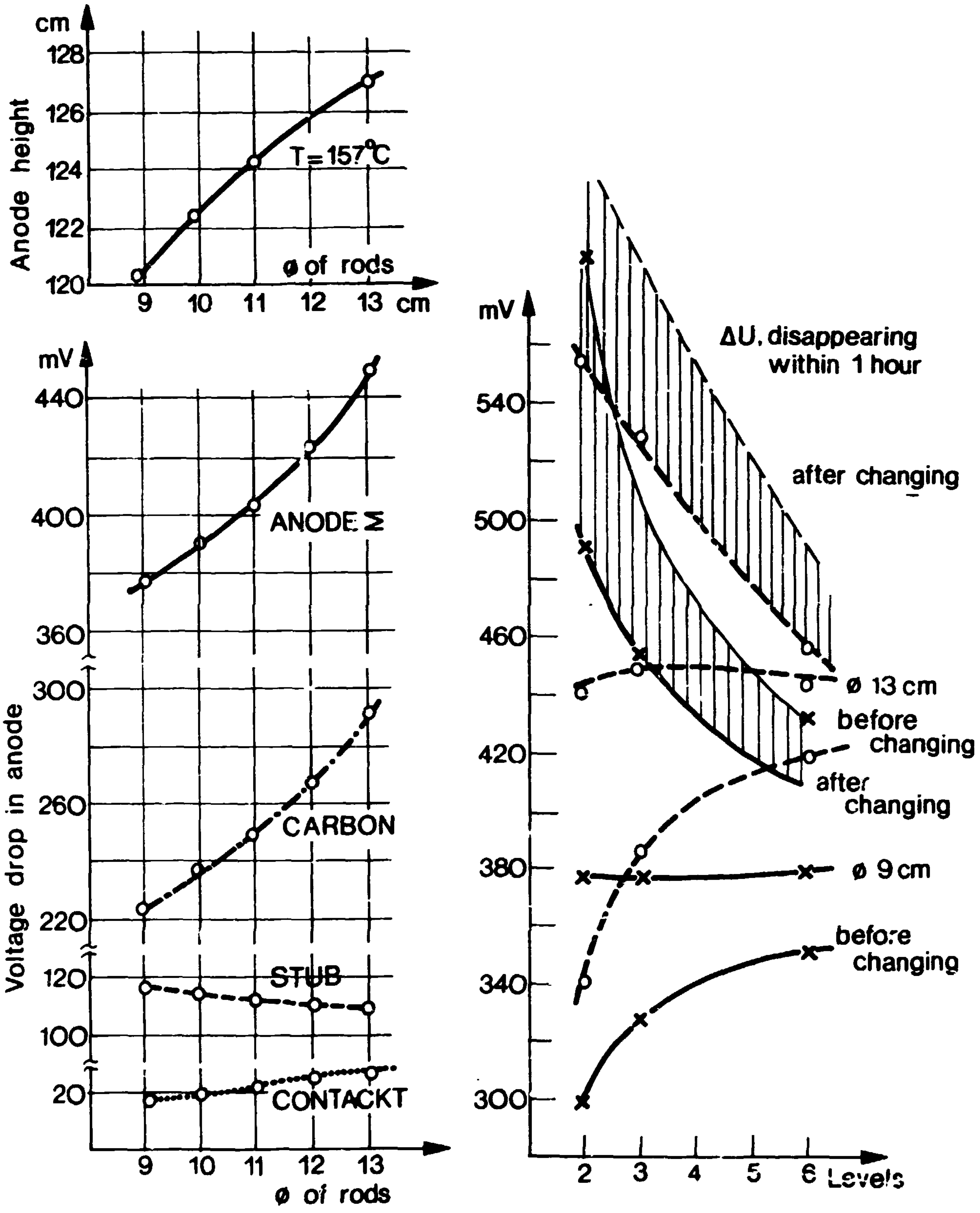


Figure 51. ANODE VOLTAGE DROP CALCULATIONS

7. ELECTROMAGNETIC MEASUREMENTS AND CALCULATIONS

7.1 Magnetic Induction Measurements in the Molten Bath

Principles

In aluminium electrolysis cells, the high current generates a strong magnetic field. When a Hall-detector is put into the magnetic field, the voltage appearing between the boundary layers is proportional to the magnetic field.

