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EXPERT SYSTEM FOR SØDERBERG ELECTRODES

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ABSTRACT

The expert system developed for the selfbaking Søderberg electrode, named EKSODUS, is a collection of rules and experiences from many years of electrode operations by experts in the field. Measurements and model simulations have also been useful.
After a computer has guided the user through a series of questions, the expert system can, in most cases, find a reasonable cause of electrode breakages and present the conclusion in a report. In addition, the problem of an irregular electrode consumption is included, but with less accuracy due to limited knowledge.
The expert system may also be used to investigate the effect of changes in electrode operation, paste and equipment, and thus lead to improved electrode performance.

INTRODUCTION

Programme

EKSODUS, ElKem SOederberg Diagnose Utviklings System, is an expert system where the main goal is to diagnose the causes of breakages and irregular consumption of Søderberg electrodes by others than "electrode experts". The results are obtained through a kind of dialogue, where a computer is asking the user for information and then the system draws the conclusions.

The Level5 Object programme from Information Builders, Inc., New York has been chosen for EKSODUS. Windows 3.1 is required. The system can be run on an IBM compatible PC of type 386 or higher with 4 MB RAM. However, a few MBs are also needed for the programme and the various files.

The original EKSODUS was developed in 1991 as the diploma work of three students from Agder College, Kristiansand with personnel from Elkem being responsible for the expertise (see FIG. 1).

Later, the expert system has been modified and further developed by Elkem. Better data have been put into the newest version of Level5 Object, and the reporting has been improved. Today the system is easy to use. A certain introduction is, however, necessary.

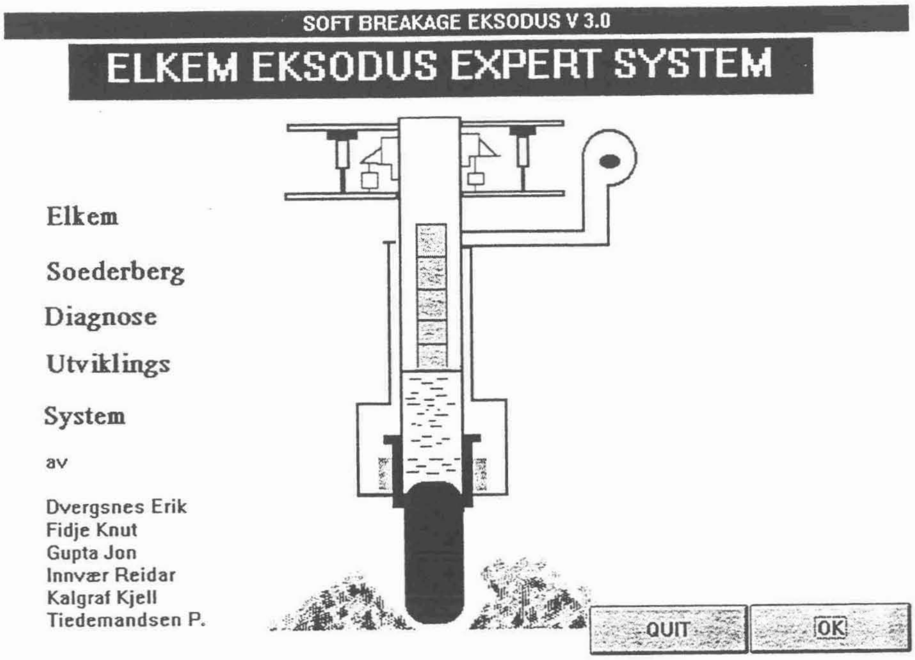


FIG. 1.
EKSODUS

Problems to be solved

Even if the Søderberg electrode basically is produced in the same way as when it was invented 75 years ago, the dimensions and current load have increased considerably. Today electrodes of 2 m in diameter and with current exceeding 150 kA are in operation.

