Production Application Study on Magneto-Hydro-Dynamic Stability of Large Prebaked Anode Aluminum Reduction Cell

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Plan of the Presentation

- Introduction
- Magneto-hydro-dynamic stability theory
- Calculated results under normal conditions
- Calculated results with some anodes removed
- Conditions observed in production
- Conclusions

Introduction

This paper introduces the MHD stability theory of pot and puts forward the concepts of "stationary state" and "transient state" of a reduction cell.

This paper also establishes the 3-dimensional calculation model of MHD stability of pot as per actual pot dimension and busbar arrangement, as well as compares the calculation against observations in one certain smelter operating 340kA pots in China.

Magneto-hydro-dynamic stability theory

The large prebaked anode aluminum reduction pot can be mathematically represented into 2 states under production conditions.

One is called “stationary state”, namely the pot is under non-disturbance conditions.

The other one is called “transient state”, namely the pot is under disturbance conditions with current fluctuation, anode change, tapping and breaking feeding which can not be prevented.

Magneto-hydro-dynamic stability theory

The study on the pot MHD stability should have 2 objectives:

1. quickly study the "stationary state" solution trying to identify characteristics of a stable design;
2. generate a perturbation and carry a much longer fully non-linear "transient state" analysis to really check if the cell design is predicted to return on its "stationary state" after such a perturbation.

Magneto-hydro-dynamic stability theory

Disturbances happen on the pot under:

a) normal production conditions or

b) in some special conditions like when some anodes are removed.

The pot can then return the its original state or transit to the new stable state after certain time. If it does, the pot is regarded as stable under such normal conditions or special conditions, otherwise it is regarded as unstable.

Magneto-hydro-dynamic stability theory

$$\partial_k u_k + \delta^{-1} \partial_{\bar{z}} w = 0 \qquad (1)$$

$$\partial_t u_j + u_k \partial_k u_j + \delta^{-1} w \partial_{\bar{z}} u_j =$$
$$-\partial_j p + \mathrm{Re}^{-1}(\delta^{-2} \partial_{\bar{z}} \bar{v}_e \partial_{\bar{z}} u_j + \partial_k \bar{v}_e \partial_k u_j) + E f_j \qquad (2)$$

$$\partial_t w + u_k \partial_k w + \delta^{-1} w \partial_{\bar{z}} w =$$
$$-\delta^{-1} \partial_{\bar{z}} p + \mathrm{Re}^{-1}(\delta^{-2} \partial_{\bar{z}} \bar{v}_e \partial_{\bar{z}} w + \partial_k \bar{v}_e \partial_k w) + E f_z - \delta^{-1} \qquad (3)$$

Nondimensional fluid flow equations: continuity, horizontal momentum and vertical momentum transport respectively.

Magneto-hydro-dynamic stability theory

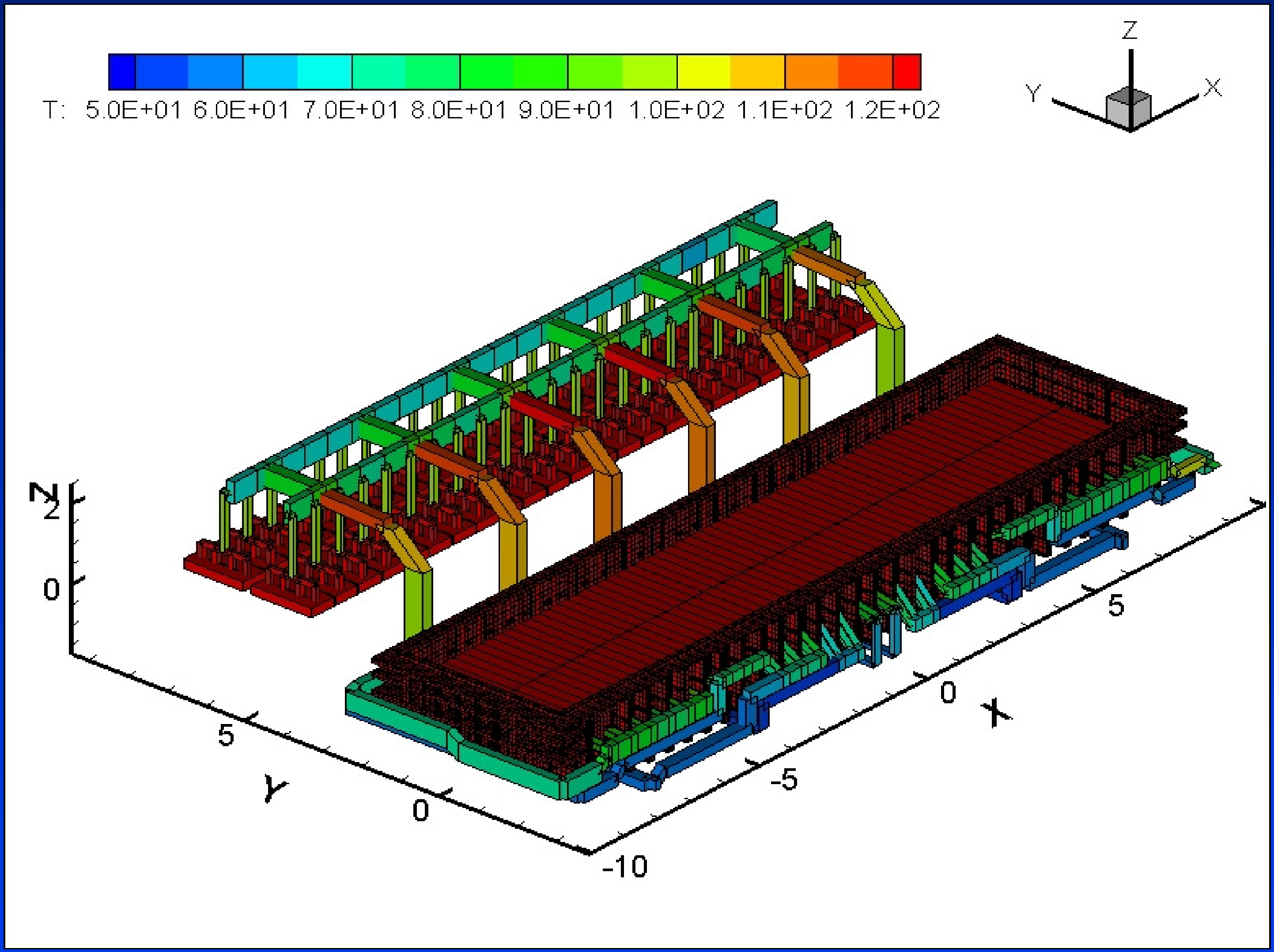
$$\partial_t \hat{u}_j + \hat{u}_k \partial_k \hat{u}_j =$$
$$- \partial_j p(\overline{H}_0) - \varepsilon \partial_j \varsigma - \mu \hat{u}_j + \mathrm{Re}^{-1} \partial_k \overline{v}_e \partial_k \hat{u}_{0j} \qquad (4)$$
$$+ E \hat{f}_j - \tfrac{1}{2} \delta E \overline{H}_i \partial_j f_{0z} + O(\varepsilon^2, \delta^2, \varepsilon\delta)$$