An instrument containing a set of Hall-detectors is developed. The temperature of the probe has to be kept under 40 C. Cooling or excelent heat-insulation is necessary. Non-ferromagnetic stainless steel covering or graphite crucible is needed to eliminate the effect of the corrosive melt.

Instrument : three axis magnetometer
Hall-probe rod
electronic anglemeter
cheramic thermal insulating cylinder
graphite crucible
steel stand
Personnel : four persons are necessary

Procedure, evaluation

First, make holes in the crust where measurements are planned. Ten points on each long side and two points on each short one are usually measured.

Push the graphite crucible into the electrolyte; the bottom of the crucible should reach down to the metal layer.

Fixe the stand to the rim of cathode shell, and fixe the haft of the graphite tube to it. Slip the Hall-probe into the cheramic thermal insulating cylinder, and put them into the graphite crucible.

Read the displayed components of the magnetic field. Check the temperature of the Hall-probe meanwhile measuring regularly.

Pull out the cheramic cylinder with the probe inside from the crucible then the probe from the isolating tube and let them cool. Slip the anglemeter rod in the graphite crucible and log the displayed value.

Pull out the graphite crucible with a great care. Strong mechanical effects may damage it.

Repeate these steps at the marked points.

Evaluate the results, calculate the stability of the cell according to Section 7.4.

Example

Table 11. demonstrates data measured in a Soederberg cell. Set of Hall-probes was lowered into the molten metal. The measured points are outlined.

```
               ----------------------!
              1   2   3   4   5      !
            ---------------------    !
      12/a *!                   !6/a ----
            !                   !
      12/b *!                   !6/b ----
            ---------------------    !
              11  10  9   8   7      !
               ----------------------!
```

Place	Components (mT)		
	B(x)	B(y)	B(z)
1	-5.8	4.0	1.1
2	-4.0	4.5	2.1
3	-2.1	5.8	-0.3
4	-0.5	5.6	-1.5
5	1.2	6.9	-2.4
6/a	4.2	3.4	-1.5
6/b	4.1	-0.7	-1.4
7	3.5	-5.7	-0.7
8	1.4	-6.0	-4.1
9	0.7	-6.1	-3.5
10	-2.9	-4.7	-4.9
11	-3.7	-4.1	-6.0
12/a	-12.9	-1.1	1.1
12/b	-13.0	-2.1	-4.8

Table 11.

INDUCTION COMPONENTS IN A SOEDERBERG CELL

7.2 Magnetic Induction Measurements in the Air I.

Principles

Magnetic field is also significant in the vicinity of the cell. Measuring principles and the developed instrument are the same as for measurements in the melt. There is no need for special protection. Cooling is much more simpler than it was in the melt.

Instrument : three axis magnetometer
Hall-probe rod
cheramic thermal insulation cylinders
auxiliary measuring rods
Personnel : three person are necessury

Procedure evaluation

Mark the measuring points around the cell on the floor. Prepare the auxilary measuring rods. Fixe the Hall-probe on the auxiliary rod. Stand it into the proper position at a marked point. Measure in the selected levels. Read and log the displayed components of the induction.

Represent the results in different projections.

Example

Some parts of a measurements are demonstrated on the following Figures. Data refer to ground level. Figvre 52. shows the induction vector projected to the x-y plane and Figure 53. shows the vertical component of the induction.

