



Council for Mineral Technology



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The Effectiveness of Resistance vs. Current Control of Submerged-arc Furnace Electrode Penetration in Selected Scenarios

4 June 2009

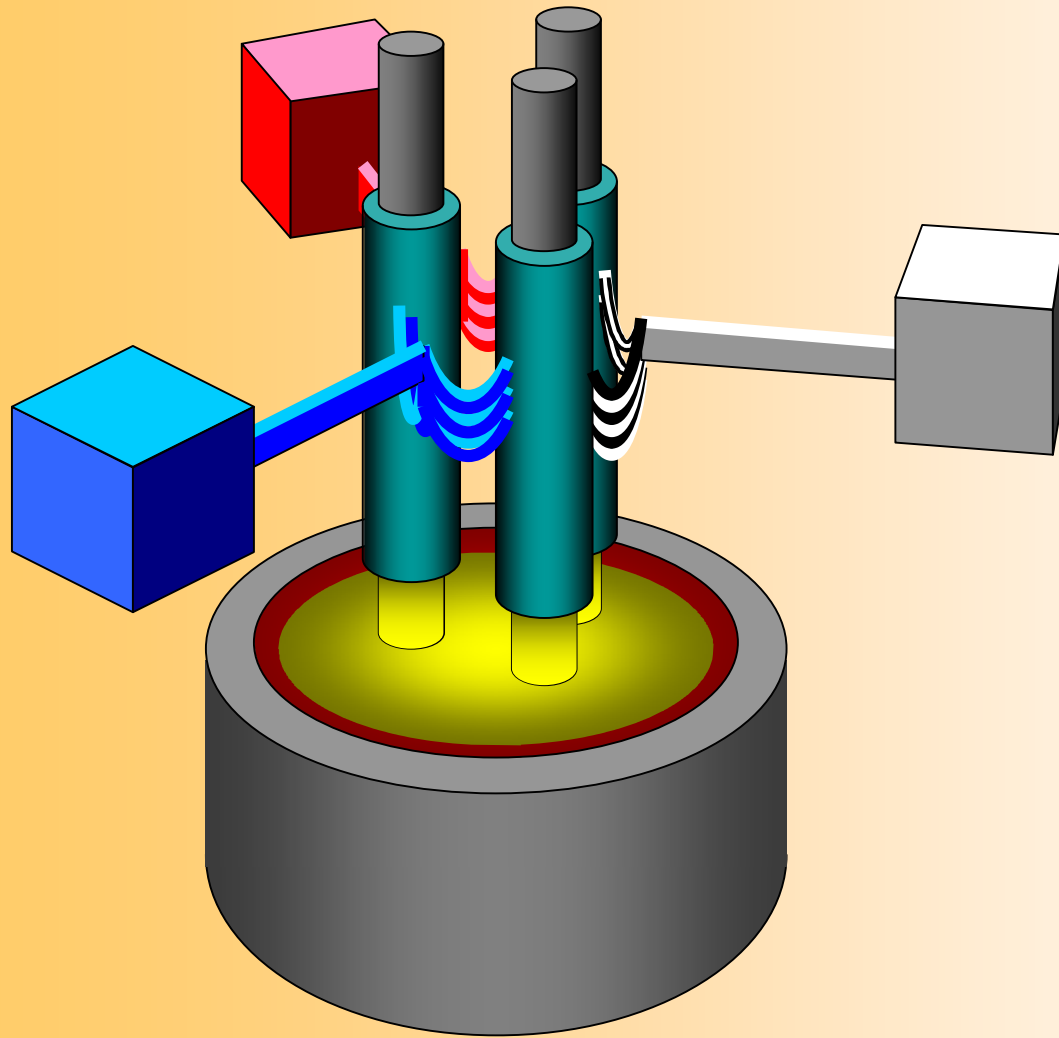
Chris Hockaday

Head: Furnace Control, Measurement and Control Division

Introduction

- Background of submerged-arc furnaces
 - Circuit
 - Electrode considerations
- Control of submerged-arc furnaces
 - Various methods
- Reasons for this study
 - May be circumstances where one is preferable to the other
 - Evaluate this from all angles, not just power input

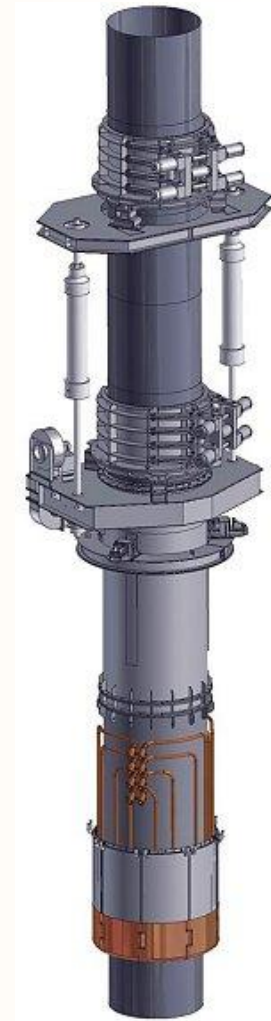
Submerged-arc Furnace



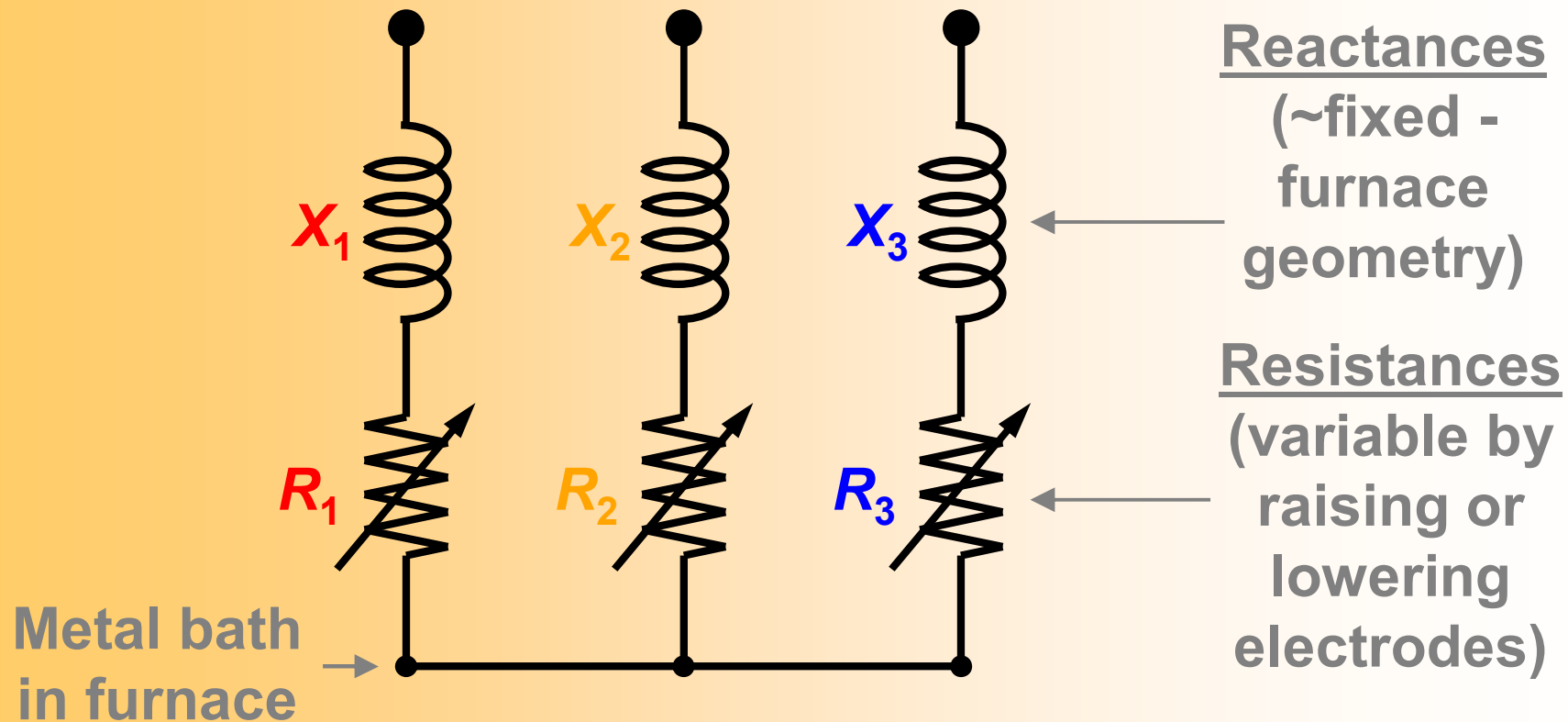
- Power supplied by three transformers
- Søderberg self-baking electrodes
- Electrodes interconnected via molten metal bath