$$\varepsilon \left\langle \frac{\rho}{\overline{H}} \right\rangle \partial_{tt} \varsigma + \varepsilon \left\langle \frac{\mu\rho}{\overline{H}} \right\rangle \partial_t \varsigma + \varepsilon \langle \rho \rangle \partial_{jj} \varsigma =$$
$$E \left\langle \partial_j \hat{f}_j \right\rangle - \delta E \left\langle \tfrac{1}{2} \overline{H} \partial_{jj} \hat{f}_z \right\rangle \qquad (5)$$
$$- \varepsilon \left\langle \frac{\rho}{\overline{H}} \partial_{tj} (\varsigma u_{jo}) + \frac{\mu\rho}{\overline{H}} \partial_j (\varsigma u_{jo}) \right\rangle - \left\langle \rho \partial_j (\hat{u}_k \partial_k \hat{u}_j) \right\rangle$$

When the depth averaging procedure is applied to the horizontal momentum equations (2) we obtain (4).

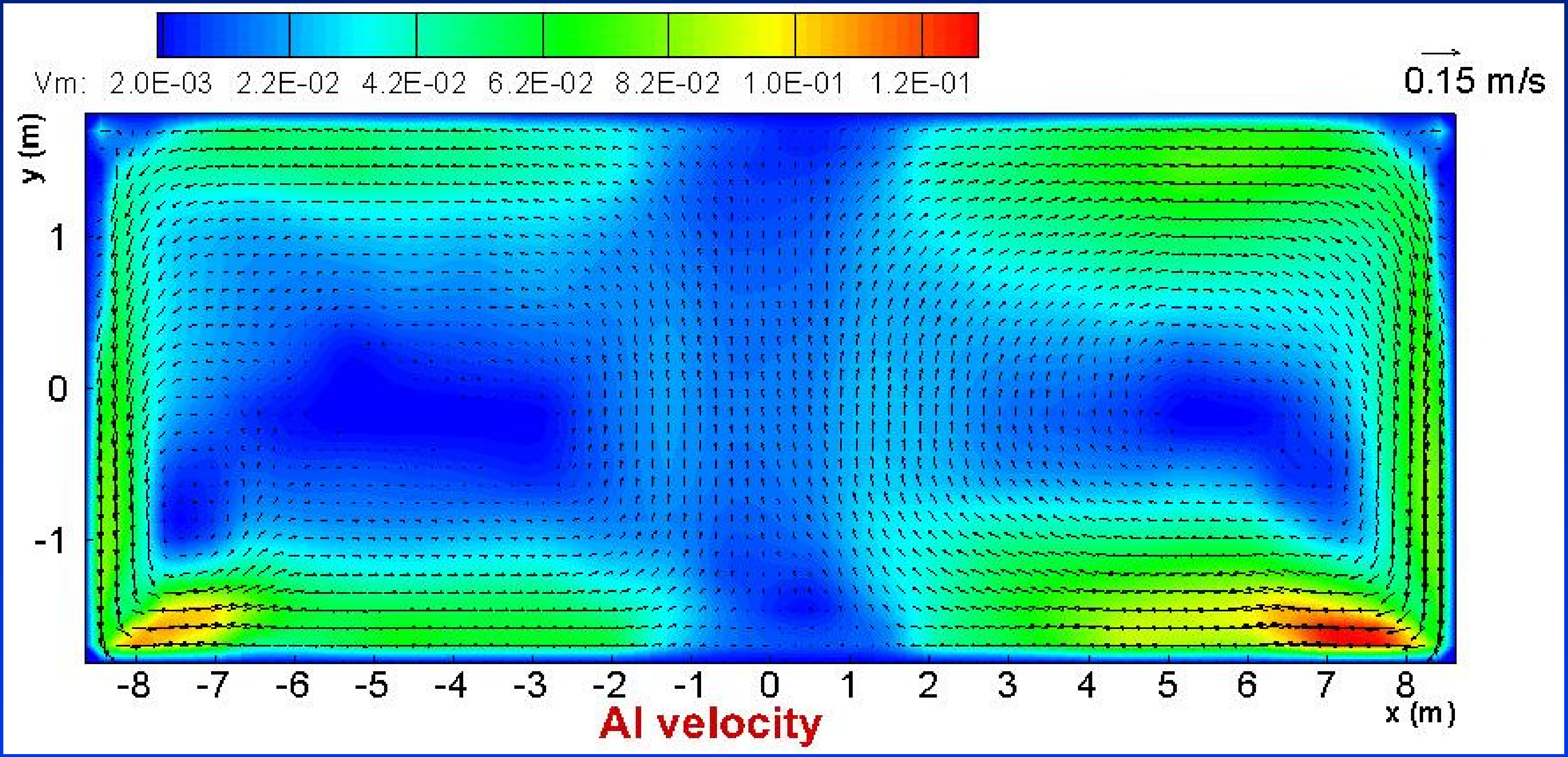
The momentum (4) and continuity (1) equations for the two fluid layers can be combined in a single nonlinear wave equation (5) for the interface ζ(x,y,t)