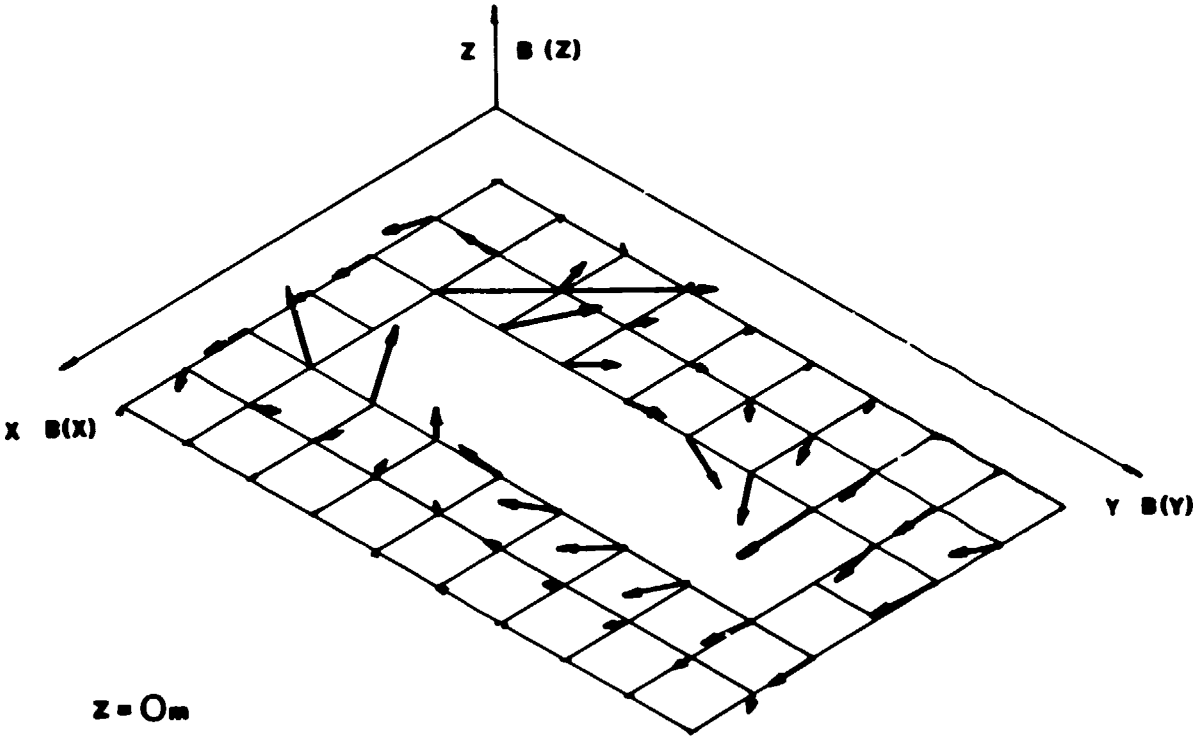


Figure 52.

INDUCTION COMPONENTS AROUND A SOEDERBERG CELL I.