Søderberg Electrodes

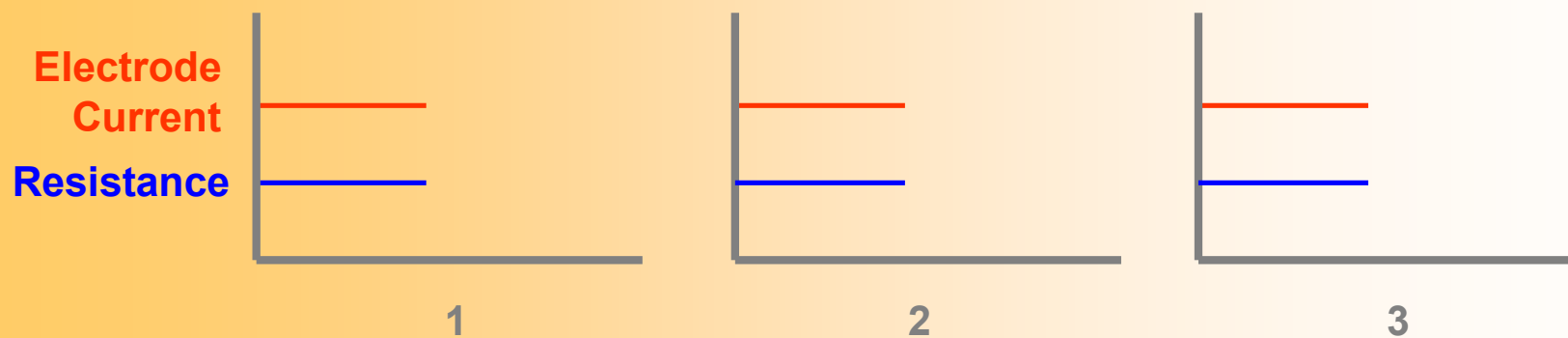
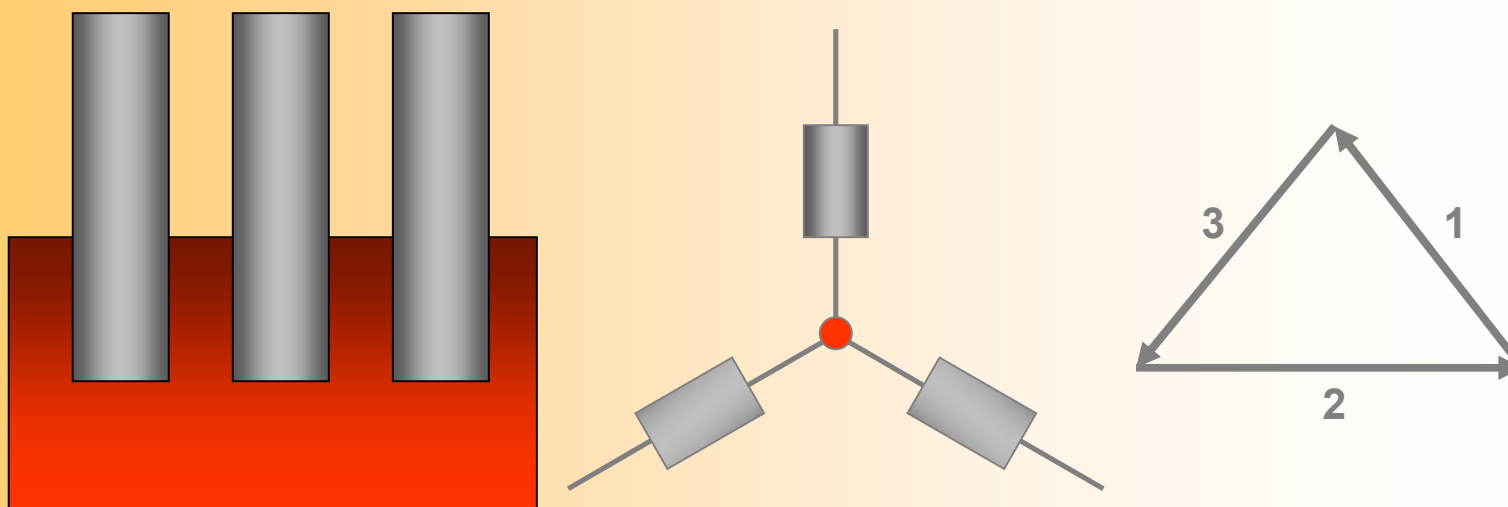
- Self baking
 - Steel casings
 - Paste blocks
 - Melted and baked solid by heat from the electrode's own current
 - Baking rate depends on $(\text{electrode current})^2$
- Slipping
 - Compensates for erosion of electrodes
 - Over/under slipping results in long/short electrodes
 - Slip rate needs to be matched with baking rate otherwise risk of breakage



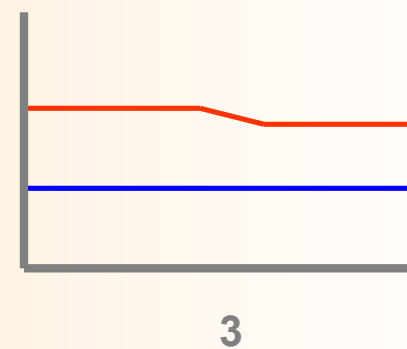
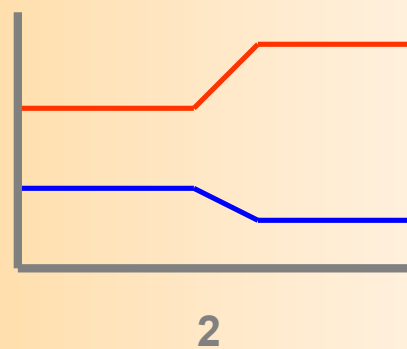
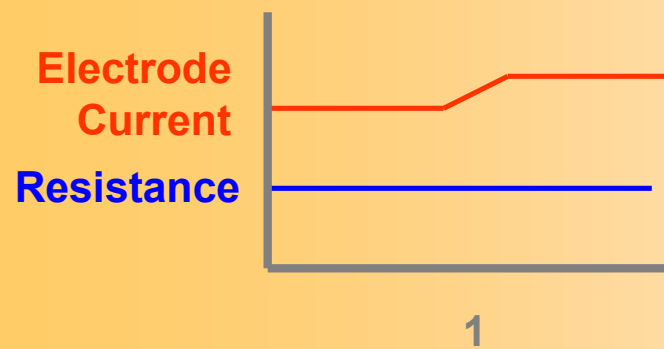
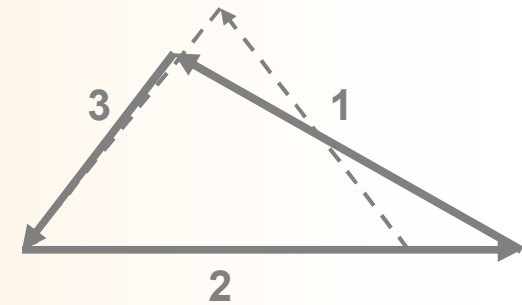
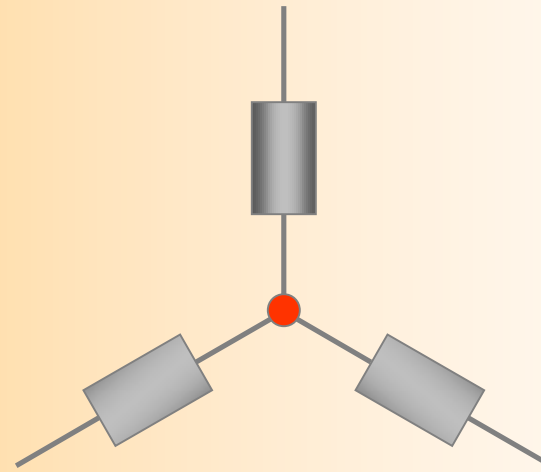
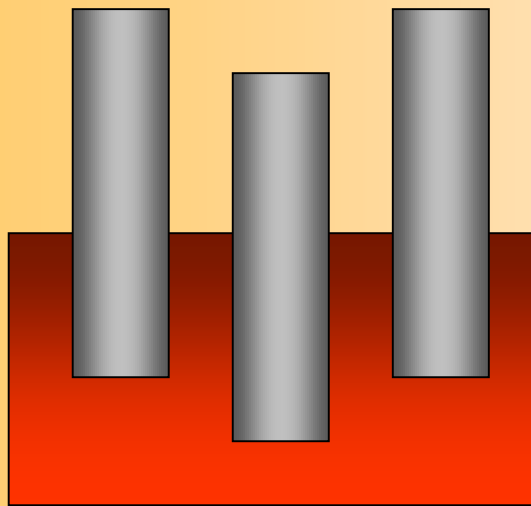
Basic Circuit of Submerged-arc Furnaces