Calculated results under normal conditions



Model of 340 kA pot including busbar layout

Calculated results under normal conditions



Initial "stationary" state metal flow under ACD = 0.045m

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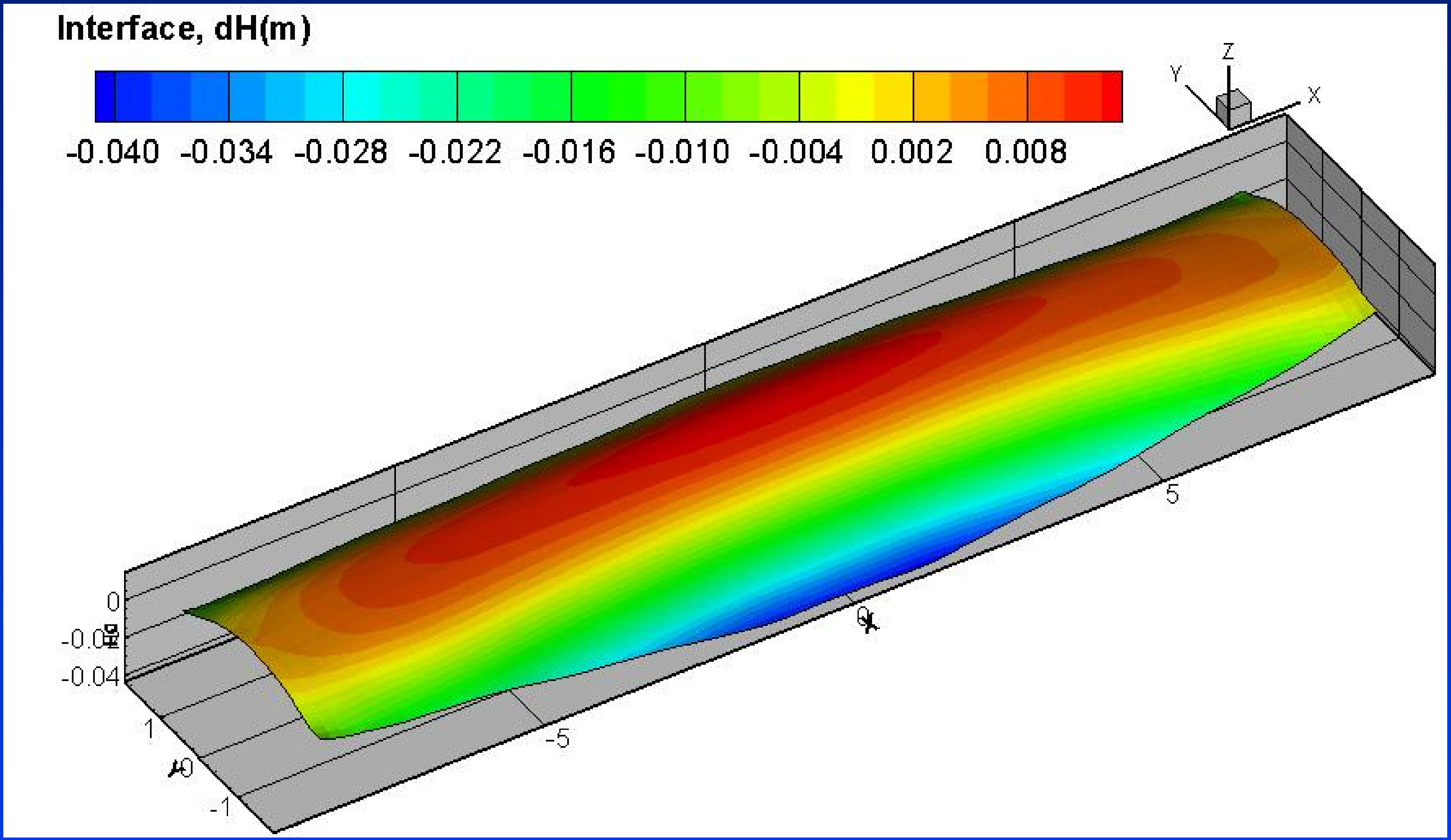
Calculated results under normal conditions