Unfortunately, on most smelting furnaces electrode problems will occur from time to time. It may be a breakage of the electrode column or an uncontrolled electrode consumption, as shown in FIG. 2. Such an occurrence may itself have great economic consequences, but normally the loss of furnace production is most costly.

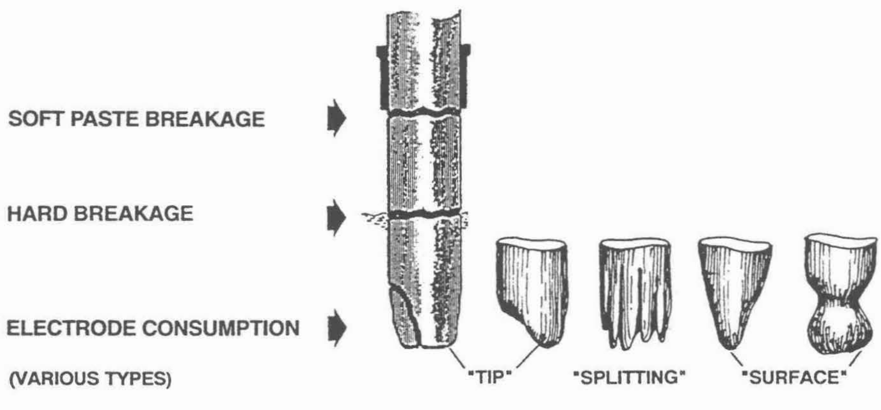


FIG. 2. Main Electrode Problems

A furnace will of course be operated in accordance with adopted procedures and instructions. Much effort is also made to achieve good maintenance and thus reduce undesired furnace shut-downs. Such stops are the main cause for breakages, due to the transient conditions developing high thermal stresses. Often, there is a compromise between a high furnace production - with an increased load on the electrodes - and a possible risk of electrode failures.

In some cases it may be difficult to solve electrode problems. Elkem may use the furnace operators, personnel from Elkem Carbon, Elkem Technology or Elkem Research. The method chosen depends on the cause suspected in the electrode operation, the paste or the equipment, all fundamental factors for a favourable electrode performance.

In most cases, however, it is possible to locate the cause of the problem. The adopted procedures are not followed or the operation exceeds recommended limits. This knowledge is the background for the EKSODUS expert system, which can offer answers just as effectively as the electrode expert.

THE EXPERT SYSTEM

Structure

EKSODUS consists of four modules, as shown in FIG. 3. There is one module for each type of problem to be solved, combined with one database module for handling of the necessary customers, furnace and electrode data, and for storing of reports.

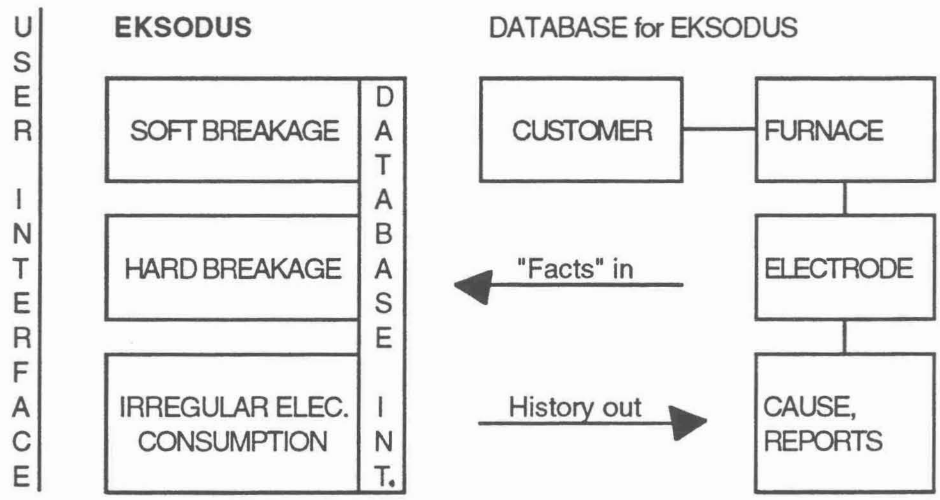


FIG. 3. The Expert System Structure

Soft Breakage

General

In modern electrode operation the very serious problem of soft paste breakages will seldom occur. However, should they do so, the cause can in most cases be given.