The Interaction Effect



The Interaction Effect (2)



Control of Electrode Penetration

- Traditionally current control
 - Availability of measurements
 - Suffers from interaction effect
 - Variable penetration at different loads
- Impedance/Resistance control
 - Less sensitive to interaction effect
 - Difficult to measure reliably due to
 - Hearth connection
 - Induced errors in measurements due to magnetic fields
- Calculated resistance control
 - No hearth connection required
 - Can be calculated from primary side which can be measured more accurately

Purpose of This Study

- Resistance control generally accepted as superior to current control
- But: in upset/unstable conditions some furnace operators attempt to balance furnace:
 - current control
 - manual operation (invariably using current as a reference)
- Is this course of action justified under certain circumstances?
 - Consider from all aspects

Aspects Considered

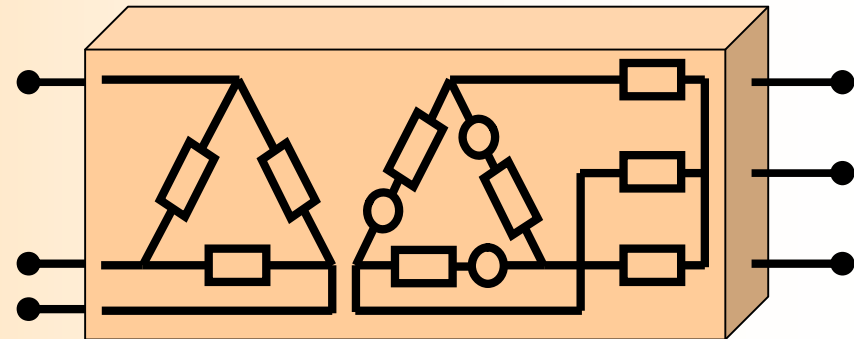
- Overall power input
 - Production
- Power distribution
 - Electrode consumption, build-ups, efficiency
- Hoist position
 - Efficiency
- Current asymmetry
 - Energy supply penalties
- Sum of squares error in current
 - Affects baking rate → maximum slip rate

Scenarios Considered

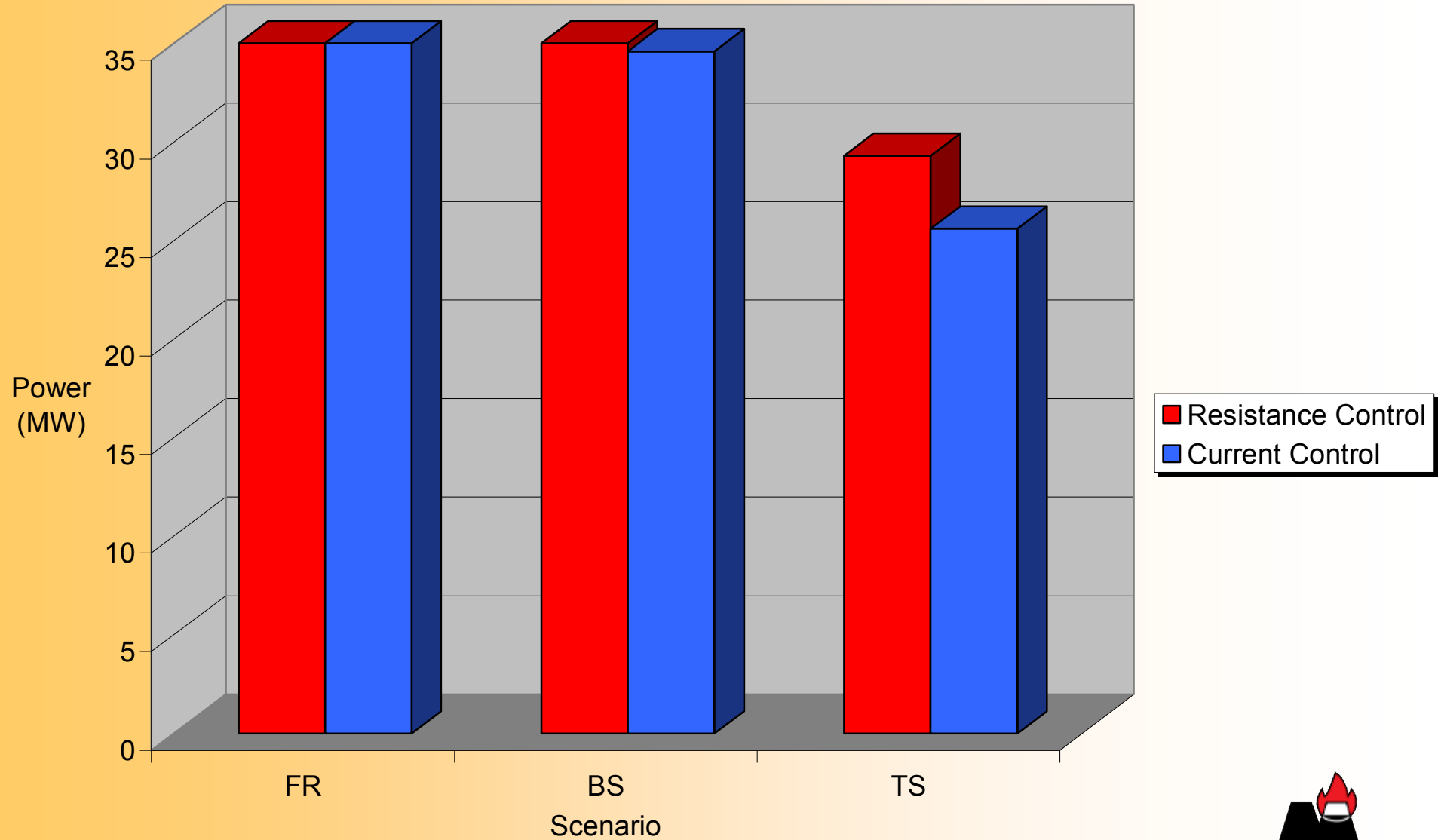
- All Electrodes Free (FR) $\updownarrow\updownarrow$
 - Analogous to having all electrodes near their correct, ideal lengths.
 - All electrodes operate within the limits of travel
- One Electrode On Bottom Stops (BS) $\updownarrow\downarrow$
 - Analogous to a short electrode on an industrial furnace
 - Electrode lowered to the bottom of its travel range in order to achieve the setpoint for resistance or current.
- One Electrode On Top Stops (TS) $\updownarrow\uparrow$
 - Analogous to a long electrode on an industrial furnace
 - Electrode lifted to the top of its travel range in order to achieve the setpoint for resistance or current.

