STUDIES OF STUB TO CARBON VOLTAGE

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The top part of a stubbed anode was sawed off to expose the bottom portion of the stub. Numerous voltage probes were attached to the stub, cast iron and carbon. Provision was made for measuring expansion. The anode was heated to simulate temperatures encountered in cell operation. A 1000 amp D.C. current flowed from the top of the stub to the bottom of the anode. During the heat-up period, appreciable voltage drops were measured at the interfaces of steel, cast iron and carbon. However, at operating temperature, these voltage drops were very low. Cast iron thickness affected the temperature at which the assembly became tight.

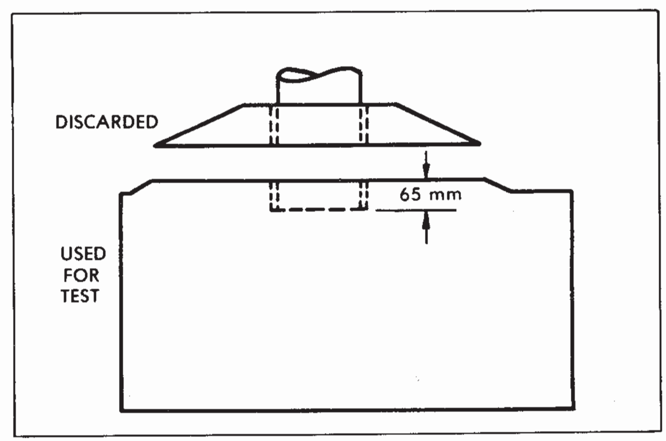
Introduction

Stub-carbon voltage drops are commonly measured by placing a probe on the steel stub and placing another probe on the carbon near the stub. Voltage readings of about 0.2 V are typical, with considerable scatter in the data due to placement of the probes, the amount of current, thermoelectric effects, the tightness of the connection, etc. Since 0.2 V is a significant fraction of pot voltage, a study was made to determine whether design changes could reduce this power loss.

Procedure

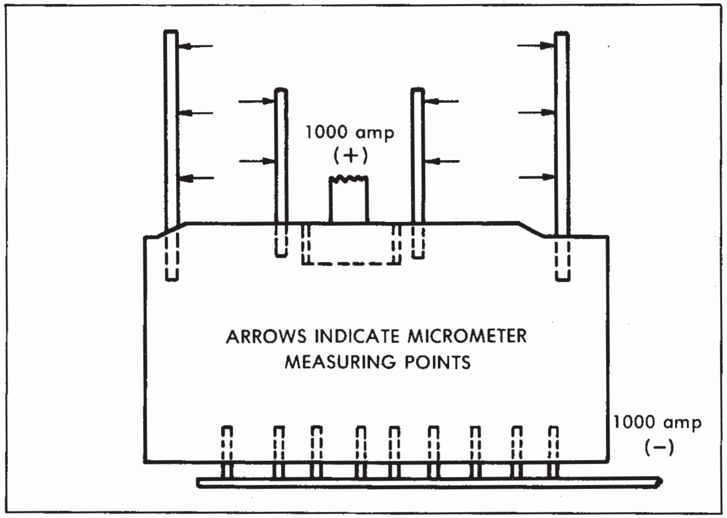
Cast iron was poured around a 150 mm diameter stub in the cavity of a prebaked anode. An ingot saw was used to cut the top off the anode to expose the center portion of the stub and casting (Figure 1a). The top part of the casting had been arc-welded to the stub prior to sawing to prevent undue vibration and movement of the casting.

The anode was placed in a furnace heated at the bottom with Glo-bar electric heaters. Eighteen steel rods, 19 mm diameter, were embedded 50 mm into the bottom of the anode to carry 1,000 amp D.C. current. A steel pipe was welded to the center of the stub to form the other end of this electrical circuit (Figure 1b). Four steel rods were driven into holes drilled in the top of the anode to measure deflection (Figure 1b). Measurements were taken at two or three elevations for extrapolation to the top surface of the carbon.



