Adaptive Control

David Androvich & Ellis Mayton

AWS SMWC Tutorial, October 16, 2018

Table of Contents

1

What is Adaptive Control?

- A tool to analyze welding data and make intelligent corrections based on that analysis.
  - The analysis is based on an input of a new variable(s) supplied to the weld control that is related to nugget diameter.
    - Steel – Dynamic Resistance obtained by secondary tip wires
    - Aluminum – Dynamic Force obtained by strain or load cells in the gun
  - The corrections are automatically made to weld current and/or weld time during the weld schedule.

1 What is Adaptive Control?

- Adaptive control is not:
  - A tool to solve impossible weld problems. If you can not make a good constant current weld you generally can not make a good adaptive weld.
  - A tool that will operate forever without normal weld and tooling maintenance.

- There are two types of adaptive controls:
  - Those that rely on internal algorithms to make adjustments.
  - Those that use a stored "reference weld" and algorithms to make adjustments. These types generally have a better ability to adjust for disturbances.

What is Adaptive Control?

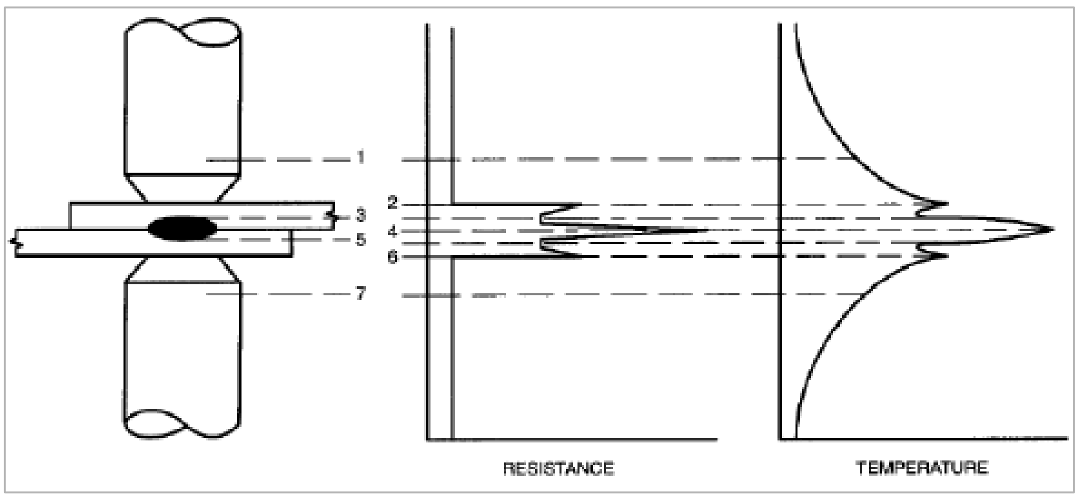
1

- Adaptive controls are designed to compensate for the following levels of production disturbances:
  - Material thickness and composition variations
  - Electrode wear (without using steppers)
  - Weld force variation
  - Gun fit up
  - Expulsions
  - Sealers
  - ……Etc
- When Adaptive controls sense an inability to compensate for a disturbance, a new series of alerts/alarms are generated.

2 Resistance's Relationship to Quality

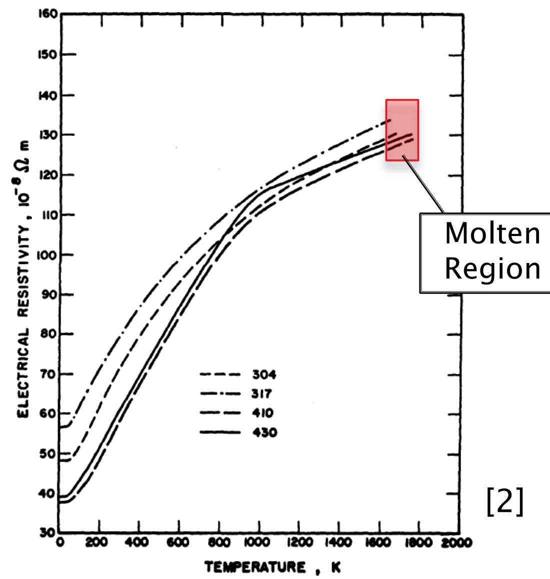
- The heat generated at the faying resistance creates the nugget.

