# DRILLING OF STUB HOLES IN PREBAKE ANODES

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## ABSTRACT

Stub holes may be a troublesome part in the production of anodes. Tension and cracks can be created around the stub hole. Vibrating the stub holes often introduces limitations for the optimisation of the production process.

Stub holes oriented towards the cassette wall during baking will be filled with packing material. This requires that the stub holes need to be thoroughly cleaned after baking. Stub holes that are oriented away from the cassette walls are unprotected during the baking process. This may lead to an increased rejection rate or additional costs to protect the stub holes.

The paper will present four years of experience with drilling of stub holes in baked anodes. This technology allows for the drilling of different stub hole designs, and the paper will summarise the results from trials where three different designs are tested in the same reduction cell.

## INTRODUCTION

Modern high amperage cells need anodes produced with special emphasis on homogeneity in properties. We want anodes with high density, low ohmic resistivity and low reactivities in air and CO2. However, high anode density makes it more challenging to produce an anode where gradients are minimised. Especially density gradients will also affect other properties of the anode like ohmic resistivity, permeability and thermal shock resistance.

Properties of anodes are determined through choice of raw material mix and the production processes of the green and baked anodes. Gradients are mostly created through the production process in the paste plant, especially in the green anode forming step. Green anodes that contain gradients may cause severe problems in the baking process by cracking or by setting limitations to the production capacity of the baking furnace. Traditionally green anodes are produced with the stub holes prefabricated in the anode. The displacement of paste caused by the stubs during the compaction of the green anode will in any case cause gradients and stress around the stub hole and this displacement increases with increasing stub volume. Typically core samples from baked anodes taken in the bottom of the stub hole may show 10 % higher values in ohmic resistance compared with samples taken parallel to the stub hole. If the anode has internal cracks under the stub hole this difference will be larger and in the worst case will affect the performance of the anode in the pot.

Low utilisation of the baking furnace leads to high production cost of the anodes. During 1998 one of our baking furnaces was rebuilt inside the existing building. By developing the technique for drilling stub holes we were free to optimize the packing of the anodes in the cassette. This gave us an extra capacity gain compared with a traditional solution.

Preliminary experiments in pots have shown significant improvements in ohmic voltage drop by choosing a stub hole design that is different from the classic.

Finally, manual cleaning of stub holes of a baked anode is not an attractive job. This operation has traditionally caused a high frequency of strain injuries and was an operation we wanted to get rid of.

## PRODUCTION OF GREEN ANODES

From the start of prebake anode production in Årdal around 1970 and up to 1998 the design of the stub hole was unchanged. Photo 1 shows the design of the stub hole in the baked anode used up to 1998:

Photo 1

The coning of the stub hole was made after baking by a drilling device. The cone was made as the drilling device approached the stub hole bottom.

By developing a new technique the primary intention was not to introduce a new stub hole design, but to get rid of the disadvantages described in the introduction. The old production line had clear limitations in the mixing facilities. Increasing the mixing temperature to temperatures above 160°C, which is a desired mixing level for a pitch with 115-120° softening point, made it difficult to cool the paste to the desired forming temperature. With these production conditions too high forming temperatures would lead to cracks connected to the stud holes. These limitations to the green anode production were solved during the modernisation program in 1998 by choosing a state of the art solution with a Buss K600 kneader combined with an

Eirich RV23 homogenizer/cooler. At the same time a new vibrator (Hydro-design) was installed. Photo 2 shows a typical baked anode from the new line.

Photo 2

The stubs traditionally mounted in the vibrator lid are removed, however the protrusions/profiles are kept. A small pit is made on the anode surface. The purpose of this pit is to give room for the graphite cylinder containing green coke for monitoring the calcining level in the baking furnace.

## PRODUCTION OF BAKED ANODES

The advantage with our baking furnace concept related to production capacity is connected to the way the energy input is distributed. To reduce the heat load to the refractory, a certain amount of packing materials is used as an energy source. Finally the gas (or oil) input is divided in two parts, where the combustion chamber either is large (as under the cover) or is constructed with high quality refractory bricks (60 % $Al_2O_3$). This concept allows us to operate with a high production rate per pit.