Test Platform

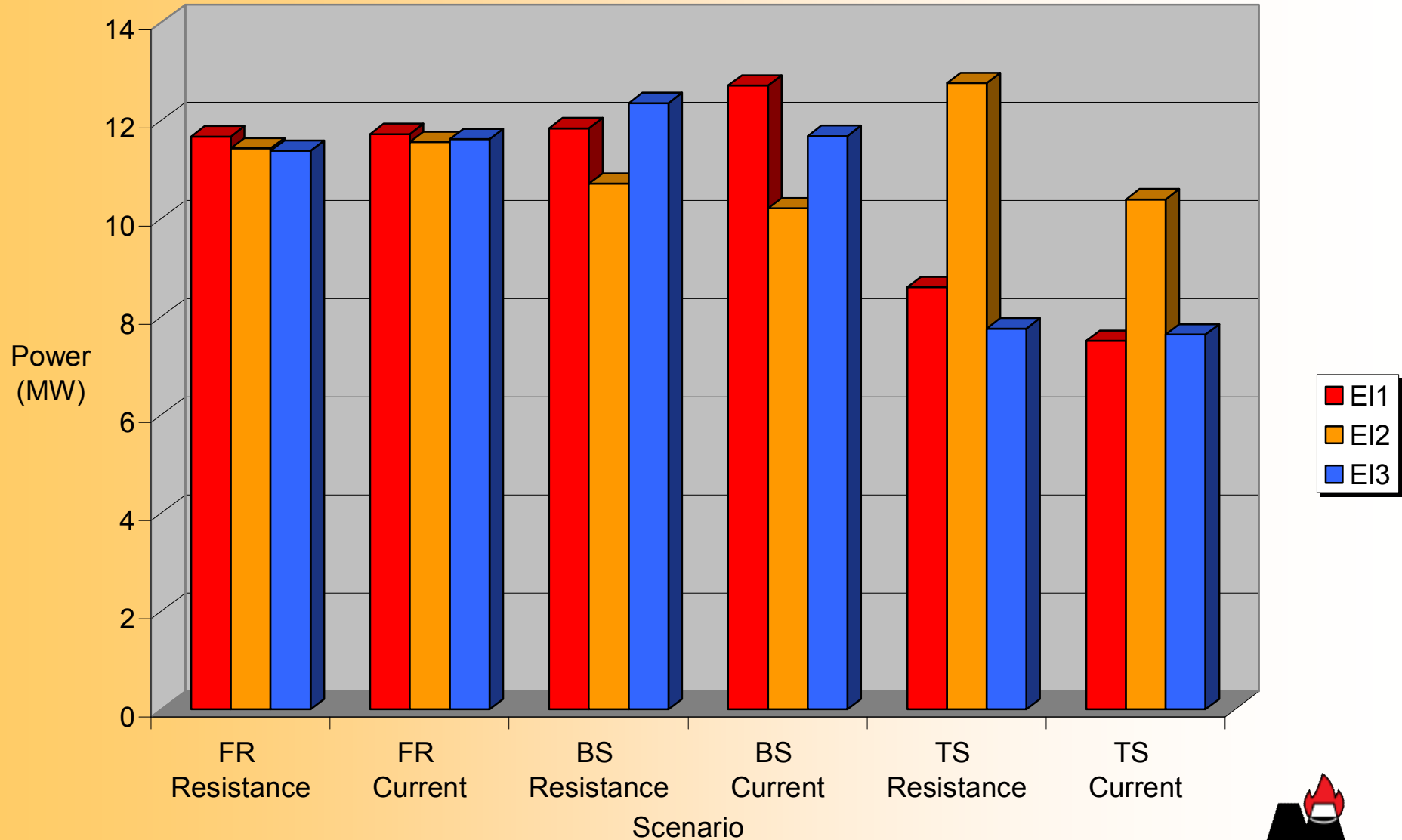
- Mintek Submerged-arc Furnace Simulator
 - Models entire electrical circuit
 - Disturbances simulated by adjusting metal bath level
 - Effectively alters tip-bath resistance/distance
 - Configurable rate and range
 - Configurable per electrode
 - Eliminates any effects caused by metallurgical conditions
 - Allows evaluation of electrical behaviour
- Simulation parameters
 - Furnace
 - 48 MVA Furnace
 - 88 kA electrode current limits
 - **Power factor ~ 0.85**
 - Control
 - 35 MW Power setpoint
 - 2.0 m Ω resistance setpoint
 - Conditions
 - Slow rate of change – tapping cycle
 - Rapid rate – burden collapse etc.
 - Disturbances simulated on electrode 3