PREPARATION OF STUBBED ANODE

FIG. 1a



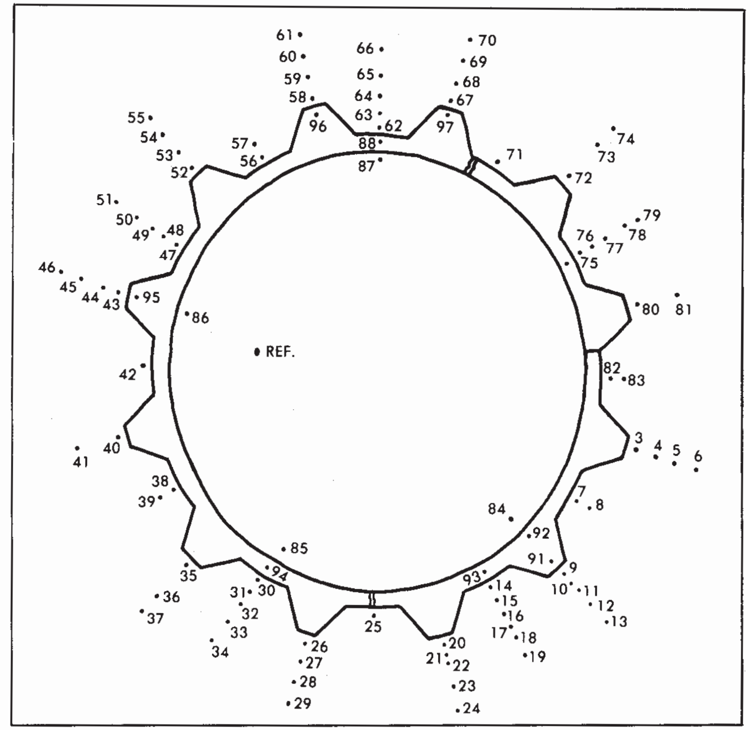
DEFLECTION MEASUREMENTS AND CURRENT SUPPLY

FIG. 1b

Vertical holes 5 mm deep, #68 drill size, were drilled in the carbon near the casting for voltage probes (Figure 2). Asbestos insulation was stripped from the end 8 mm of 20 ga. iron thermocouple wires and the bare ends were placed in the drilled holes. The other end of each wire was connected to a Doric Digitrend 220 recorder. Other voltage probe wires were welded to the cast iron and the steel stub. Thermocouples in the stub and anode were connected to the Digitrend and more were connected to an L&N multipoint temperature recorder. The Digitrend recorder was connected to an isolation transformer and the anode stub was grounded to the Digitrend chasis to avoid problems of common mode voltages.

The bottom of the furnace was tightly sealed with Fiberfrax insulating blanket around the current-carrying rods. The top of the anode was covered with 150 mm of vermiculite insulation. The furnace was purged with nitrogen to prevent air from burning the anode.

The furnace controller was set at 950°C and turned on. The D.C. rectifier was then activated with the current set at 1000 amps. Every 30 minutes a complete set of voltage readings and temperatures was recorded with the 1000 amp current on and off. The "off" readings provided data for correction of thermoelectric effects in the voltage probes. Measurements between the rods were made manually using dial indicators attached to suitable extension rods. These measuring gages were checked after each set of readings against a reference gage held at room temperature. The anode neared steady state temperature in about 16 hours. The furnace was shut off after 30 hours.