By rebuilding and expanding the dimensions of the section, the building itself may set physical limitations. The traditional way of baking anodes with substantial differences in the width and height (>13 cm) would be by orienting the top and bottom surfaces towards the cassette walls. Otherwise the furnace would be slow, i.e., must be operated at higher fire steps. In our case the furnace was dimensioned for anodes with dimensions L, W, H (mm) = 1510, 700, 600. Baking of anodes with prefabricated unprotected stub holes 90$^o$ to the cassette wall was not an option. In the old furnace this anode orientation gave us severe problems with stub hole slumping as the main problem. Introducing stub hole drilling, keeping the old anode orientation and combining this with the optimum utilisation of the available space in the building gave the following characteristics:

| Baking furnace characteristics | Unit | Old Furnace | Baking furnace combined with stub hole drilling |
|---|---|---|---|
| Nos. of sections | Nos | 30 | 30 |
| Nos. of fires | Nos | 2 | 2 |
| Nos. of pits | Nos | 5 | 7 |
| Section capacity | t/section | 77 | 160 |
| Cycle time | h | 36 | 27 |
| Annual production | t/y | 37500 | 104000 |
| Specific area requirement | t/m$^2$y | 18.2 | 46.2 |

The alternative with prefabricated stub holes towards the cassette walls would in the actual building have given a baking furnace with annual production of 98000 tons. Introducing the drilling concept thus gave us 6000 tons extra annual capacity.

However, in a green field plant the baking furnace could have been constructed with 8 pits. Such a furnace would have had the same section load, but could, independent of prefabricated stub holes, had orientation of the anodes with the top and bottom surface towards the cassette walls. For comparison this furnace could have been operated on a 2-hour faster cycle time and have given an annual capacity of 112000 tons of anodes. The arguments for introducing stub hole drilling for this furnace had to be based on:

- ✓ Anode quality (especially in the area around the stub hole)
- ✓ Reduced rejection rate of green and baked anodes
- ✓ Simplified cleaning procedures of the baked anodes
- ✓ Effect of modified stub hole design in the pots

## EQUIPMENT FOR STUB HOLE DRILLING

The following design features were set for the stub hole drilling equipment:

- ✓ The new technique should give as good or better performance data in the pot as experienced in the past.
- ✓ The equipment should be flexible and possible to use for different anode dimensions as shown in Figure 1. The anode type is recognised from the dimension of the anode by the computer system.
- ✓ The equipment should be flexible to use for different stub hole designs.

- ✓ The drilled out material should not be a source of waste but be used as raw material for anodes. The material should be transported without manual handling.

The equipment is constructed by combining a modern machine tool with a specially designed drilling head. A Norwegian company that specialises in constructing drilling heads for oil drilling in the North Sea constructs the drilling head. The drilling tool can easily be removed and changed.

Figure 1 shows a drawing of the principle of the arrangement.

The drilled out material is sucked off and into a small silo, which is connected to a filter system. The material is sent pneumatically to the paste plant. Temporarily this material goes into the butts feed, but will later go into the petroleum coke feed. The particle size of this material will depend on the drilling speed. The drilling speed can be adjusted and higher drilling speed will give coarser material. Typical maximum size today is < 2 mm.

The system has eliminated all previous manual cleaning of the stub holes. Today one operator uses his time to control the finished anode.

***Investment cost***
Two parallel installations including programmable drilling machine, anode handling system, suction and pneumatic recycling system:

Indicative investment cost: Approximately 2 M USD.

***Tooling cost of the drilling machine***
Approximately 0,1 USD/stub hole.

**TESTS OF THREE DIFFERENT STUB HOLE DESIGNS**

Three different stub hole designs were tested with regard to the electrical resistance between stub and anode. Two of the designs had drilled stub holes (standard Årdal design and a new design, z-profile) while the third design was a prefabricated stub hole (standard Sunndal design).

The three different stub hole designs are shown in Figures 2-4. The new design with the z-profile was based on model calculations and was designed to achieve a lower voltage drop between stub and anode. Twenty anodes were produced with each stub hole design. The anodes came from the same production line and were produced within two days to eliminate anode quality as a factor in the test.