Initial "stationary" state metal surface under ACD = 0.045m

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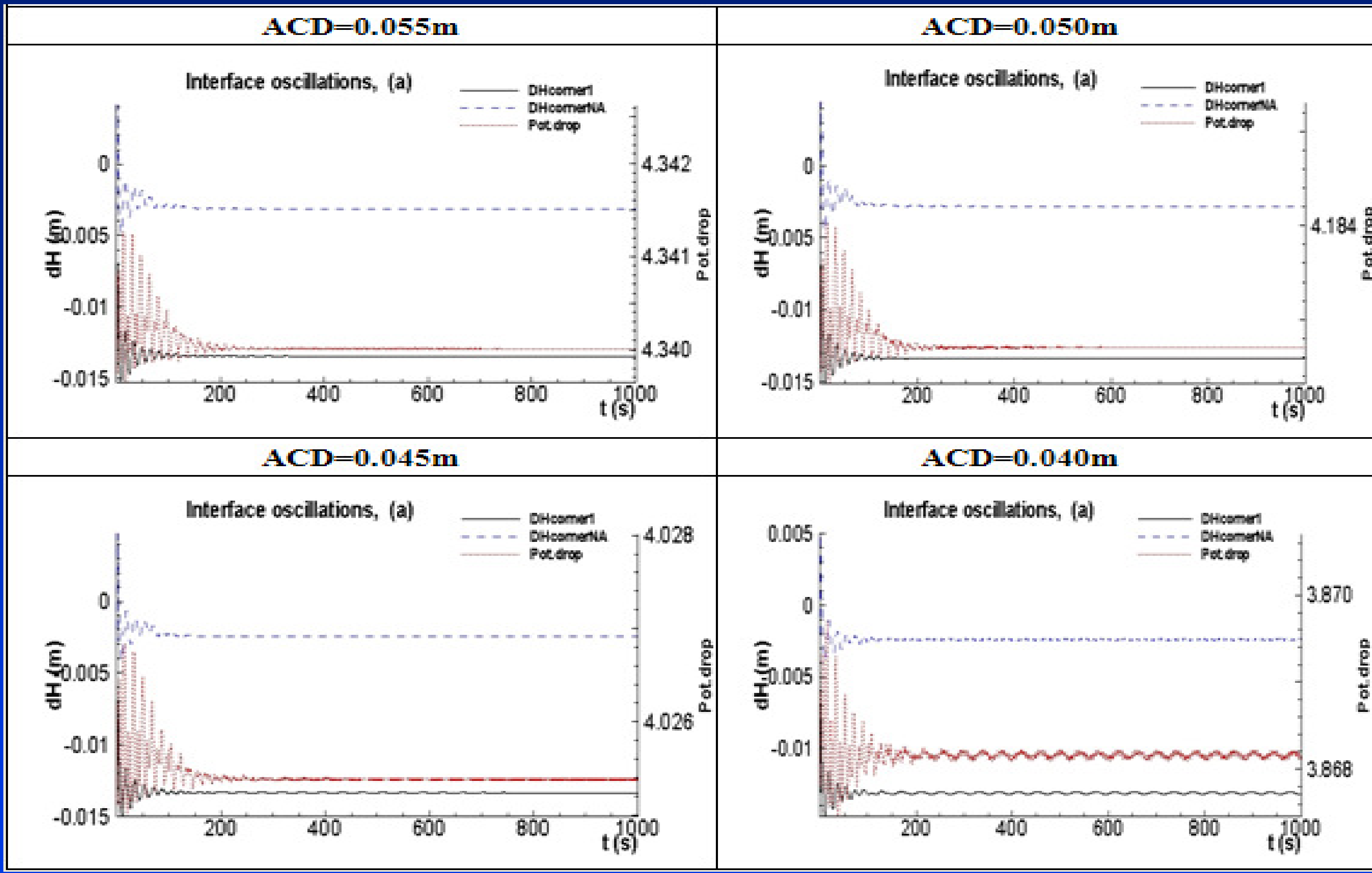
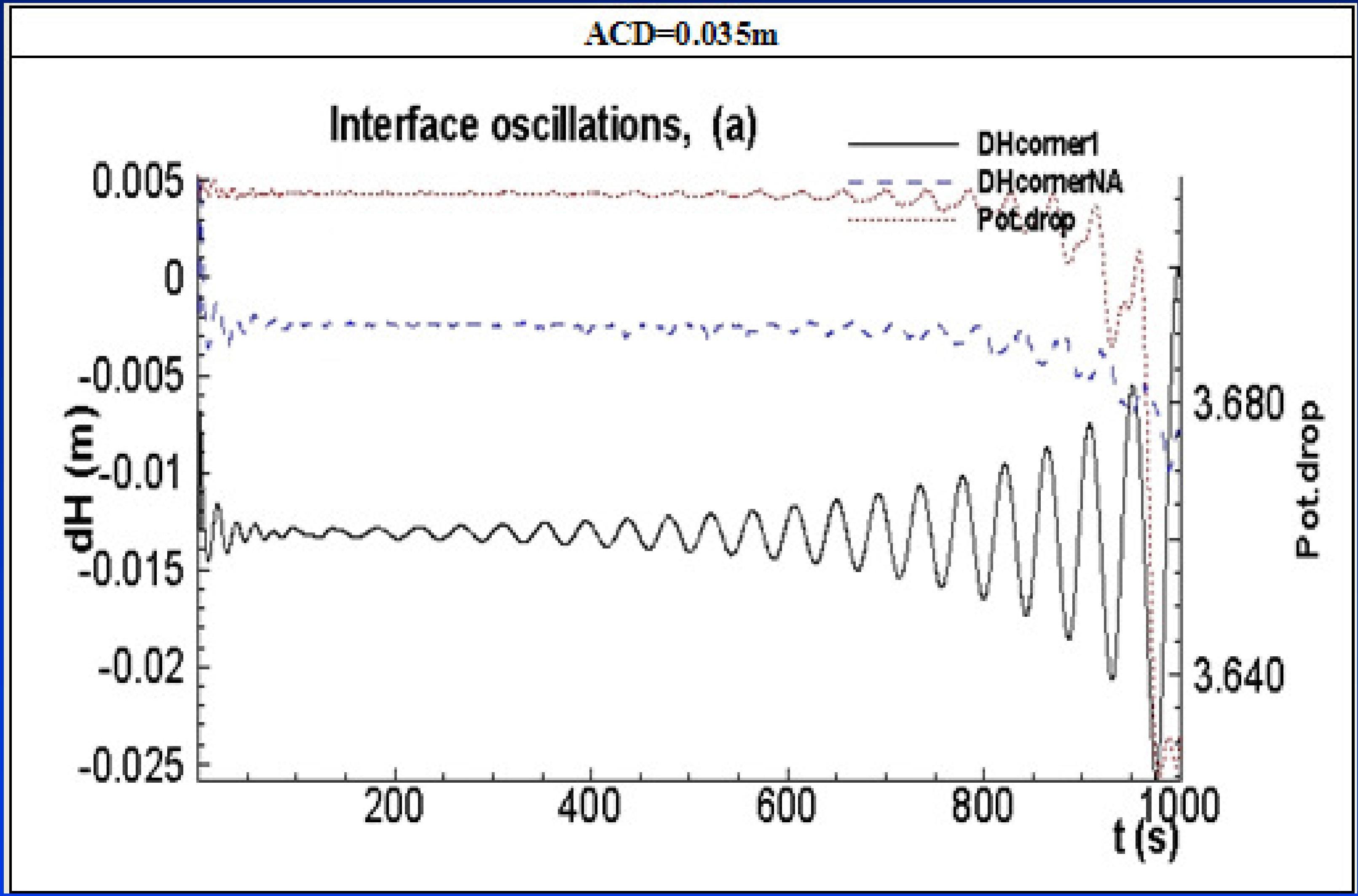
Calculated results under normal conditions