VOLTAGE PROBES

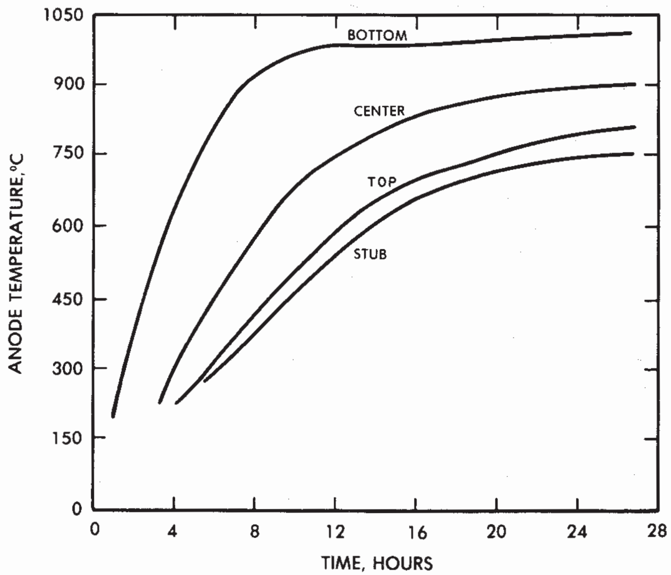
FIG. 2

Results and Discussion

Heating rates and temperature gradients through the anode (Figure 3) were quite close to those measured in commercial anodes.(1) The bottom of the anode reached 950°C in a few hours and the top surface attained 750°C at 20 hours.

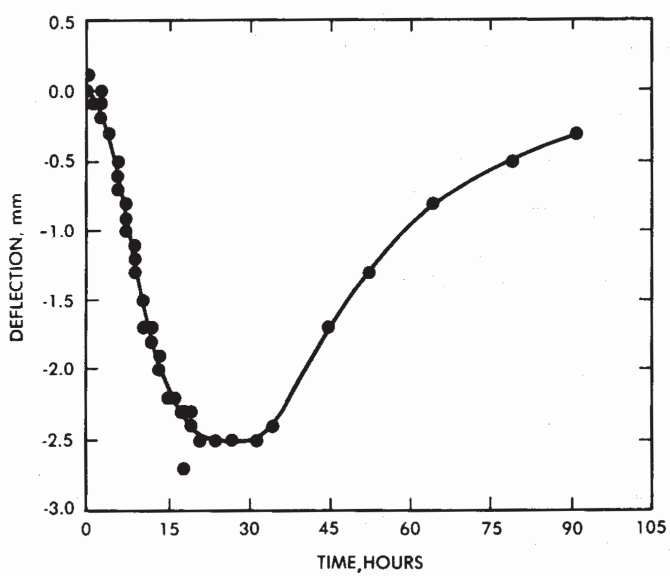
These temperature gradients produced bending of the anode in a "smile" or saucer shape, which put the top part of the carbon in compression. Measurements on the outer rods indicated the top part of the anode was 2.5 mm smaller at operating temperature than at room temperature (Figure 4). Standard deviation of this measurement was estimated to be ±0.025 mm.

Deflection measurements near the stub hole indicated the hole became slightly smaller during the early part of the test due to the bending of the carbon. After a few hours the stub expanded enough to force the stub hole outward to a maximum deflection of 1.1 mm (Figure 5).