The anodes were tested in 20 cells in the SU3 pot line. One anode with each stub hole design was put into each cell in neighbouring positions. This ensured that the three anodes in each cell had similar conditions. The anodes had four stubs and two stubs on each anode were measured.

Each anode was equipped with bolts and cables on two of the four stubs. Bolts and cables were also mounted in the anodes. The bolts in the stubs were placed 15 cm above the anode top surface, and the bolts in the anodes were placed 10 cm away from the stubs. This made it easy to measure the voltage drops. The outer stub was always measured and the second measurement was alternated between the second and the third stub (counting the stubs from the side channel towards the centre channel). The voltage drop was thereby measured on 40 stubs for each stub hole design.

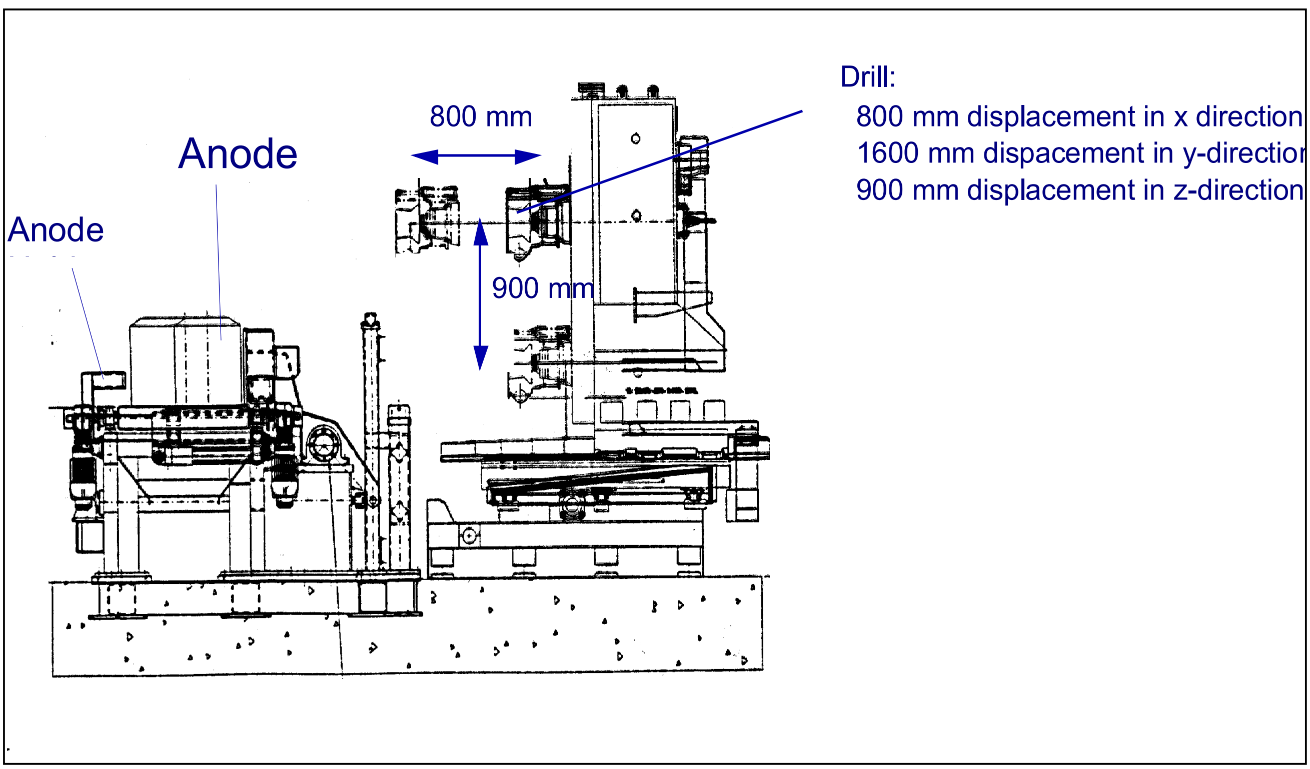


Figure 1: Stub hole drilling machine.