Voltage fluctuation chart under ACD between 0.040m and 0.055m

Calculated results under normal conditions



Voltage fluctuation chart under ACD = 0.035m

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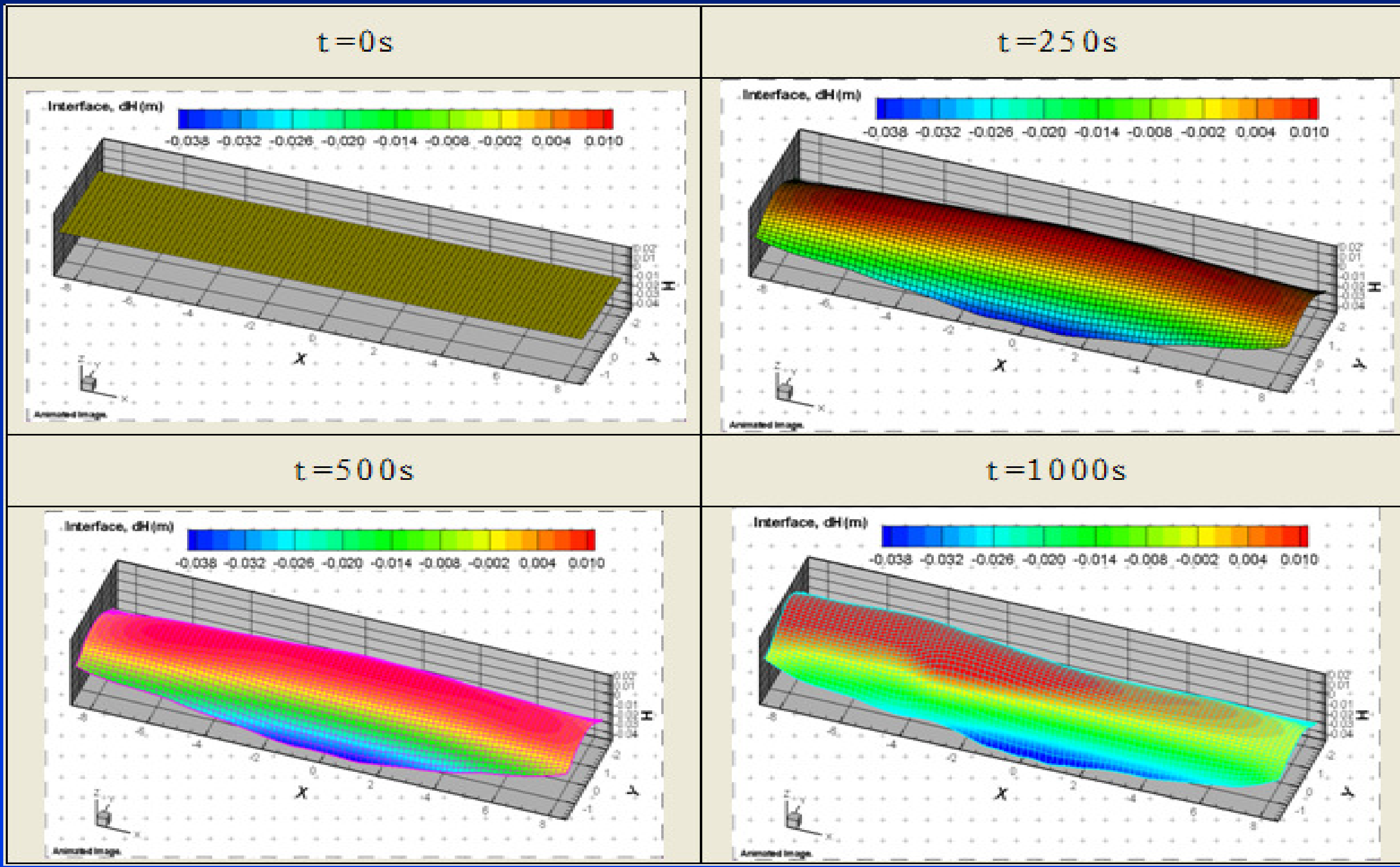
Calculated results under normal conditions