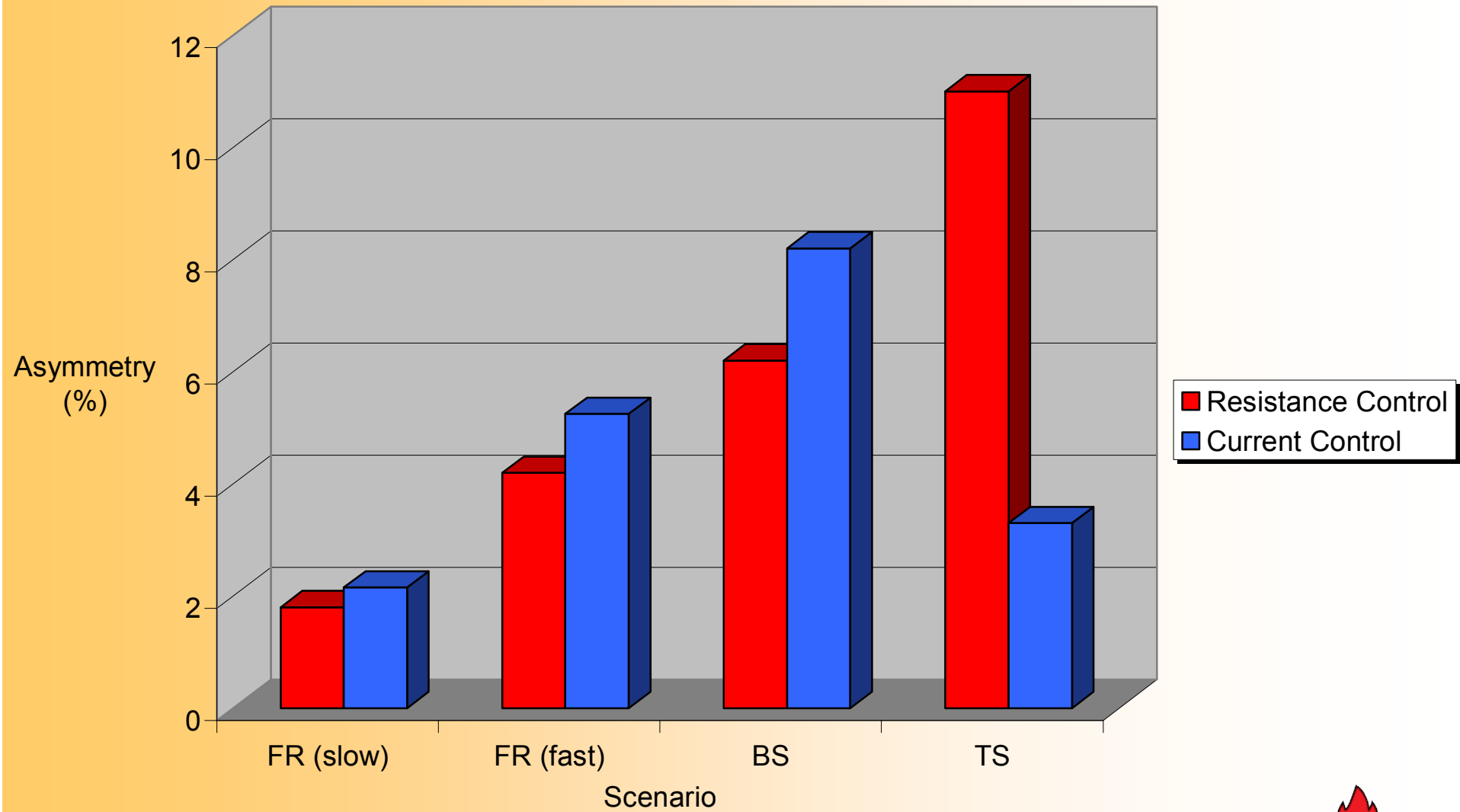
Results – Total Power Input



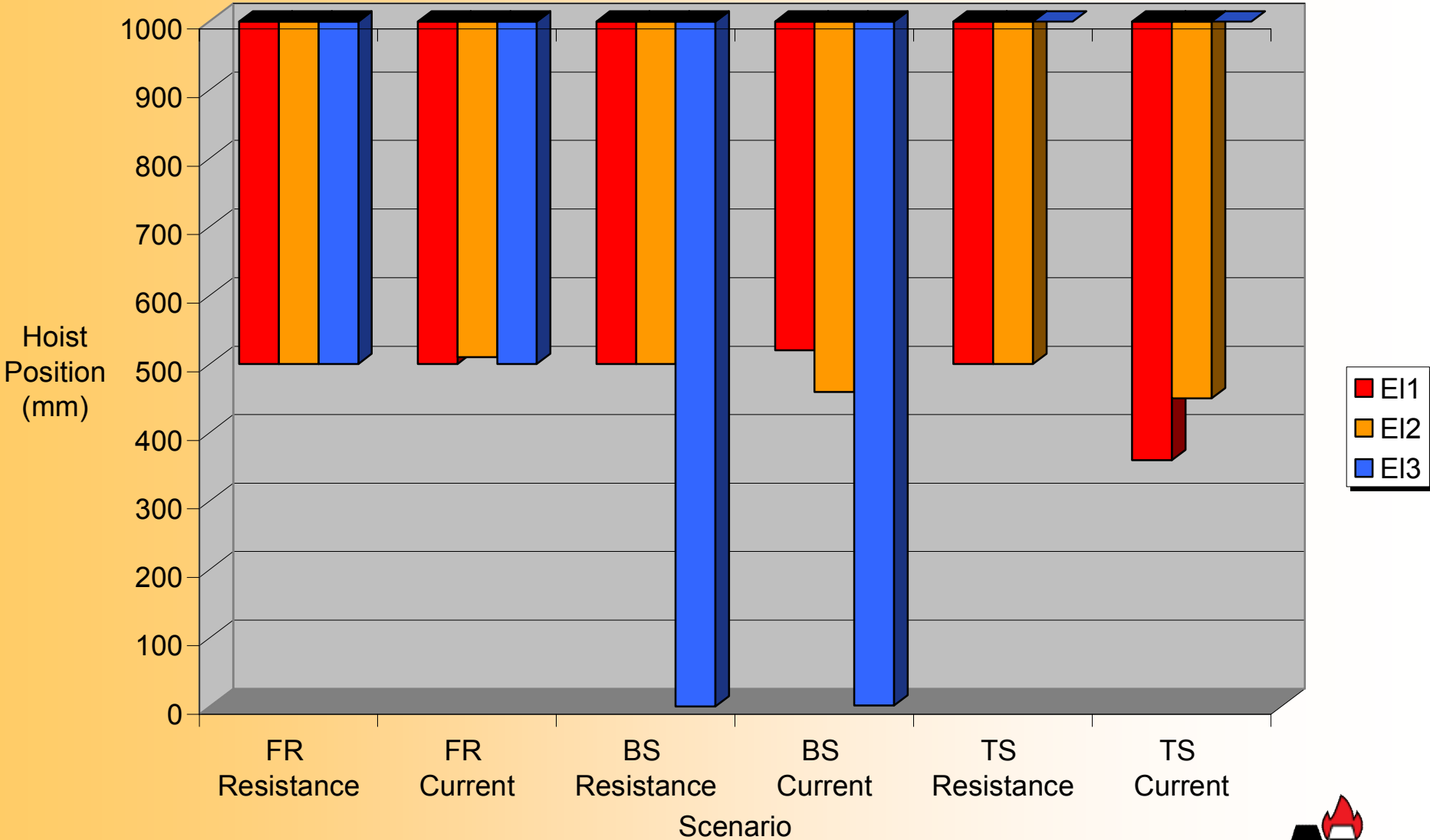
Results – Electrode Power Distribution



Results - Asymmetry

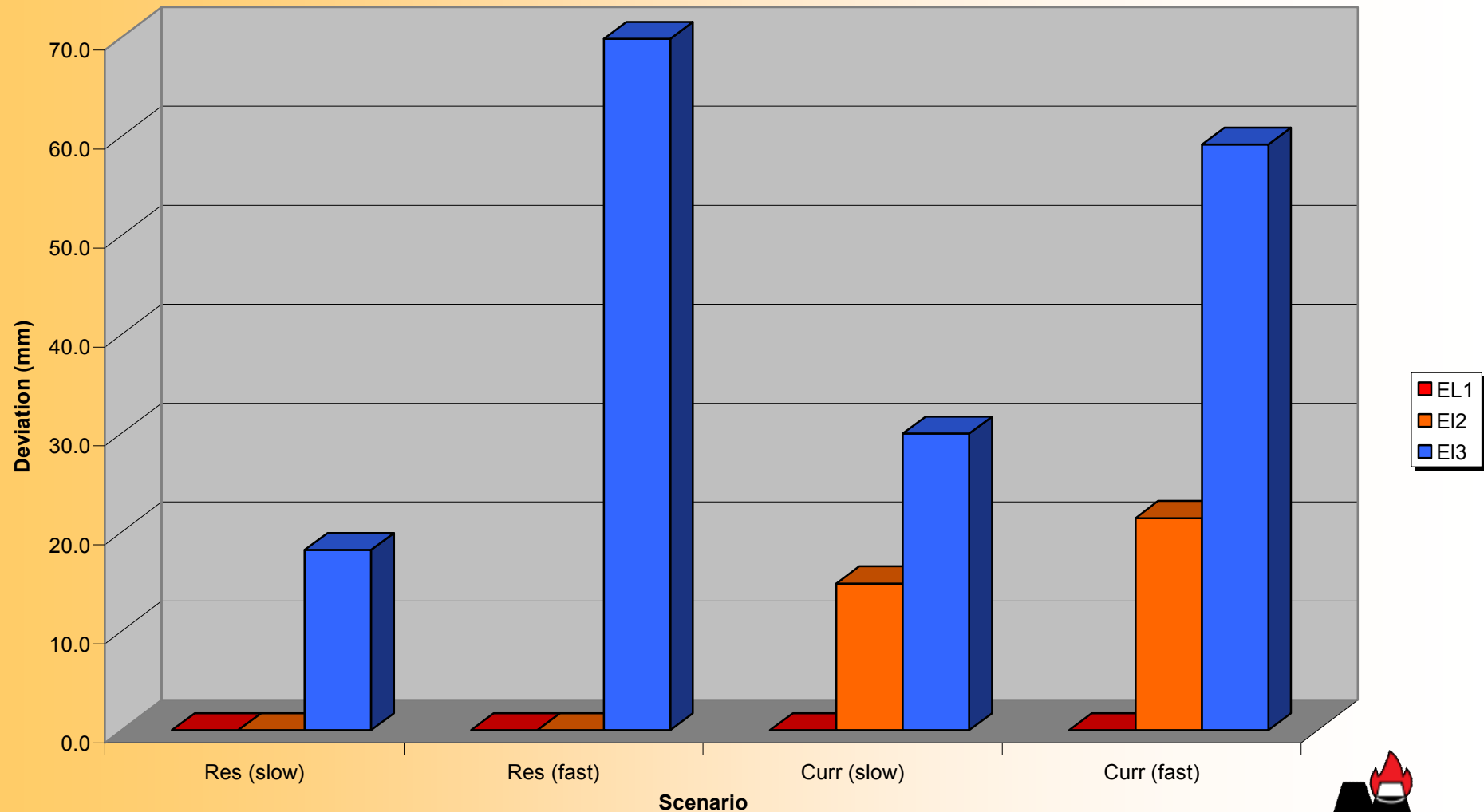


Results – Hoist Position