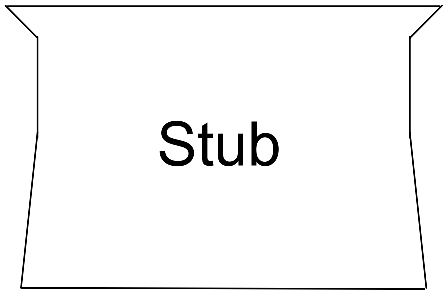


Figure 2 shows a vertical cut of the Årdal stub hole design.

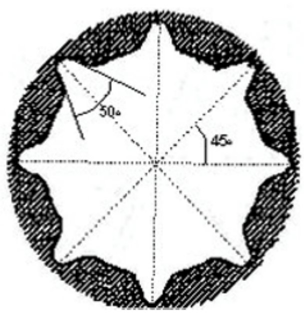


Figure 3 shows a horizontal cut of the Sunndal stub hole design. (Standard screwed stub hole)

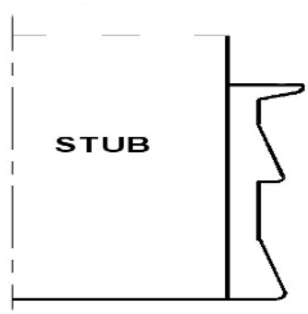


Figure 4 shows a vertical cut of the new z-profile stub hole design.

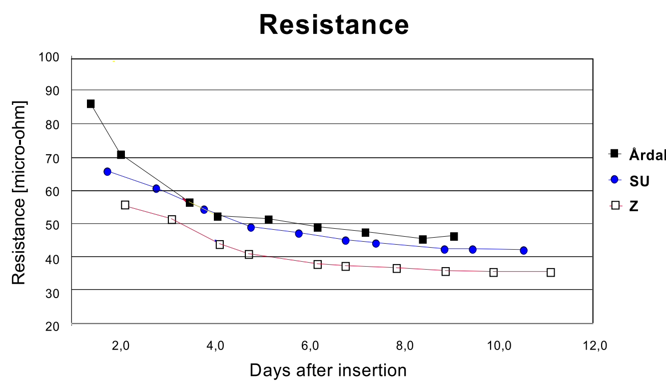


Figure 5. Measured resistance between stub and anode, with the different stub hole designs, as a function of time after insertion.

The voltage drop between stub and anode and the current in each stub were measured daily from 2 to 12 days after the insertion of the anode. The results are shown as calculated stub – anode resistance in Figure 5. Each point represents an average of approximately 40 measurements.

The results show that the drilled z-profile design gives the lowest resistance between stub and anode. The difference between the Årdal and the Sunndal design is small, but the Sunndal design gives slightly better results. The resistance is stable 10-12 days after insertion of the anode.

Results

The z-profile design gives an average resistance between stub and anode of 36 $\mu\Omega$ (std. dev. 3 $\mu\Omega$).

The Sunndal design gives an average resistance between stub and anode of 43 $\mu\Omega$ (std. dev. 4 $\mu\Omega$).

The Årdal design gives an average resistance between stub and anode of 46 $\mu\Omega$ (std. dev. 5 $\mu\Omega$).

The z profile is not considered as a final solution. We are making use of models for further optimisation of both the cast iron consumption and the voltage drop.

**SUMMARY OF FOUR-YEAR EXPERIENCE USING STUB HOLE DRILLING**

Two identical machines are installed in series in the production line. So far around 600000 anodes have been core drilled on these machines. The practical experiences are:

- ✓ The machinery has worked according to expectations, including the flexibility in stub hole designs and anode dimensions.
- ✓ Previous problems connected to stub hole slumping and cracks associated with prefabricated stub holes are eliminated.
- ✓ The internal customers, who have not changed the design of the stub hole, have seen a clear reduction in anode anomalies in the pots. This observation is not only connected to the introduction of stub hole drilling, but to a general quality improvement of the anodes in the same period.
- ✓ Low filter capacity and core drilling of too hot anodes were the main obstacles in the initial operative phase.
- ✓ External customers who were used to profiled stub holes with inclined flutes have had to perform minor adjustments of the stud hole dimensions.
- ✓ The results from the pot room test are as expected from model calculations and show that the new stub hole design gives a lower electrical resistance between stub and anode.