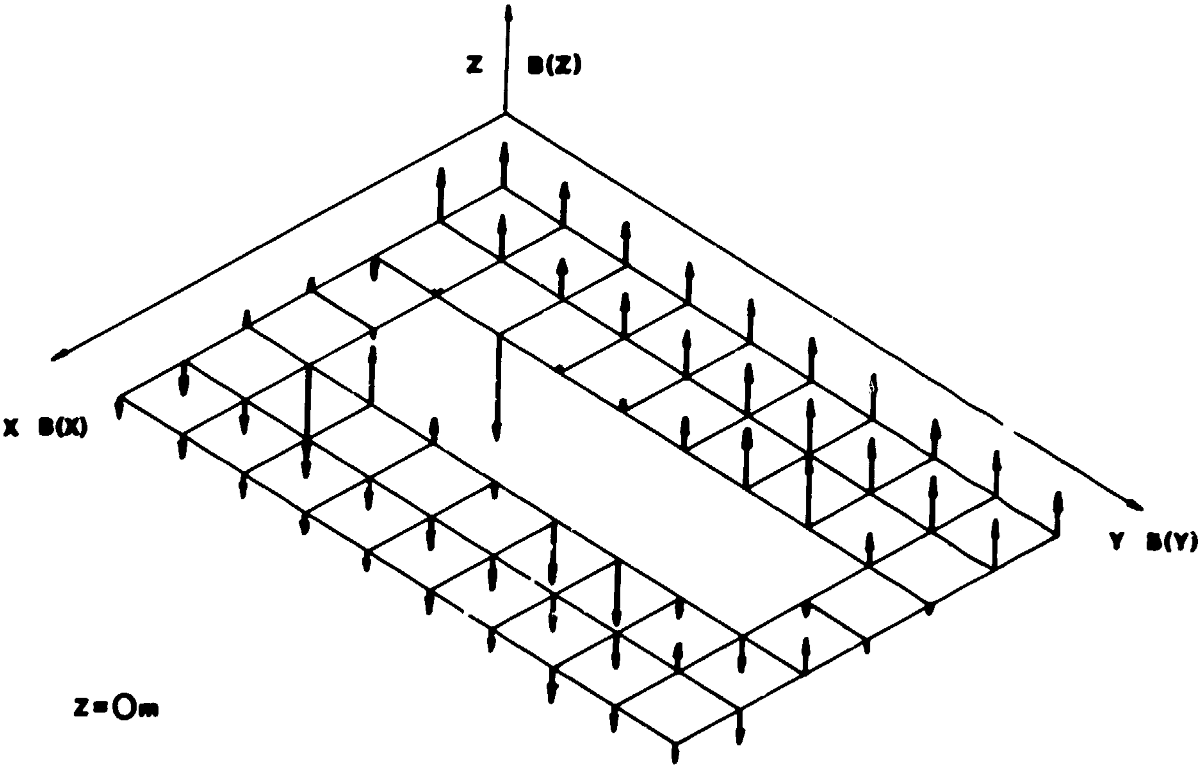


Figure 53.

INDUCTION COMPONENTS AROUND A SOEDERBERG CELL II.

7.3 Magnetic Induction Measurements in the Air II.

Principles

Principles are the same as in Section 7.2. Magnetic measurements at different places of the potroom, far from the cell are sometimes necessary. Such types of problems may be:

-interactions between cells or lines

-influence of the magnetic field on electric devices

-electromagnetic interferences with microwave remote control

Instruments and personnel are the same as in Section 7.2

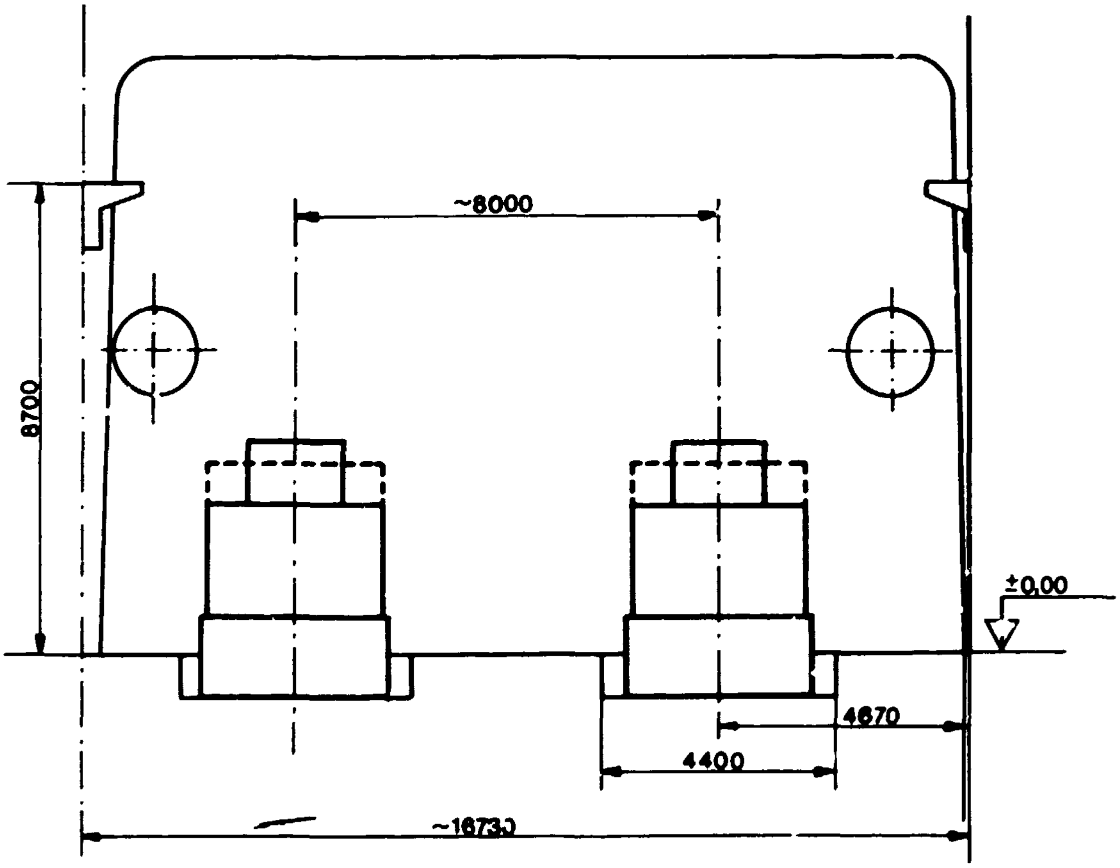


Figure 54.

CROSS-SECTION OF A POTROOM

Procedure, evaluation

Mark the points where the induction has to be measured and follow the steps detailed in Section 7.2. Represent the results in different projections.

Example

Figure 54. shows the cross section of a potroom. Measurements were done in the whole cross section, from the ground level up the height of 6 m. The measured data are demonstrated on Figure 55.

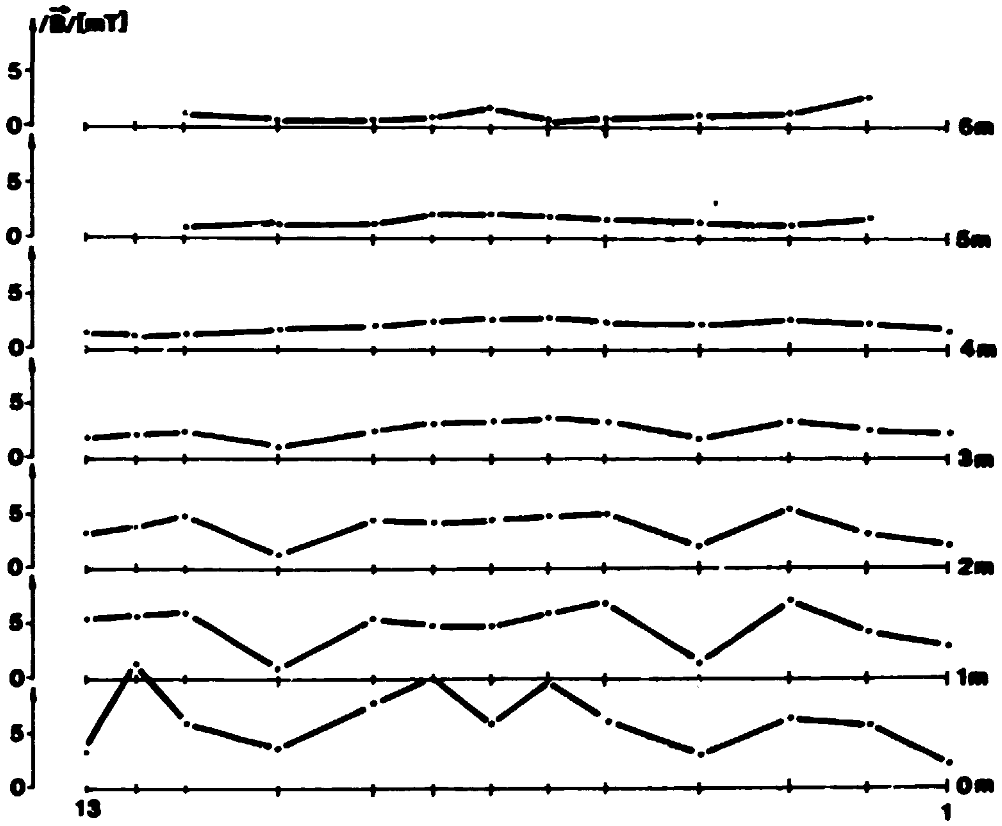


Figure 55.