The expert system uses the same problem solving procedure as that applied by the expert in real life - one or up to three different areas of concern are possible to choose: slipping rules, casing design rules and other possible factors.

Slipping Rules

It is primarily the heat generation caused by the current which assures the baking of the electrode paste. There must therefore be a definite relation between slipping rate and electrode current. The actual slipping, often called the slipping index, can then be expressed as : mm/A^2h.

The slipping index for each electrode should have a fixed value, kept as constant as possible, and with an absolute maximum limit. If the electrode is operated with a slipping index exceeding this fixed limit, the baking zone (500°C) will move below the contact clamps and a soft breakage may occur. This occurrence is seen from FIG. 4 and is the first step in the strategy of diagnosing a soft breakage.

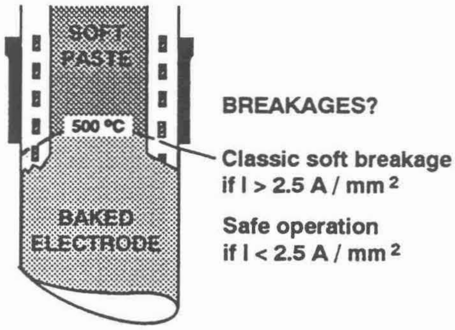


FIG. 4 Soft Paste Breakage due to Low Baking Zone

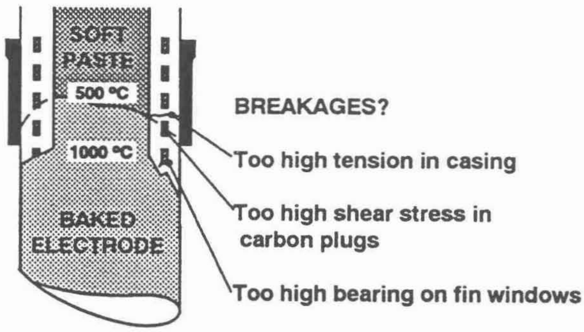


FIG. 5 Soft Paste Breakage due to Unfavourable Casing Design

The expert system uses the same procedure. The slipping rules are checked in order to determine the position of the baking zone by comparing the computed slipping index (from applied current and slipping rate) with the index (from data base) accepted for the electrode in question. Exceeding the fixed limit indicates a "classic soft breakage".

A possible uncontrolled slipping or sliding of the electrode column is an additional test. Furthermore, the current carrying capacity of the electrode casing alone is controlled. If the electrode current, I, is below 2.5 A/mm^2 casing cross-section, the position of the baking zone is in most cases of minor importance (see FIG. 4). Such operation is utilized in several processes, e.g. in slag smelting [1].

Casing Design Rules

If the baking zone has a normal position in the contact clamps (slipping index below fixed limit), as shown in FIG. 5, there must be another cause for a possible soft breakage. The strength of the electrode casing will be controlled both by expert personnel and the expert system. Large deviation in the construction from a normal casing design, combined with a very heavy electrode, may lead to a special type of soft breakage where the baked carbon is not sufficiently anchored in the casing.

FIG. 5 shows three casing areas to be computed :

- The fins (casing) are meant to serve as suspension for the carbon part of the electrode and must therefore have sufficient tensile strength in the baking zone region, before the carbon material obtains its strength. The joints between the casing sections can be a problem since they may weaken the casing column. Welding techniques/ methods and possible fin overlap in the joints are taken care of in the evaluation.