$$Heat = I^2 \cdot R \cdot t$$



[1]

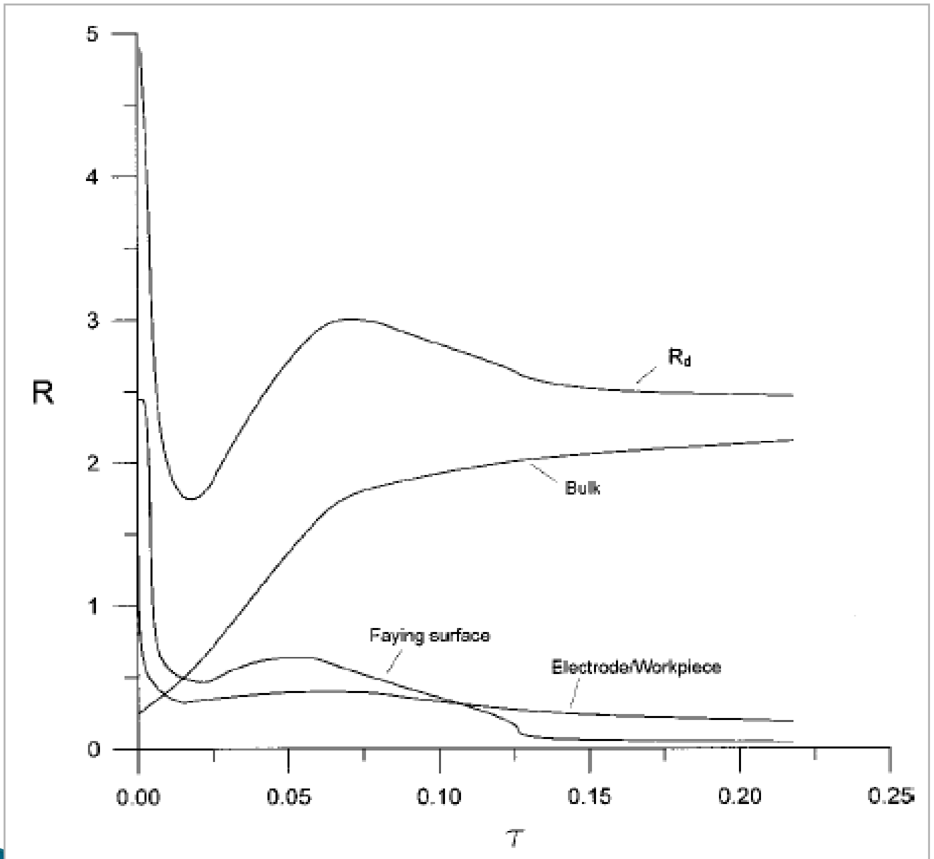
$$R \propto \frac{\rho \cdot l}{A}$$



[2]

2 Resistance's Relationship to Quality

- The bulk & contact resistance values fluctuates during the weld as a result of the mechanisms of nugget formation.