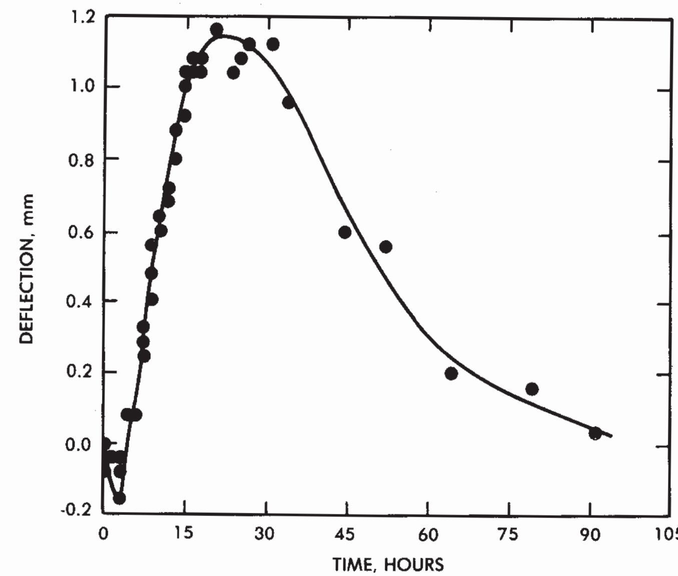
ANODE HEATING RATE

FIG. 3



DEFLECTION AT TOP EDGE OF ANODE

FIG. 4



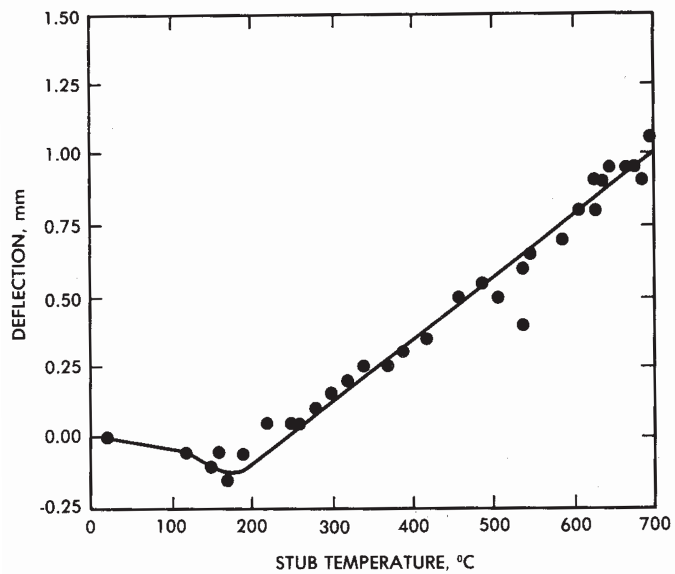
DEFLECTION NEAR STUB HOLE

FIG. 5

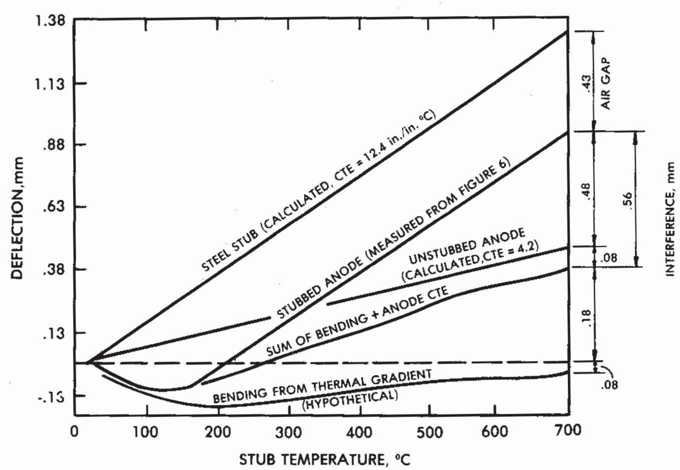
Plotting carbon expansion near the stub hole versus stub temperature showed a straight-line expansion after an initial lag for the stub to expand enough to make up for any looseness in the casting (Figure 6). This looseness was due to shrinkage of the cast iron after solidification and perhaps some surface crushing of the carbon.

Replotting this expansion along with the calculated expansion of the steel stub showed that the carbon near the stub hole expanded at the same rate as the stub--after the initial lag for the stub to catch up with the carbon (Figure 7). The calculated expansion for an unstubbed anode of CTE 4.2 mm/mm °C is also shown. If there were no thermal gradient in the anode, the amount of interference fit (or strain) would be the difference between the measured deflection of the carbon and the calculated expansion of an unstubbed carbon (0.48 mm). However, the bending had the effect of making the hole smaller so the actual interference was thus greater (0.56 mm, estimated). This value of 0.56 mm deflection is close to the amount of deflection required to break an anode.

Relative resistance at various parts of the assembly was calculated by subtracting the voltage readings on adjacent pins and dividing by the total current flowing through the anode. Review of the data indicated uniform distribution of current to all parts of the casting and carbon, so this procedure should be fairly accurate. Where probe spacing in the carbon was not uniform, a suitable correction was made.