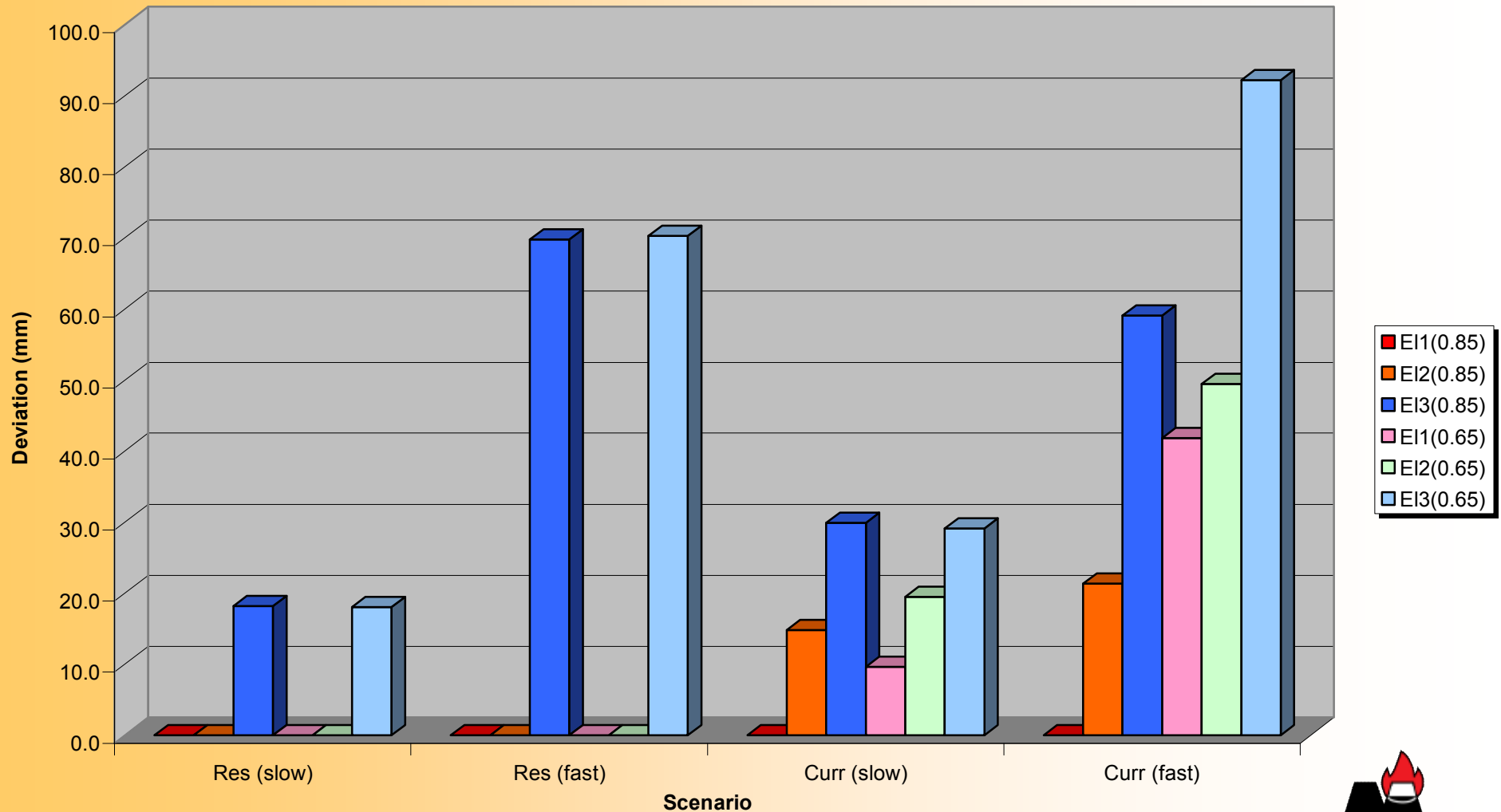
Electrode Penetration – Free Travel

Average Deviation of Tip-Bath Distance

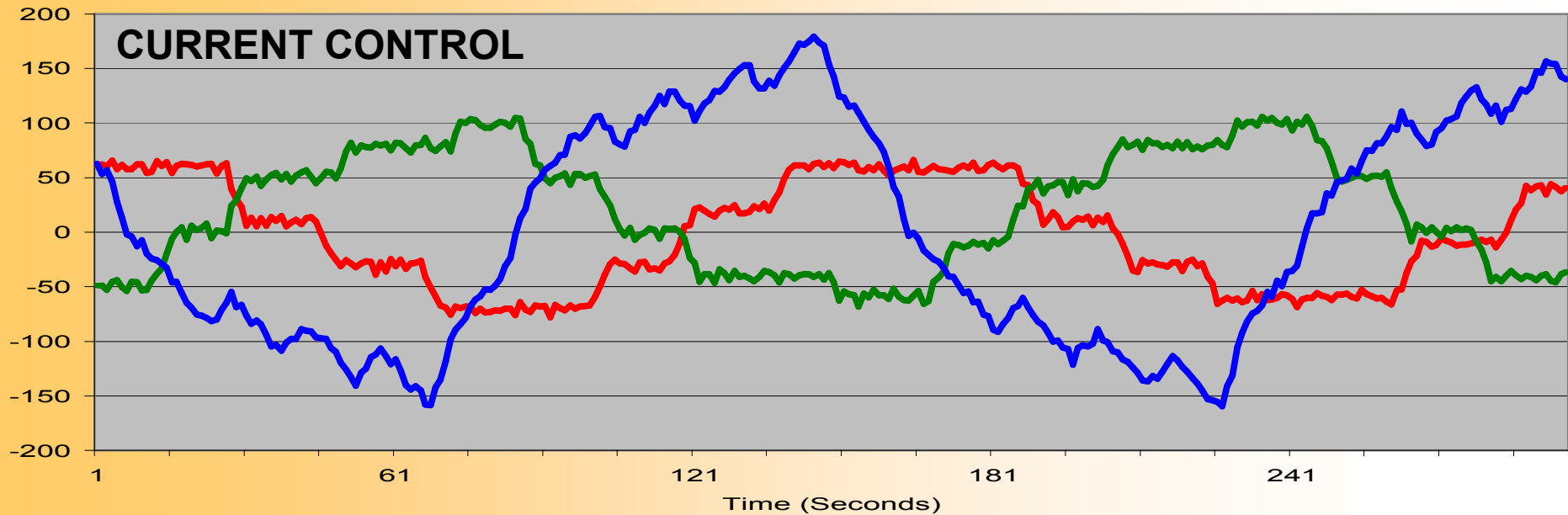
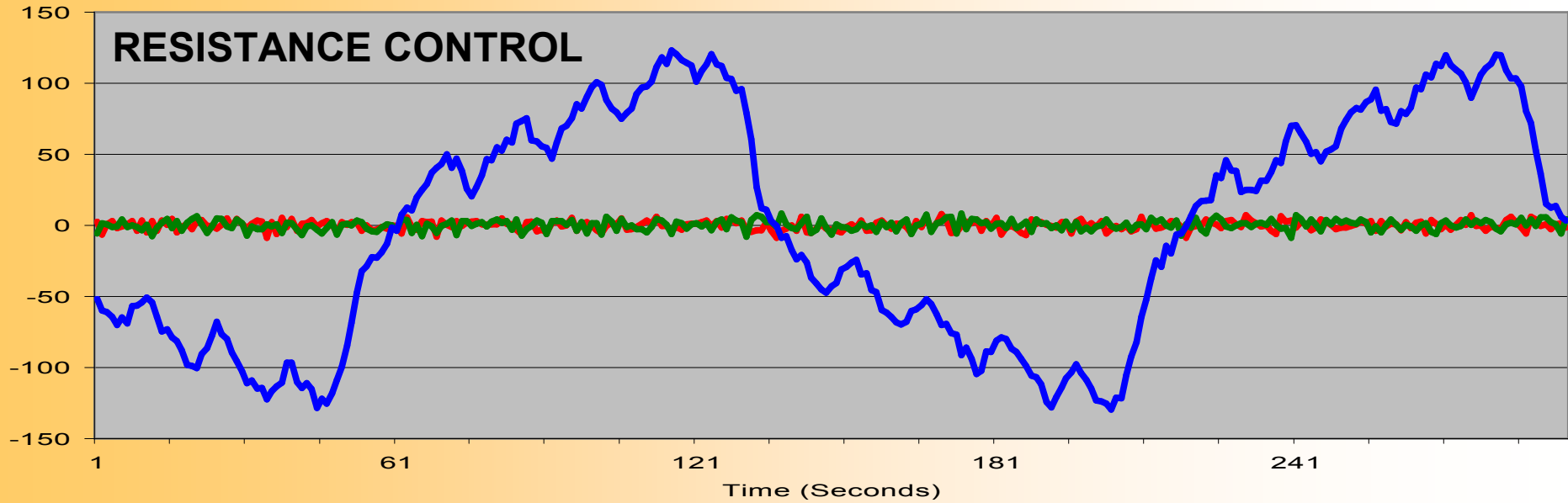


Electrode Penetration – Free Travel (2)