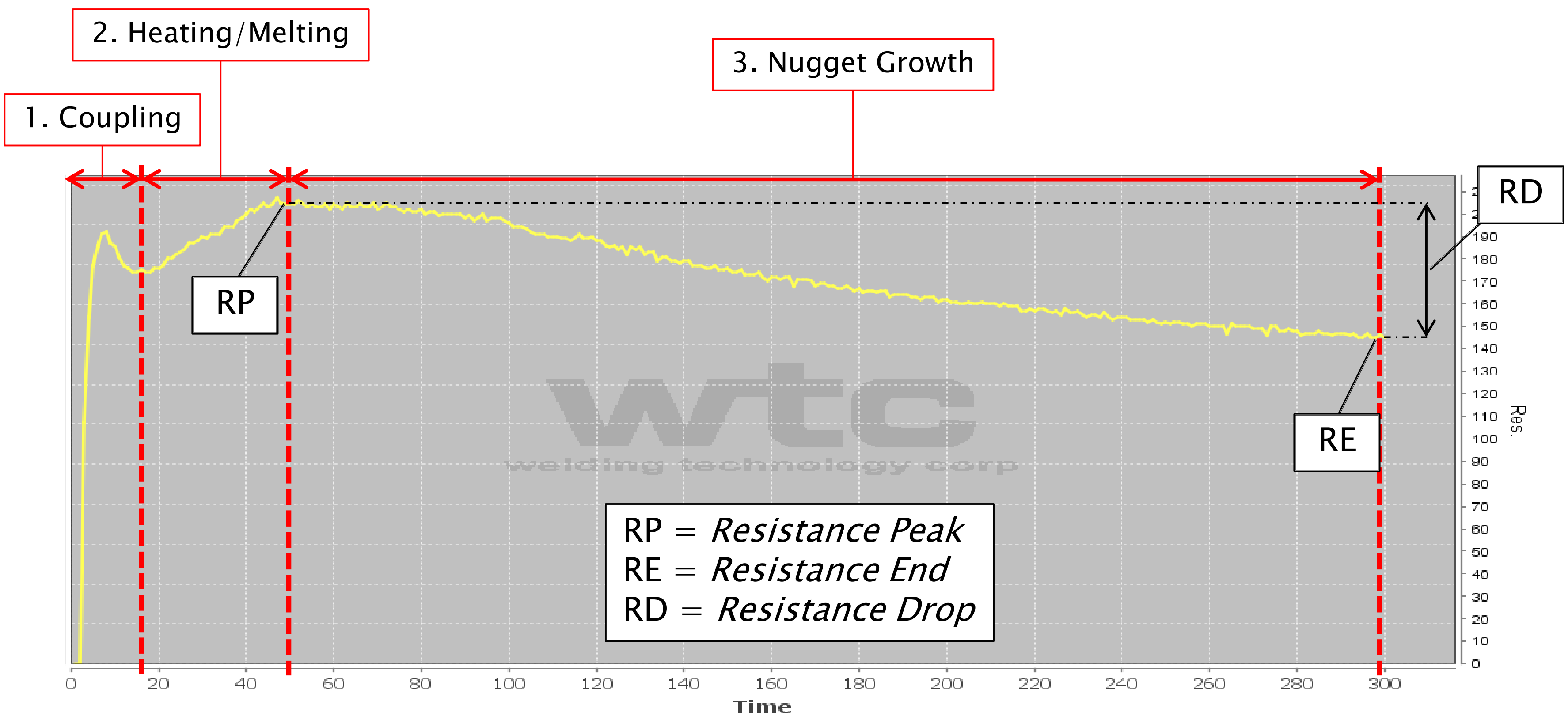
[3]

The total dynamic resistance observed during RSW is the sum of:

- Contact resistance between the metal sheets (faying surface
- Bulk resistance of the metal sheets
- Contact resistance between the electrodes and sheets
- Bulk resistance of the electrodes and the electrode holders

3 Importance of the Resistance Curve

- The dynamic resistance curve can take on a variety of shapes, but will generally exhibit 3 phases.
- The data from the curve provides quality indicators for the weld.