INDUCTION COMPONENTS IN THE CROSS-SECTION OF A POTROOM

7.4 Calculation of Cell Stability

Principles

It is of a great interest to estimate the stability limit of an electrolysis cell on the basis of the main technological parameters. An empirical formula for stability calculation by T.Sele is presented here. The simplified mathematical formula is :

$$(D+D_0)\cdot H_M > A\cdot B_z\cdot I_s \qquad (7.1)$$

where

D : anode-cathode distance, (m)

D_0 : equivalent "anode" distance, (m)
0.04 m for prebaked cells and
0.036 for Soederberg ones

H_M : metal height, (m)

A : $5\cdot10^{-6}\,(m^2/\text{Gauss}\cdot\text{kA})$
empirical constant

B_z : mean aritmetical value of vertical magnetic field under the anode, (Gauss)

I_s : serial current, (KA)

The cell is in a normal operation mode when the inequality is fulfilled.

Calculation example

Calculate the stability of a Soederberg cell. Let the technological parameters be the followings :

D = 0.04 m
D_o = 0.036
H_M = 0.28
I_s = 80 KA
B_z = 23 Gauss (mean value)

Calculating by the given formula, the left side gives 0.021 ,and the right one is 0.0092 . That is, the cell is stable in this mean.

Literature

T.Sele :
Instabilities of the Surface in Electrolytic Cells
Proceedings, Vol.I., pp.7-24.
AIME Light Metals Annual Meeting,Atlanta, 1977.

APPENDIX

Basic Instrumentation of an Electrical Measuring Group

Basic Electric Instruments

1. Digital multimeter	AC/DC voltage,current, resistance measuring 10 uV-1000 V 10 mOhm-1 MOhm
2. Portable multimeter	100 mV-600 V 0.2 A-10 A
3. Universal measuring bridge	
4. Function generator	0.01 Hz-10 MHz 0.01 V-110 V sine,triangle,rectangular
4. Double beam storage oscilloscope	0-25 MHz max. input 100 V
5. Double power supply 2 x 0-2A	2 x 0-40 V
6. Auto transformators	
7. Isolation units	up to 50 channels
8. R-L-C sets and standards	
9. Thermostat	

Recorders

1. Analog recorders	
2. Multiline recorders	4-6 channels
3. X-Y recorders	0.2 mV/cm - 20 V/cm A3 writing surface
4. Point recorders	6-12 channels

	for thermocouples
5. Analoge - digital tape recorder	4 channels 4-6 hours
6. Cassete data recorder	7 channels 0 - 5 KHz 4 speeds

Digital Test Instruments

1. Microprocessor development system	32K ROM,Prom
2. Logic analyser	multi channel
3. Logic probe, logic pulser	
4. ROM emulator	
5. ROM eraser	

Complete Measuring Systems

1. Real-time signal analyser	Dc-100 KHz up to 200 channels
2. Automatic data acquisition and analysing system	A/D inputs and outputs
3. Infrared thermovision system	
4. Desc-top computer	with standard interfaces
5. Printer	
6. Plotter	
7. Graphic digitiser	
8. I/O modules	

Special Instruments for Potroom Measurements

1. Current distribution meter (Rogameter)

2. Specific resistance meter for carbonaceous materials (Carbotest)
3. Alumina concentration meter (Aluminatest)
4. Magnetic induction meter
5. Electrolyte temperature meter 900 - 1000 C
6. Infra-red tele-thermometers
7. Thermo-couples,thermo-elements
8. Heat-flux meter
9. Thermal conductivity meter
10. Air-flow meter

Transport

1. Trolleys
2. Measuring containers
3. Mini bus