DEFLECTION NEAR STUB HOLE VS. STUB TEMPERATURE
FIG. 6



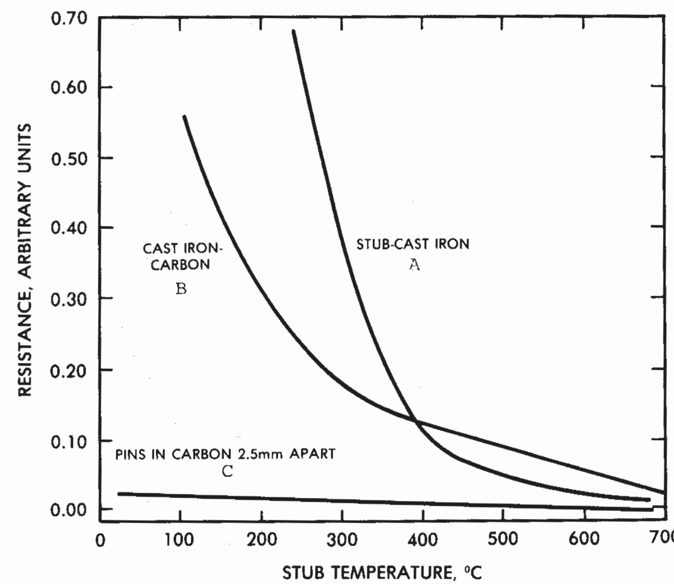
DEFLECTION VS. STUB TEMPERATURE
FIG. 7

The current flow was assumed to radiate outward from the stub in two dimensions. This again is believed to be reasonable since previous work had shown most of the current leaves the bottom half of the stub and there is considerable horizontal flow as the current fans out in the anode.

In general, the stub-cast iron resistance was high at room temperature, decreasing to a very low value as the assembly heated (Curve A, Figure 8, for a thick section of cast iron). The cast iron-carbon interface behaved in a similar fashion (Curve B, Figure 8). Resistance between adjacent carbon pins was low and nearly constant throughout the test (Curve C, Figure 8).

These curves indicate that at 600-700°C, the resistance between probes in the stub and the cast iron was about the same as for closely spaced probes in the carbon. And at 700°C, the resistance between probes in the cast iron and carbon was a similar low value.

Resistance or voltage drop in the assembly thus was shown to be due largely to resistance of the constituent materials, rather than discontinuity between materials.



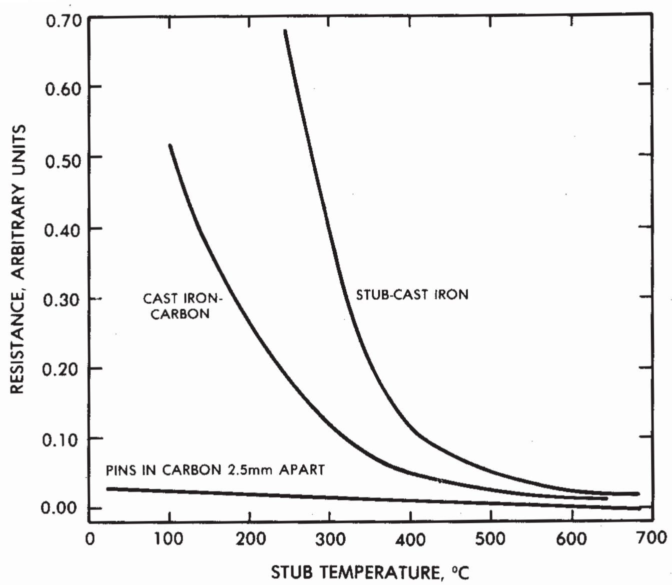
EFFECT OF STUB TEMPERATURE ON
RESISTANCES (THICK FLUTE SECTION)
FIG. 8

Similar results were shown for a thin section of cast iron (Figure 9). In this case, however, the cast iron-carbon resistance reached a low value at a much lower stub temperature than in the case of thick casting. A thick section would be expected to shrink more after rodding; thus, there would be greater air gap to be taken up by stub expansion. A thin section would shrink less and the stub would soon push it into tight contact with the carbon.

In some parts of the assembly such as the thick flute section, the stub and cast iron were found to be in fairly good contact even at low temperatures (Figure 10). The cast iron in this case still did not make good contact with the carbon until stub temperature was 600-700°C.