Metal surface fluctuation chart under ACD = 0.035m

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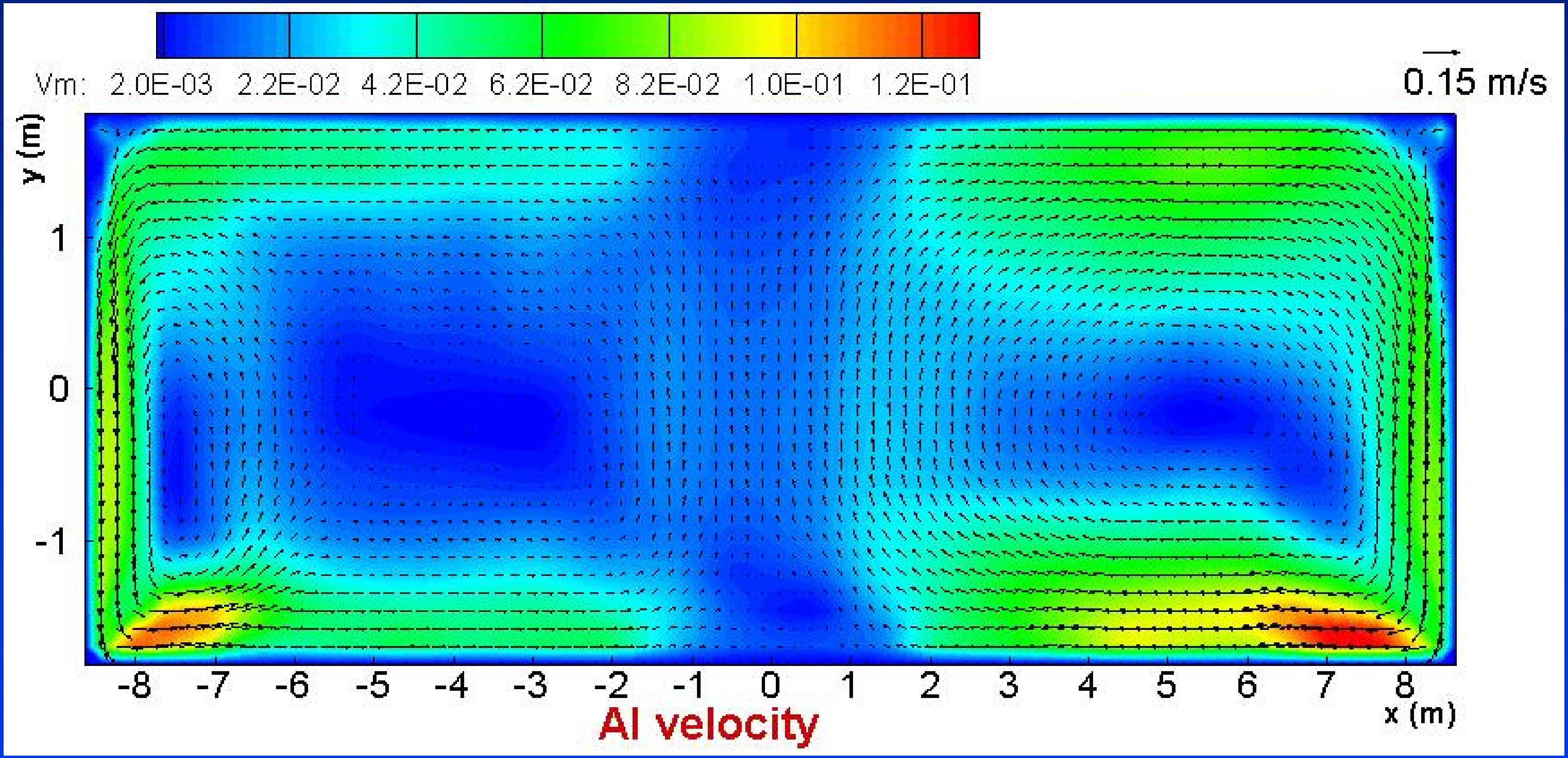
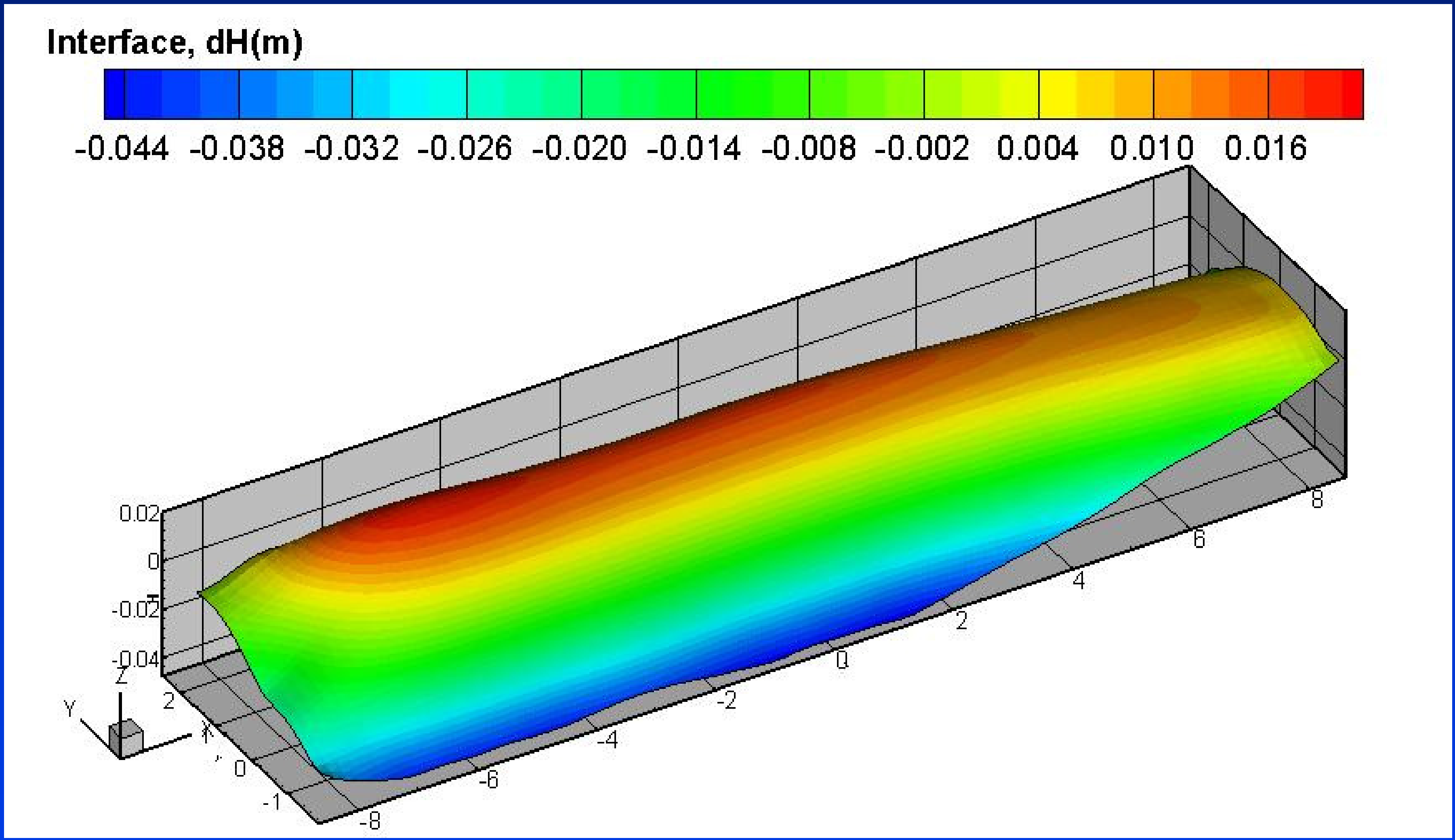
Calculated results with some anodes removed