- The fins should be well anchored in the baked paste, which is mainly taken care of by the use of fin windows. In this connection the shear stresses in the carbon plugs of the fin windows are calculated. The contact area between the baked electrode and the steel casing before it loses its strength and melts - within a temperature range of about 500°C to 1000°C (FIG. 5) - must be given in order to determine the plug area. The band width can be found from measured (during actual operation) or computed (with mathematical models) isotherms, or simply estimated from experience.

- The lower edge bearing strength of the fin windows - equipped with possible flaps - is also calculated. In order to find the number of windows and the critical cross-section for the calculations, the above-mentioned temperature band must be given.

Exact calculation of the casing strength is impossible to obtain based on the description given above. Uncertainties are introduced. The values computed in the system are compared with the limits of the material strength from the literature. To compare the results with experience from casings in actual operation is also an important control of the reliability.

Other Possible Factors

Other factors than electrode current and slipping rate can also, to some extent, affect the baking process, and the slipping rules should be adjusted accordingly [2].

In EKSODUS the following factors influence the "baking quality" :

- paste charging routine
- soft paste level
- paste segregation
- long and forced electrode slipping
- slipping increment
- clamp coolant temperature
- casing fin overlap

If one or a combination of several of these factors are outside normal operating procedures or limits, a reduced slipping index is required in order to operate safely with the baking zone in the holder. The computer asks for the conditions and corrects the fixed slipping rules before testing with new limits.

Report

If the information given to the system exceeds a limit and a breakage is indicated, the programme will not go further and search for other solutions, but end with a report.

A report on a 1.7 m diameter electrode in the ferrosilicon production, where the slipping rules have been exceeded, is shown below.

Customer No.......: 1
Customer............: Elkem Standard
Furnace No.........: 10
Process type.......: FeSi 75%
Electrode diam....: 1.70 m
Breakage date...... 06/06/94
*************Reason List************ ****** Limits ** *****
Report from Soft Breakage
*
Computed slipping index=$2.53 \cdot 10^{-9}$ mm/A^2 h $2.24 \cdot 10^{-9}$ mm/A^2 h
*
Major cause: * The current exceeding the casing capacity
Major cause: * The baking zone was under the contact clamps
*

Hard Breakage

Methods

Breakage in the baked electrode part is normally the most common electrode problem. About 90% of these breakages are connected to furnace shut-downs. Therefore, the system focuses on the shut-down conditions involving the main factors shown in FIG. 6.

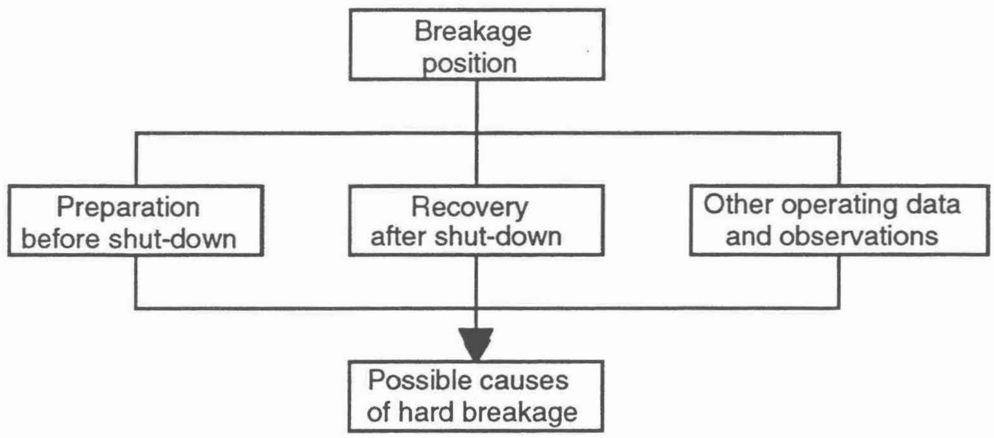


FIG. 6 The Hard Breakage Structure

"Preparation before shut-down" takes care of the following parameters: Shut-down time, current reduction, electrode slipping rate and if the shut-down is expected or not. "Recovery after shut-down" is related to the shut-down time and the electrode diameter. It is important to know "Breakage position" in order to judge if a normal thermal stress failure has occurred. In many processes the most critical breakage area is close to the furnace charge level.