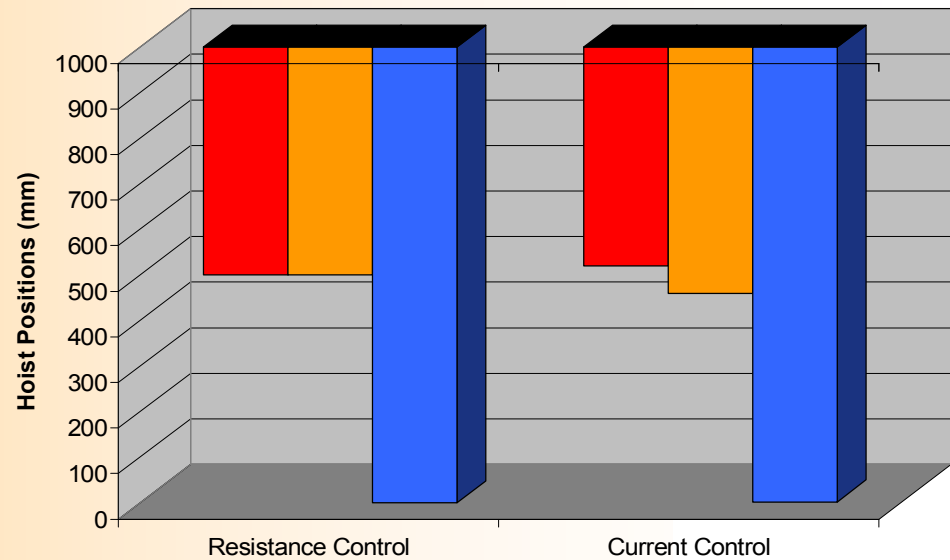
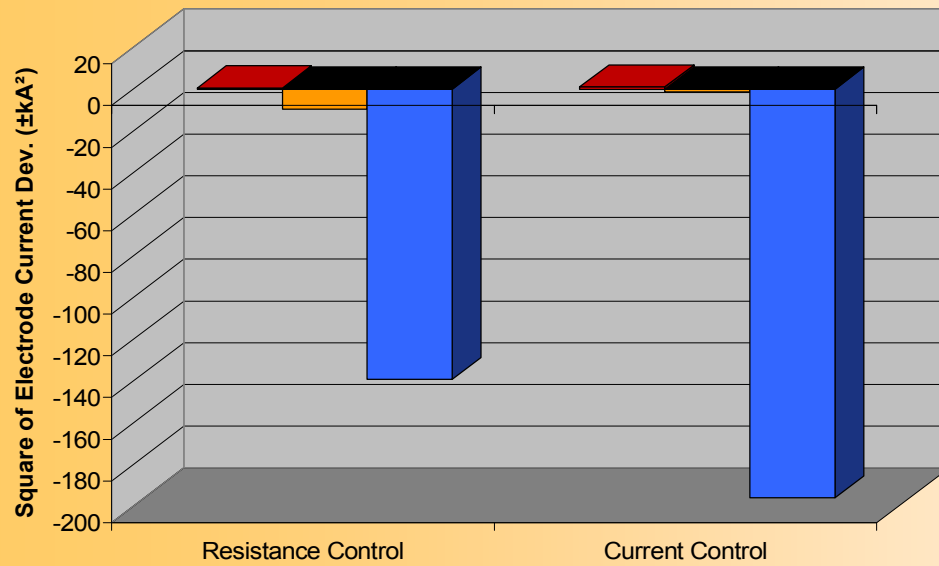
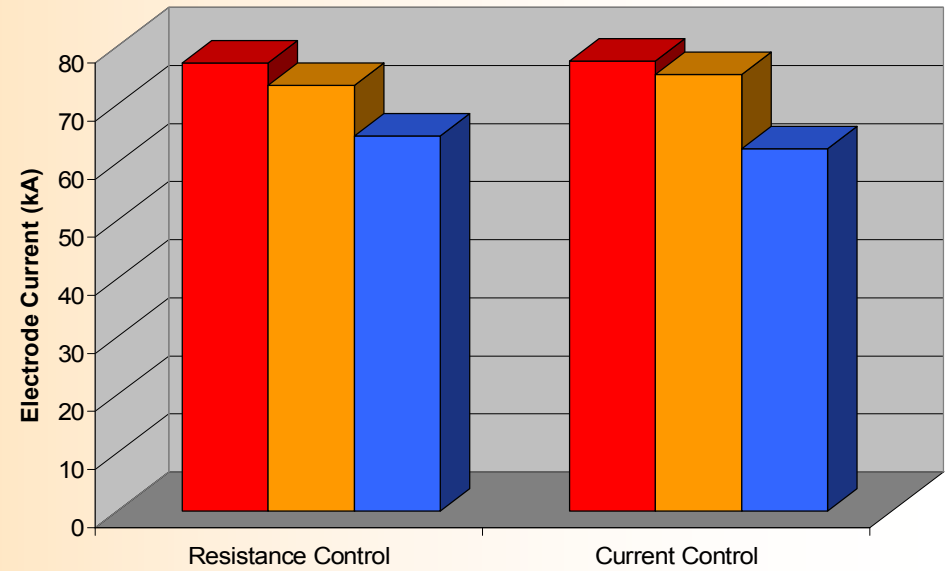
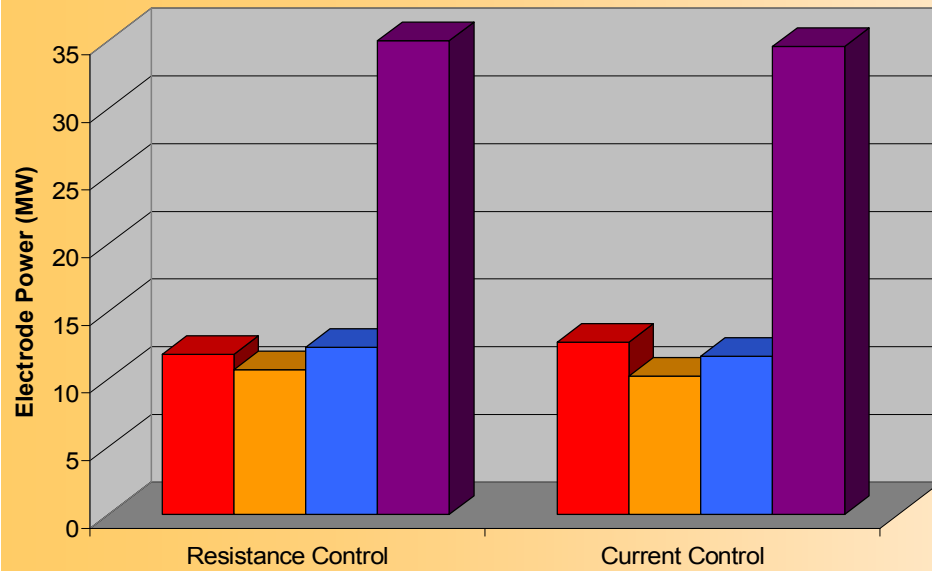
Average Deviation of Tip-Bath Distance (multiple power factors)