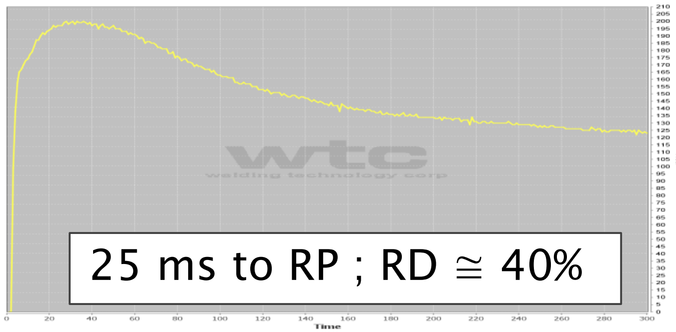


*Constant Current Data

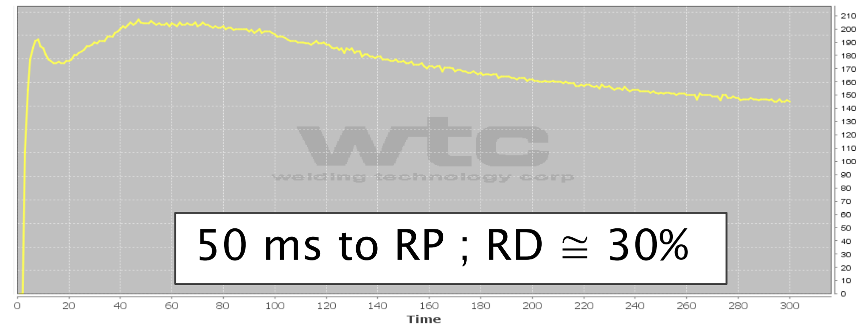
Importance of the Resistance Curve

Different materials = Different resistance characteristics

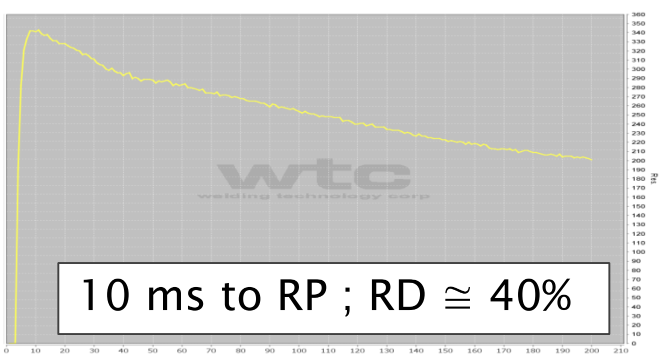
Mild/Bare



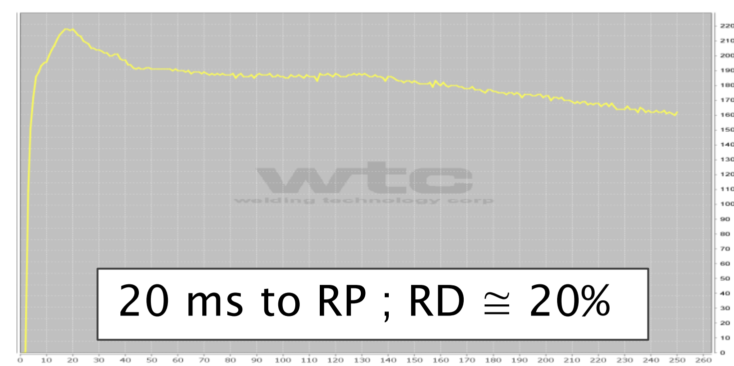
Mild/HDG



AHSS (Boron; Hot Stamped)