The information will be compared with recommended shut-downs stored in the database. These recommendations are based on experience from operating electrodes and also calculations of thermal stresses with mathematical models. Results from such shut-down calculations are listed in Table I below.

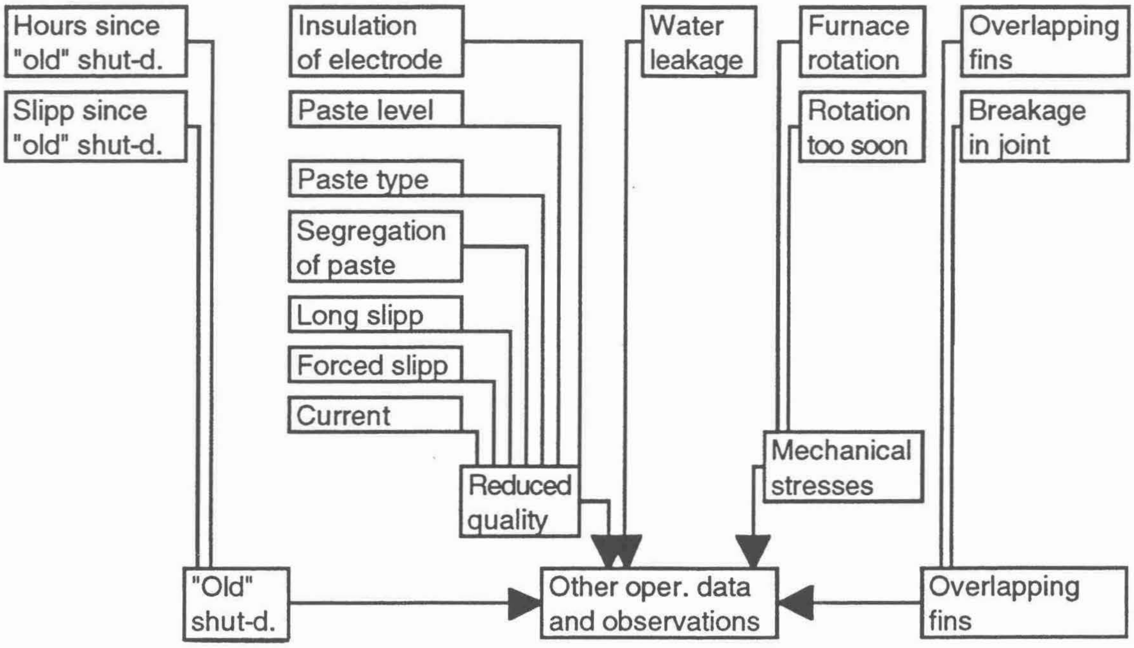
TABLE I. COMPUTED THERMAL STRESSES DURING FURNACE SHUT-DOWN

Standard case: 1.7 m dia. electrode, 6 hour shut-down and 6 hour recovery.
Normal charge level. Current 140 kA and slipping 0.6 m per day before stop.

Electrode conditions, changes from standard case	Stresses *
Standard case	4.1
Electrode current: 100 kA	2.4
Electrode slipping rate: 0.2 m per day	4.6
Current recovery: 1 hour	3.6
Thermal insulated electrode flank during shut-down	3.1
12 hour shut-down, 12 hour recovery	4.8
12 hour shut-down, 6 hour recovery	5.3

* Tensile stresses in longitudinal electrode direction, N/mm^2

"Other operating data and observations" will be the next step to diagnose the breakage. The possibility of a breakage not related to furnace shut-down is also taken into account. Factors to be examined are shown in FIG. 7.