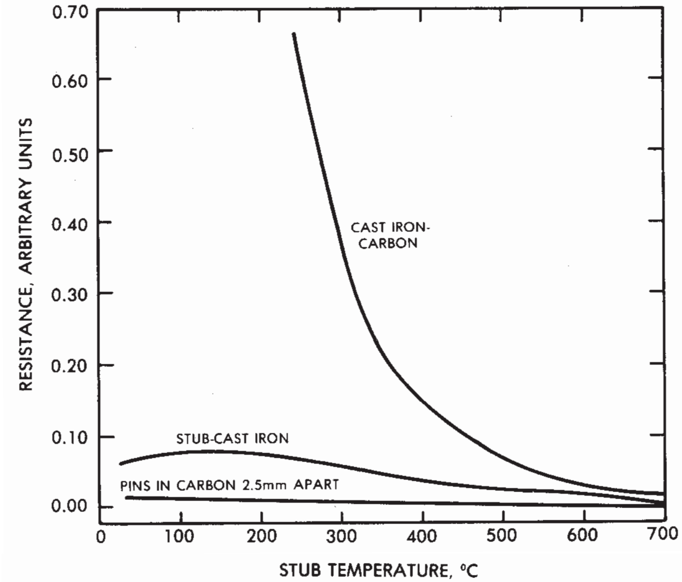
In other places the casting made fairly good contact with the carbon at low temperatures (Figure 11). This was apparently due to a shifting of the casting against the carbon during cooling or handling. As the assembly heated, the contact became poorer, then improved at even higher temperatures.

All of the preceding concepts are shown graphically in Figure 12. Curve A shows typical stub-carbon resistance decreasing as stub temperature increased. Curve B shows carbon deflection near the stub hole. Below 100°C stub temperature, the stub-carbon resistance was very high (off-scale). At this time, the connection was loose enough that the stub hole was decreasing in diameter due to the vertical thermal gradient bending the anode.



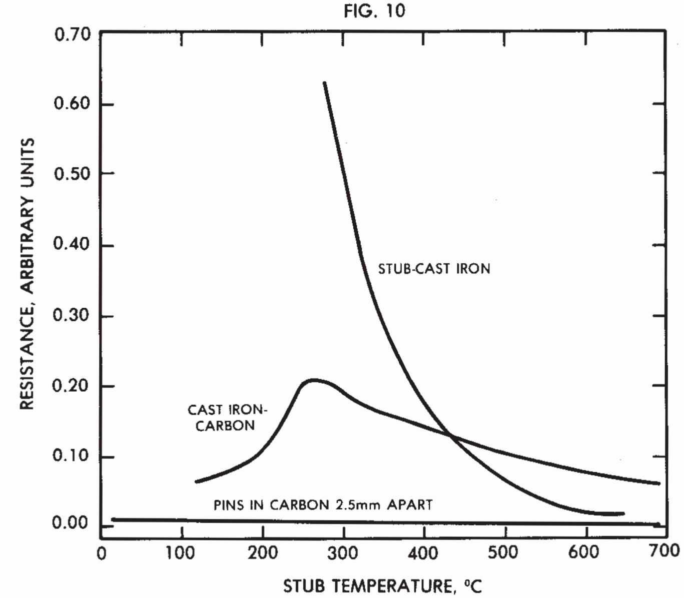
EFFECT OF STUB TEMPERATURE ON RESISTANCES (THIN SECTION)