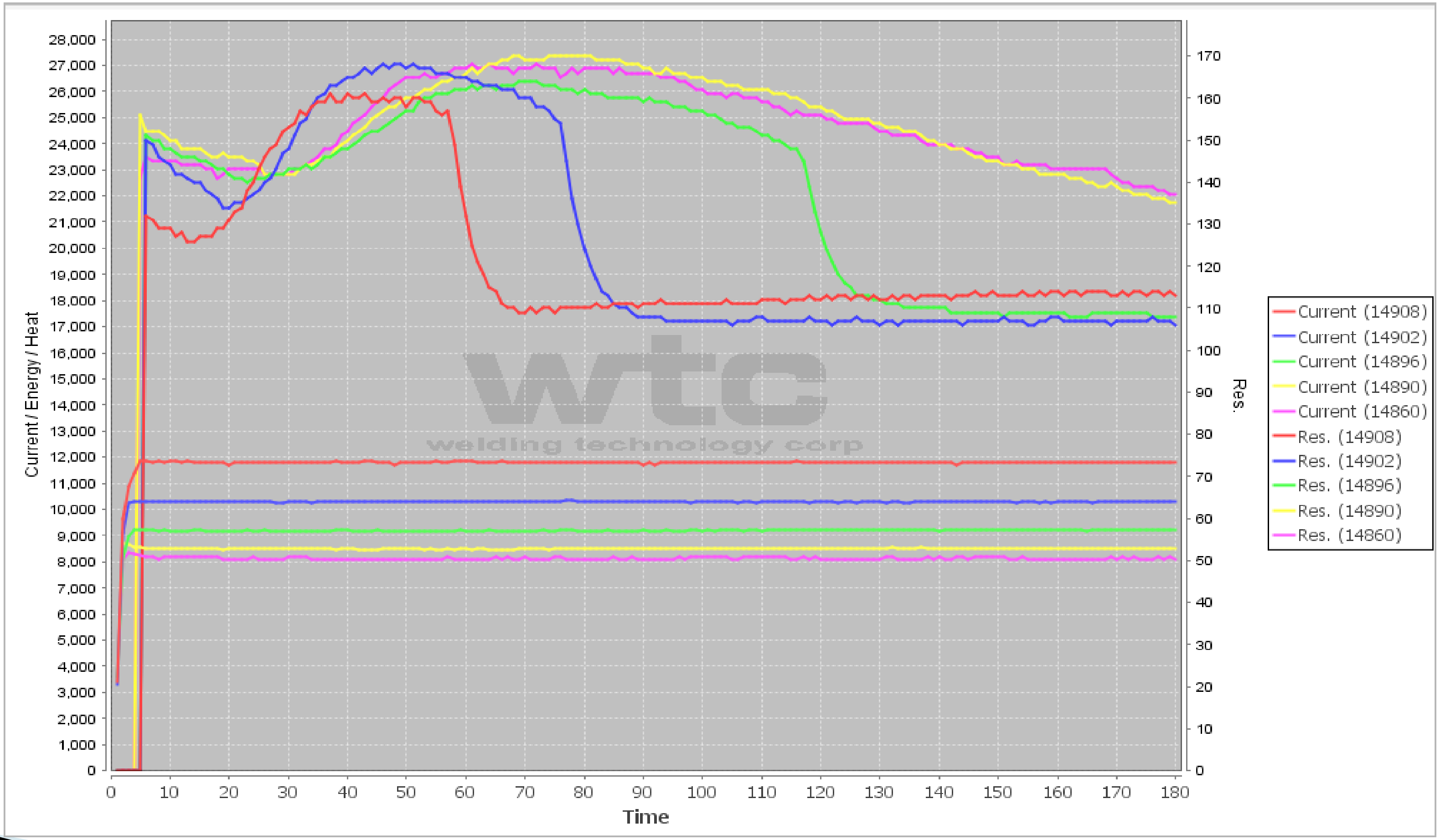
DP980/EG



**Constant Current Data*

3 Importance of the Resistance Curve