"Old" shut-d. is a possible, second last shut-down within reasonable time before breakage.

FIG. 7 Factors not related to Shut-down affecting Hard Breakages

Report

Based on all the information, EKSODUS will finally produce a report indicating the causes for a hard breakage. Below is a typical report from a breakage.

Customer No...: 1
Customer........: Elkem Standard
Furnace No......: 10
Process type...: FeSi 75%
Electrode No...: 1
Breakage date.: 06/06/94
****

Report from Hard Breakage

*

There has been an unexpected shut-down
The shut-down length was 12 hours
A water leakage was registered near the actual electrode
The restart period to reach normal load after shut-down was 4 hours
The right length of the restart period should be between 9 and 11 hours
The electrode flank was not sufficiently covered during the shut-down

*

The breakage was located to the stress zone before the restart

*

Irregular Electrode Consumption

General

Consumption data in various processes and furnaces show great variations, which indicate that there may be a large potential at some plants concerning optimal electrode operation [1]. However, it is difficult to pinpoint a clear connection between the consumption and the various operational parameters, even if they may be supervised by computers. One explanation is that a (large) consumption may often be retraced to several causes.

In the expert system the consumption diagnosis divides the rules into the areas where the usage probably has taken place : at the electrode tip, electrode splitting or surface losses (see FIG. 2).

Furthermore, the user of the system has to answer questions about details within each area, indicate known factors that have changed, or indicate all factors of interest. The purpose is to collect information about the size or the changes of important operational parameters. The system will also record if the new condition is periodical or constant. The information will be included in an evaluation of the parameters, where the irregular data are compared with "normal" data stored in the database.

Electrode Tip Consumption

Relevant mechanisms are as follows : oxidation and other chemical reactions, evaporation/sublimation at the electrode spots, splitting (due to thermal shocks), arc and slag erosion. The consumption occurs as a continuous process, with periodical variations.

Electrode conditions and questions about them are important factors in this connection. New factors can easily be added to the existing :

- electrode current
- current variations
- furnace shut-downs, etc

Furnace conditions will also affect :

- carbon stoichiometry
- segregations of raw materials
- changes in raw materials, etc

Electrode paste quality :

- electrical resistivity
- modulus of elasticity and tensile strength
- reactivity of electrode carbon, etc

Electrode Splitting

Splitting with fracture of the baked column can normally be explained by : thermal stresses, mechanical forces and erroneous operation. This type of consumption will usually occur spontaneously.

Factors to be examined :

- current variation / furnace shut-downs

- visible horizontal cracks in baked electrode
- casing fin overlap and cavities because of fins
- brittle electrode

Surface Losses

Consumption from the electrode surface is due to oxidation, which normally is a continuous process.

Factors of interest, varying much from one smelting process to another :
- even surface oxidation
- necking or pencil shape
- changes in gas or slag composition
- changes in gas velocity

Report

The conclusions are reported (see example below). Here the importance of each parameter of interest is judged by giving different "weight" ; a large number means a great effect on the consumption, because exact information is not available. In most cases, several furnace conditions change at the same time. However, it is well known that the carbon content in the furnace charge is closely connected to the consumption. Consequently, this content should be carefully watched.

```
Customer No....... 1
Customer............: Elkem Standard
Furnace No.........: 1 0
Process type.......: FeSi 75%
Electrode diam....: 1.70 m
Date.................... 06/06/94
**********************************              ******  Weight  *******
Report from Irregular Consumption
*
Variation in electrode current more than 10%            40
Two furnace shut-downs the last 24 hours                20
     Shut-down times: 60 min, 110 min
Fix C is more than 4% under normal                     100
Segregation in the furnace has occurred                 40
Changes in the raw materials have occurred              40
    The changes have been: Reduced grain size
Electrical resistivity is greater than 80 µΩm           30
Modulus of elasticity is greater than 3.8 kN/mm²        30
*
```

Database Management

The database stores the customers, furnaces, electrodes, and relevant breakage reports. The database has the layout of a dBaseIII database, and this format is supported automatically by Level5.