FIG. 9



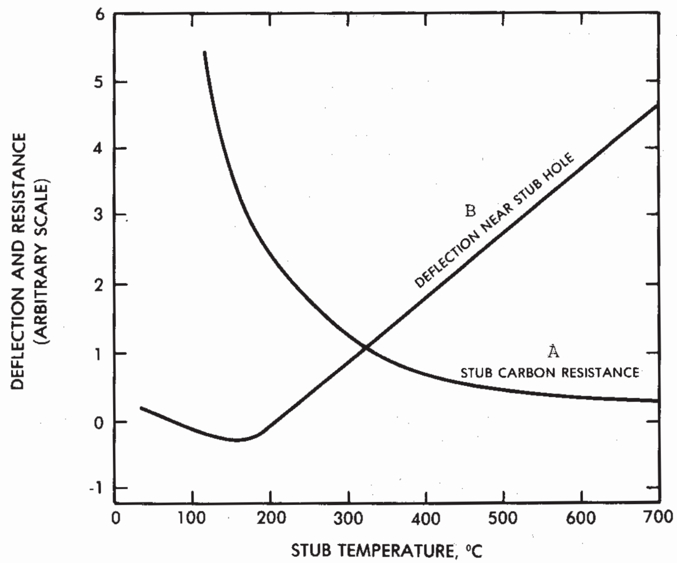
EFFECT OF STUB TEMPERATURE ON RESISTANCES (THICK FLUTE SECTION)

FIG. 10



EFFECT OF STUB TEMPERATURE ON RESISTANCES (THICK FLUTE SECTION)

FIG. 11



EFFECT OF STUB TEMPERATURE ON DEFLECTION AND STUB-CARBON RESISTANCE
FIG. 12

Between 100 and 200°C the stub-carbon resistance decreased sharply. The deflection curve shows that the inward movement of the stub hole had ceased and the stub was coming into good contact with the stub hole.

Above 200°C, the carbon deflected linearly at a rate equal to stub expansion. The stub-carbon resistance decreased to a low value and leveled off. Any further deflection beyond this level point (500°C) would risk breaking the carbon but would not reduce stub-carbon resistance.

This shows that any voltage losses in the stub-carbon connection are due largely to the resistance of the materials employed and the path of the current. There is no appreciable voltage drop between the steel and the cast iron or the cast iron and the carbon. For a given stub size and shape there is little to be gained by changing flute configuration or increasing contact pressure. In similar situations such as heat transfer, this concept is well documented. In heat conduction between two solid materials under good pressure contact, resistance and thermal gradient are often small enough to be neglected.(2)

Another point of confirmation is that electrical measurements in this test check roughly with control readings. At 1100 amps in this test, the voltage drop to the outer pins averaged 0.0265 volt. This would correspond to 108 mv in an anode carrying 4500 amps. The horizontal probe spacing was roughly equivalent to plant control readings.

The voltage drop could also be calculated as follows: Assume 3500 amps flow outward from the bottom two inches of a 150 mm diameter stub. If the casting is considered to be a 10 mm thick shell around the stub, the diameter is 172 mm. A 25 mm thick shell of carbon around the 172 mm diameter casting would have a log mean diameter

$$\frac{192-172}{\ell n(192/172)} = 182 \text{ mm}$$

The area of a cylinder 182 mm in diameter, 50 mm tall is 28600 mm^2.

Current density = 3500 amps/28600 mm^2 = 0.122 amp/mm^2

If the resistivity of the carbon is 0.0060 ohm-cm, the voltage drop through the first 25 mm of carbon is

$$0.12 \text{ amp/mm}^2 * 0.0060 \text{ ohm-cm} * \frac{10 \text{ mm}}{\text{cm}} * 25 \text{ mm} = 0.18 \text{ V}$$

which is close to plant control readings.

Thus it seems reasonable that most of the resistance can be attributed to that of the materials employed; the interfacial stub-carbon resistance is close to zero.

The bending and shortening of the top of the anode are probably not generally recognized but again these are supported by sound principles as well as the experimental measurements reported here.

Conclusions

1. Stub-carbon voltage drop is due largely to electrical resistances of the stub, cast iron and carbon. Interfacial resistance between these materials contributes little voltage drop at operating temperatures.

2. The thickness of the cast iron has a bearing on the tightness of the connection. Thin sections provide a tighter fit than is necessary for a good electrical connection and could contribute to carbon breakage.

References

1. Temperature and Voltage Measurements in Hall Cell Anodes, by R. W. Peterson, Light Metals 1976, Vol. 1, p. 365.

2. "Conduction in Solids", General Electric Report G502.5, November 1970, Heat Transfer Division.