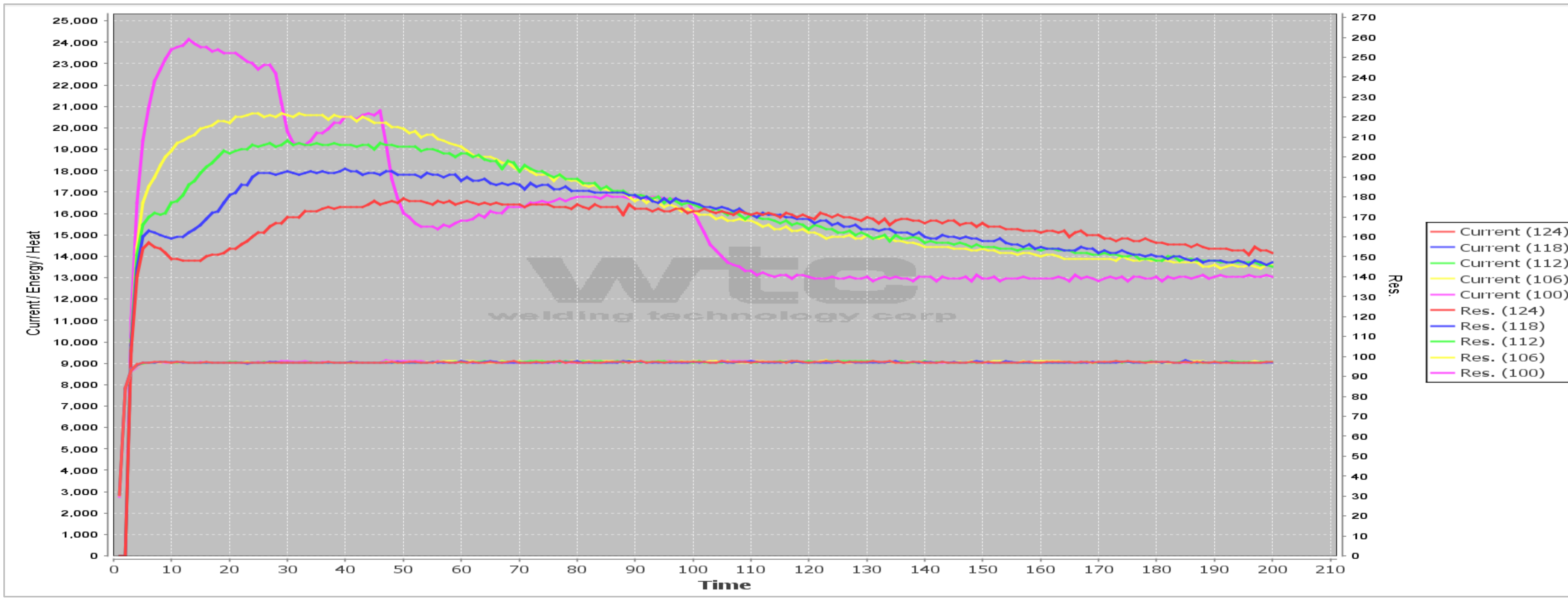
Weld current level effects the resistance curve.