Initial "stationary" state metal flow under ACD = 0.045m

Calculated results with some anodes removed



Initial "stationary" state metal surface under ACD = 0.045m

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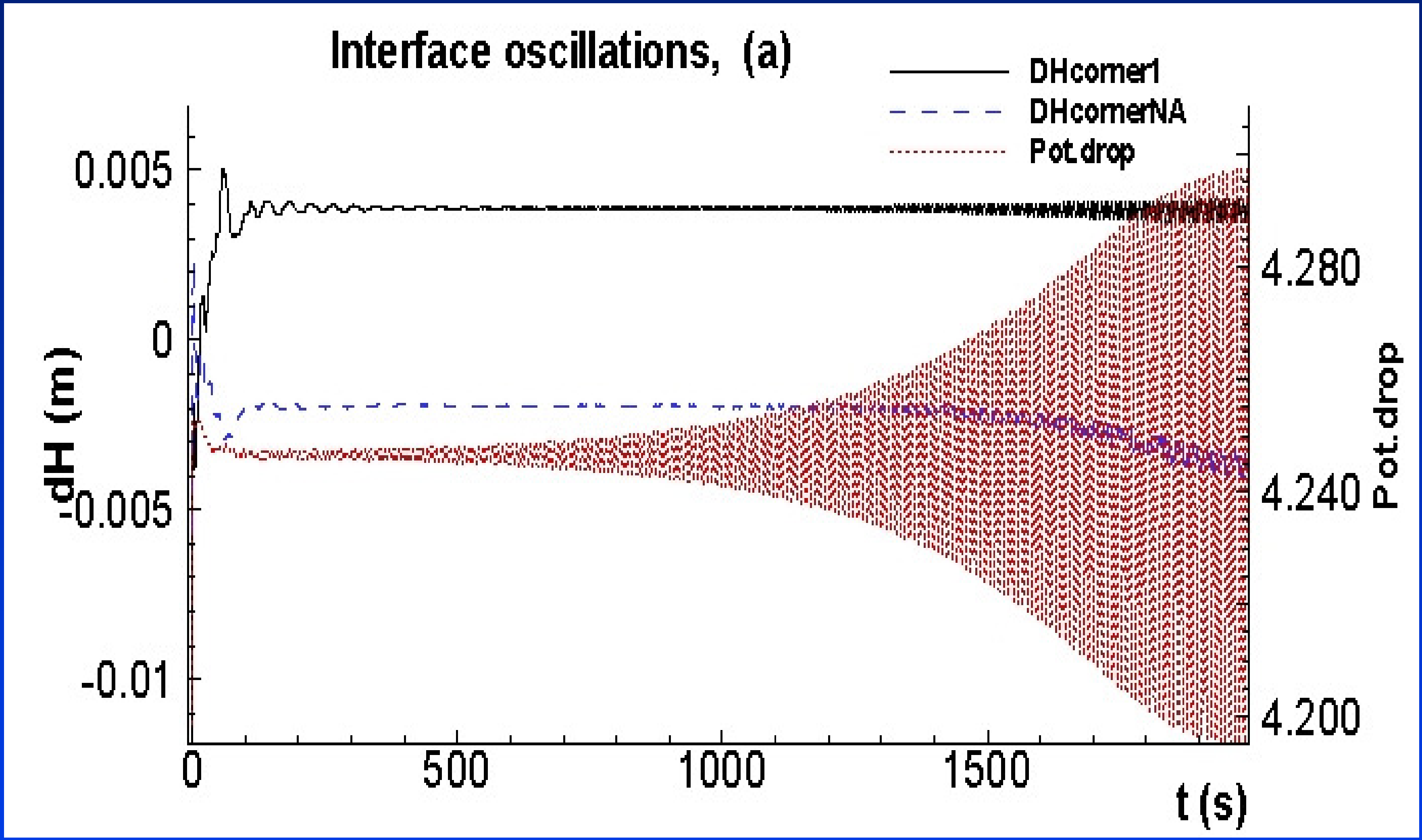
Calculated results with some anodes removed