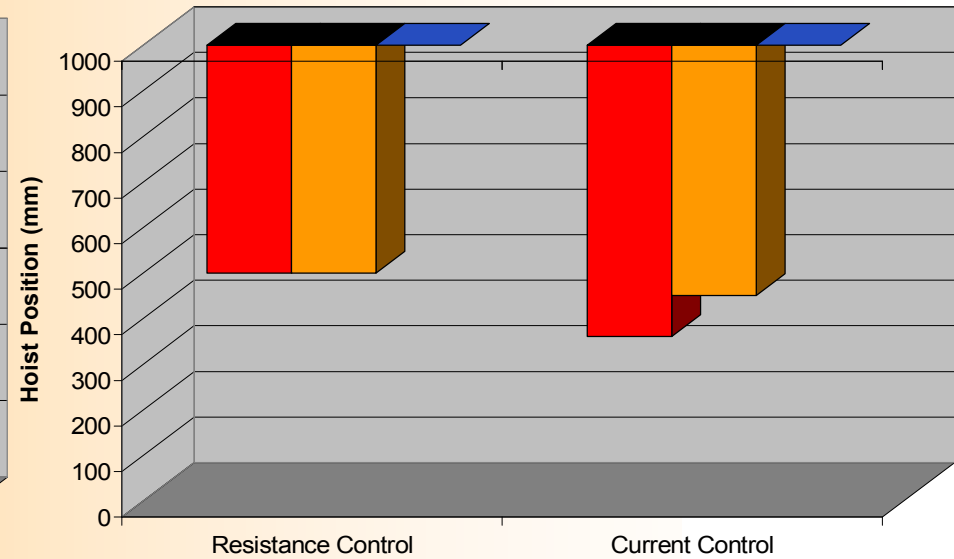
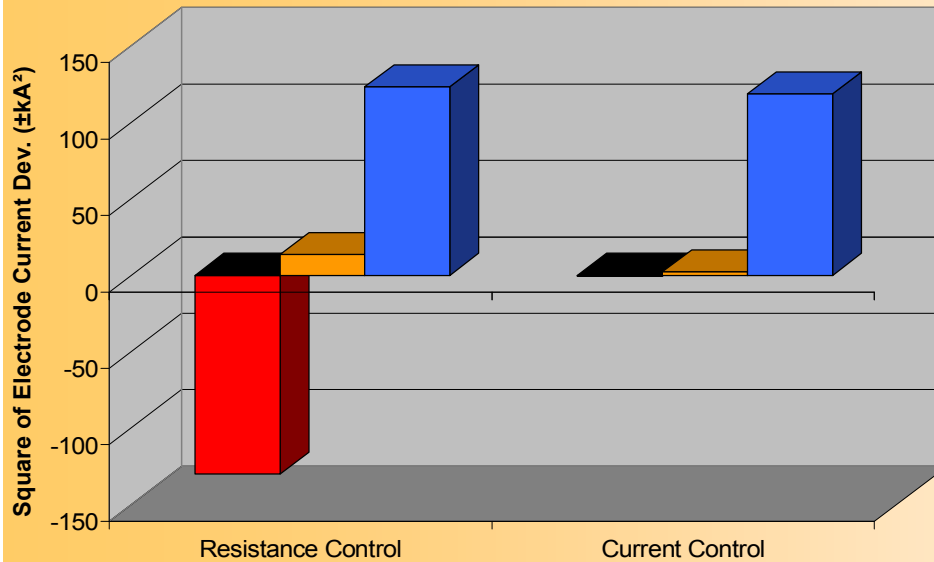
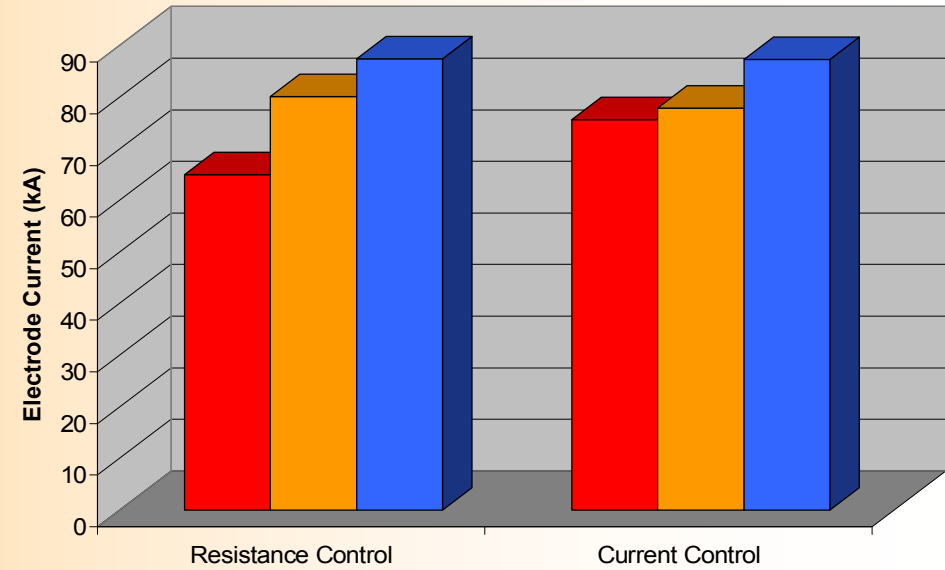
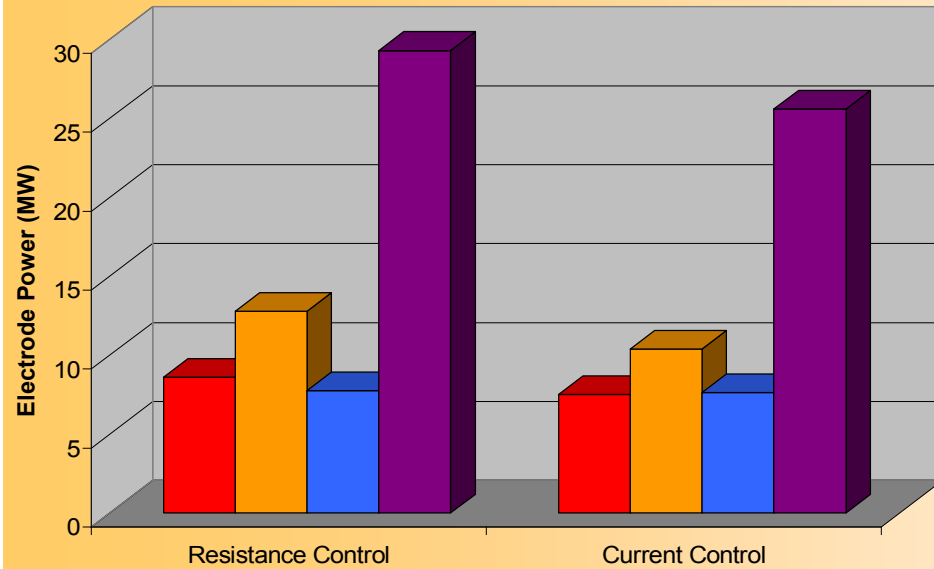
Electrode Penetration – Free Travel (3)



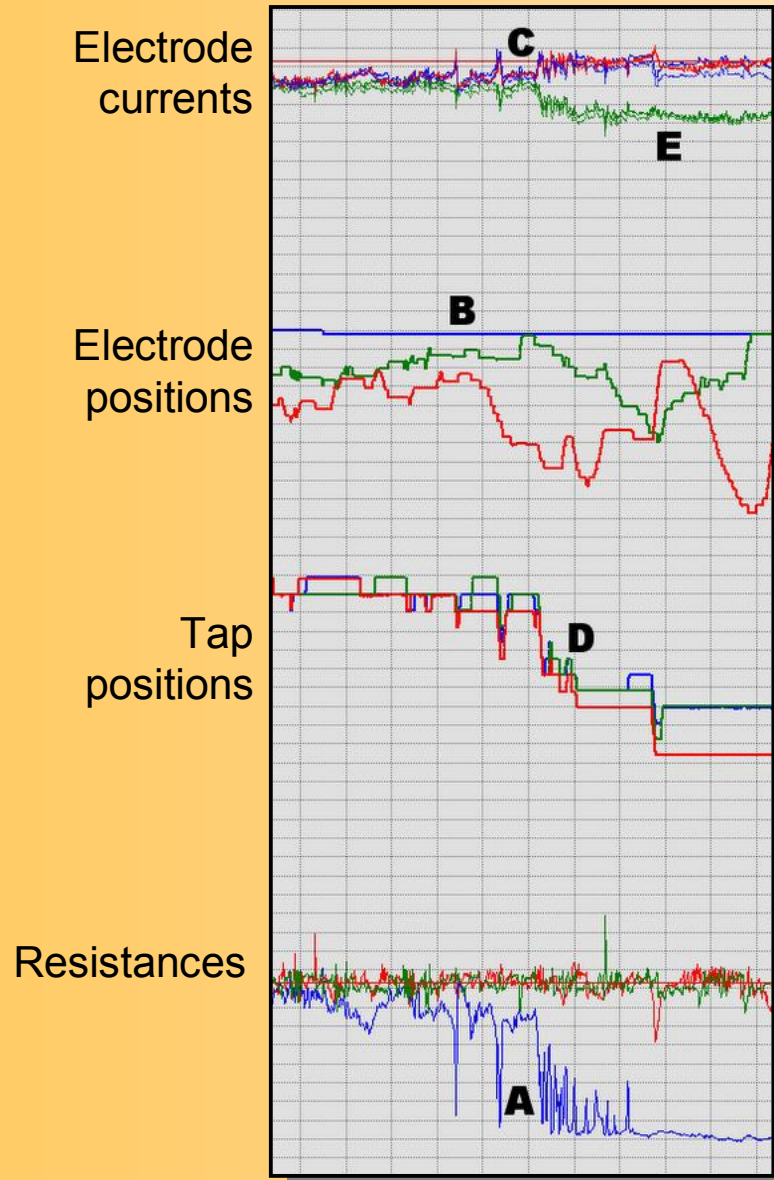
Summary – Bottom Stops



Summary – Top Stops



Top Stops – Real World Example



Explanation:

- A. Resistance 3 drops
- B. Electrode 3 already at top stops
- C. Current 3 (and 1) exceeds limits
- D. Controller taps down to reduce currents
- E. Current 2 drops

If under current control:

- F. *El 2 would be pushed in to restore current;*
- G. *El 3's current would increase further!*
- H. *Further tap down actions required yielding lower power*

Summary

	Resistance Control	Current Control
Free Travel ↑↑↑	Similar to current control in stable conditions, high pf	More unbalanced/more electrode movement in upset conditions (interaction effect)
Bottom Stops ↑↑↓	Balanced power, avoids chronic imbalance	MW on shallow electrode – low efficiency Chronic imbalance
Top Stops ↑↑↑	Better MW	Lower power Better penetration, symmetry & I ² -> better baking

Options/Conclusions

- Better to use resistance control under all scenarios, including top stops, unless baking of electrodes is a major issue
- With a flexible control platform one could monitor electrode conditions, slipping, baking zone etc and intelligently adapt control method
- Little justification, however, since power input is typically the main objective from a production perspective

Thank you



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