New records for customers, furnaces, and electrodes may be added, or old ones deleted, whenever needed. Other possibilities with the database are indicated in FIG. 8.

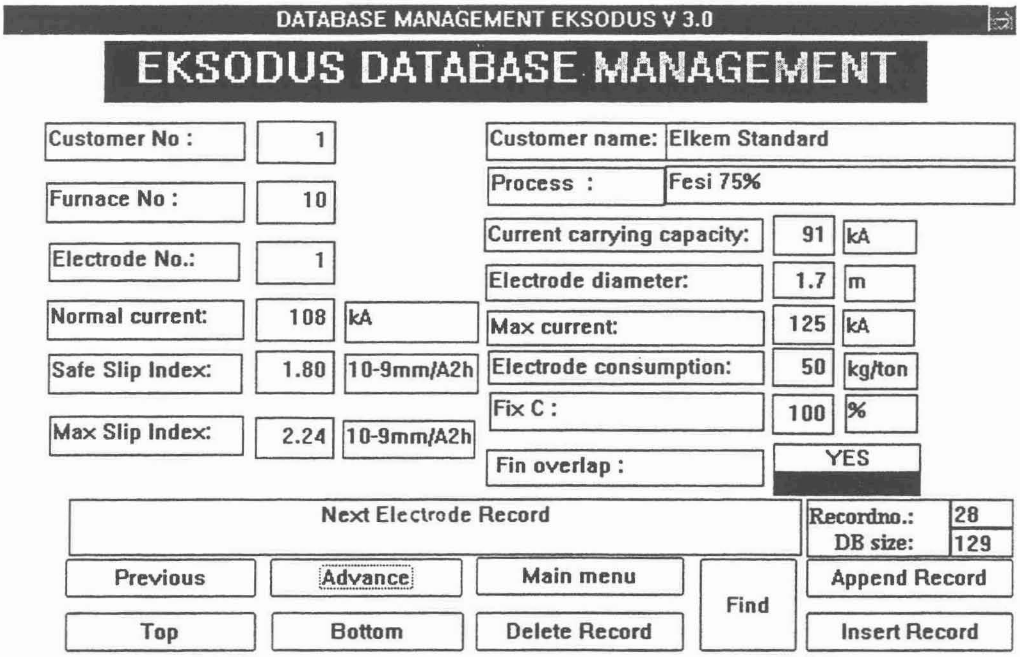


FIG. 8 Electrode Information stored in the Database

APPLICATION

The users of EKSODUS are Elkem Carbon's marketing people, but in the future our customers, mainly the furnace operators, will hopefully be more involved. In such cases, a certain modification may be necessary in order to fit the expert system to the actual type of electrode conditions.

If a breakage occurs at a plant, the system can be used to find an explanation of the problem. After the necessary information has been received, the system can be run, and a report presents the diagnosis of the problem. Normally, this procedure requires some work from the furnace operators as well. A sheet for reporting electrode breakages has been worked out, giving sufficient information to the electrode expert, but also to the expert system. In addition, the system can also be used to investigate the effect of changes in operation, paste and equipment. This work can be combined with training and education of the furnace staff.

The present EKSODUS is a valuable tool. However, it should be continuously improved, and this requires assistance from the furnace operators. Such cooperation concerns in particular the electrode consumption, where limited knowledge is available. Also to improve the rules, limits, procedures and material properties more experience and measurements are needed. Such data can easily be changed in the programme.

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[1] Innvær,R , "A Status for the Søderberg Smelting Electrode". UIE, ELECTROTECH 92, Montreal 1992

[2] Innvær,R, Olsen,L and Vatland,A ,"Operational Parameters for Søderberg Electrodes from Calculations, Measurements, and Plant Experience". Mintek 50, Johannesburg 1984