Voltage fluctuation chart with anode removal of ACD=0.045m

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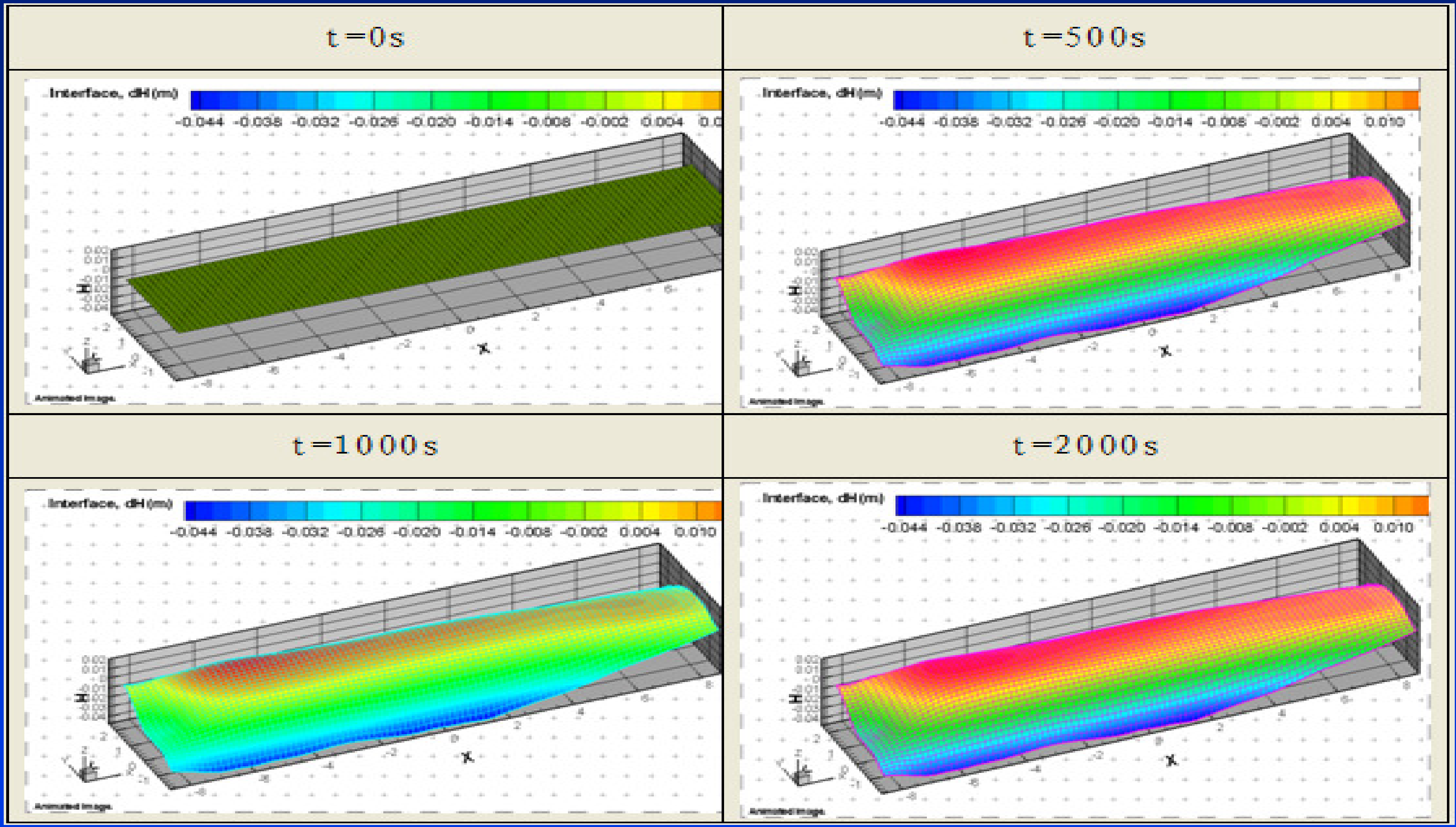
Calculated results with some anodes removed



Metal surface fluctuation chart with anode removal of ACD= 0.045m

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Conditions observed in production

This kind of pot has been in production for years, and it conditions observed in production are summarized as follows:

1) The pot voltage was minimized to about 4.0 V.

2) Under the conditions without anode change, metal tapping and AE, the pot is in good condition all the day without voltage fluctuation.

3) Once the pot has anode changed, generally within 8 hours it has bad stability, high noise and heavy voltage fluctuation, in this case even through the voltage is increased appropriately, it is hard to control the conditions.

4) Since the pot has anode change every day, the pot voltage fluctuation is a cyclic occurrence in sync with the cyclic of anode change time, thus brings out that the process technical conditions are hard to be stabilized quite often.

Comparison of calculated results vs conditions observed in production

The conditions observed in production are compared with the calculated results of pot MHD stability, and the analysis is as follows item by item:

1) **Under normal conditions, the calculated pot voltage can be minimized to 3.87 V while the noise is high.**

2) **Under normal conditions, if ACD is 0.040 m or more, the pot can remain stable.**

3) **The pot is sensitive to the anode change under ACD 0.045 m, so the pot can have instability period after anode change unless the ACD is more than 0.045 m, and hence the power consumption need to be increased.**

4) **As per statistics, generally the full current passes through new anodes 8 hours after they are put in the pot, so the pot is in special anode change conditions within one-third of the time of all day. Due to cyclic occurrence of anode change every day, the pot suffers an impact within 8 hours every day, which will certainly cause the successive unbalanced energy.**

Conclusions

- As the pot capacity increases, it will become more and more important to study the MHD stability which has the value of directing design and operating conditions.
- For the design of MHD stability, the normal conditions and the special anode change conditions of pot must be calculated fully.
- The calculation model of MHD stability in this paper is reasonable, calculated results and conditions observed in production match pretty closely, thus confirming the value of the MHD-Valdis software for the purpose of production applications.