**Constant Current Data*

3 Importance of the Resistance Curve

Weld force effects the resistance curve.

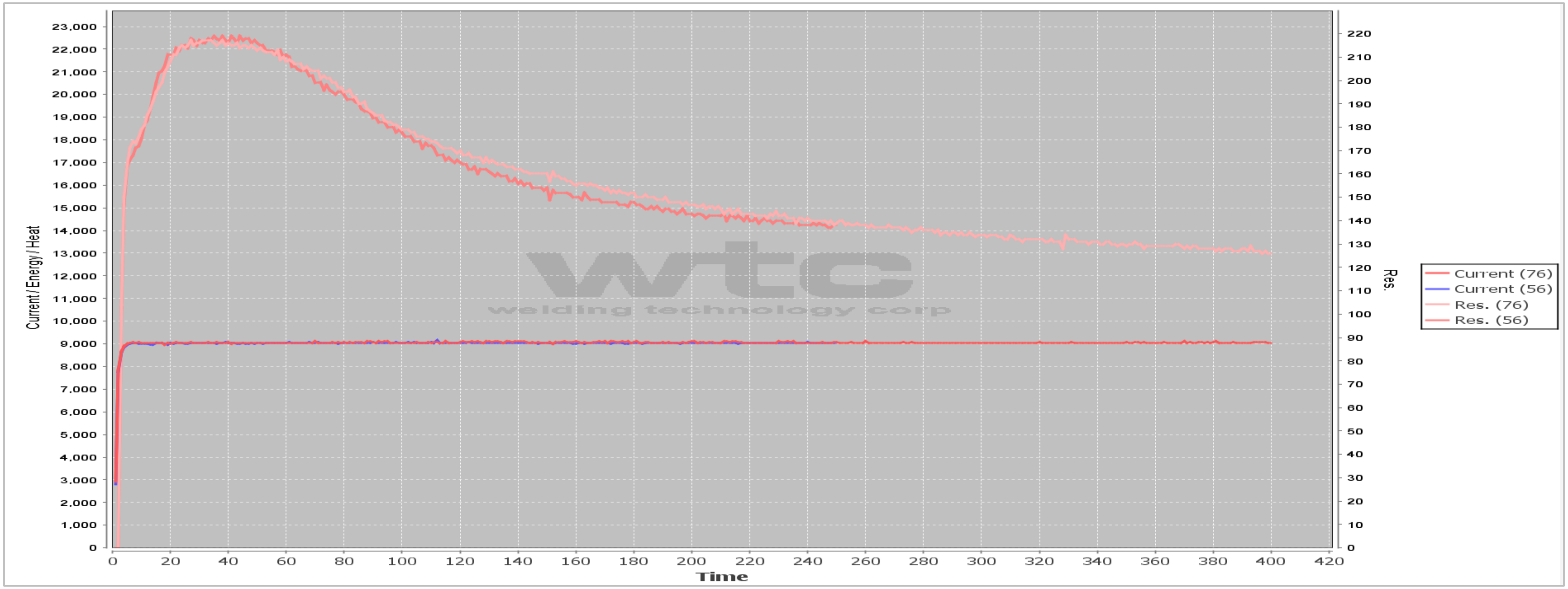


300 lb
450 lb
600 lb
750 lb
900 lb

**Constant Current Data*

3 Importance of the Resistance Curve

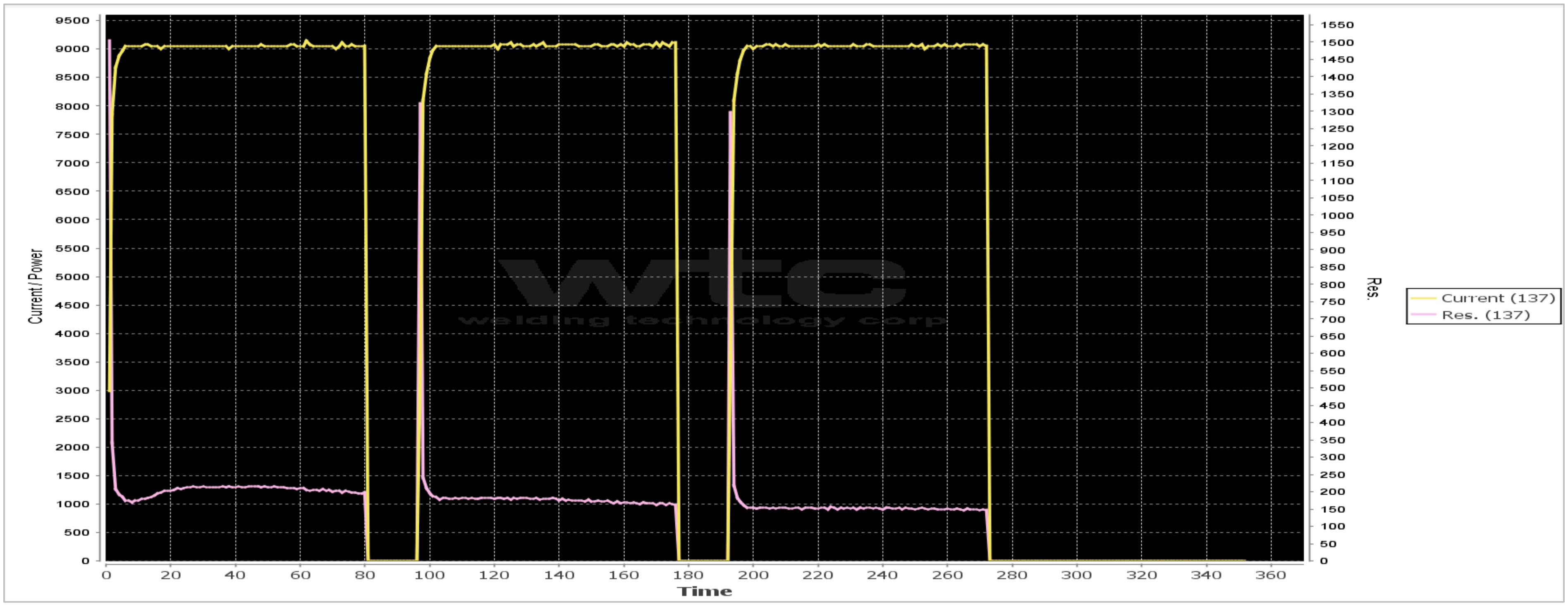
Weld time effects the resistance curve.



**Constant Current Data*

3 Importance of the Resistance Curve

Pulsation effects the resistance curve.

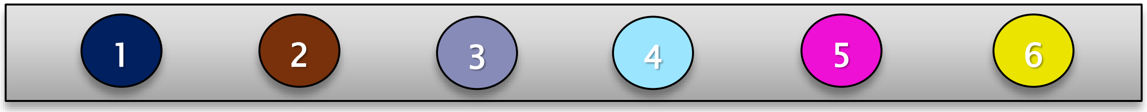


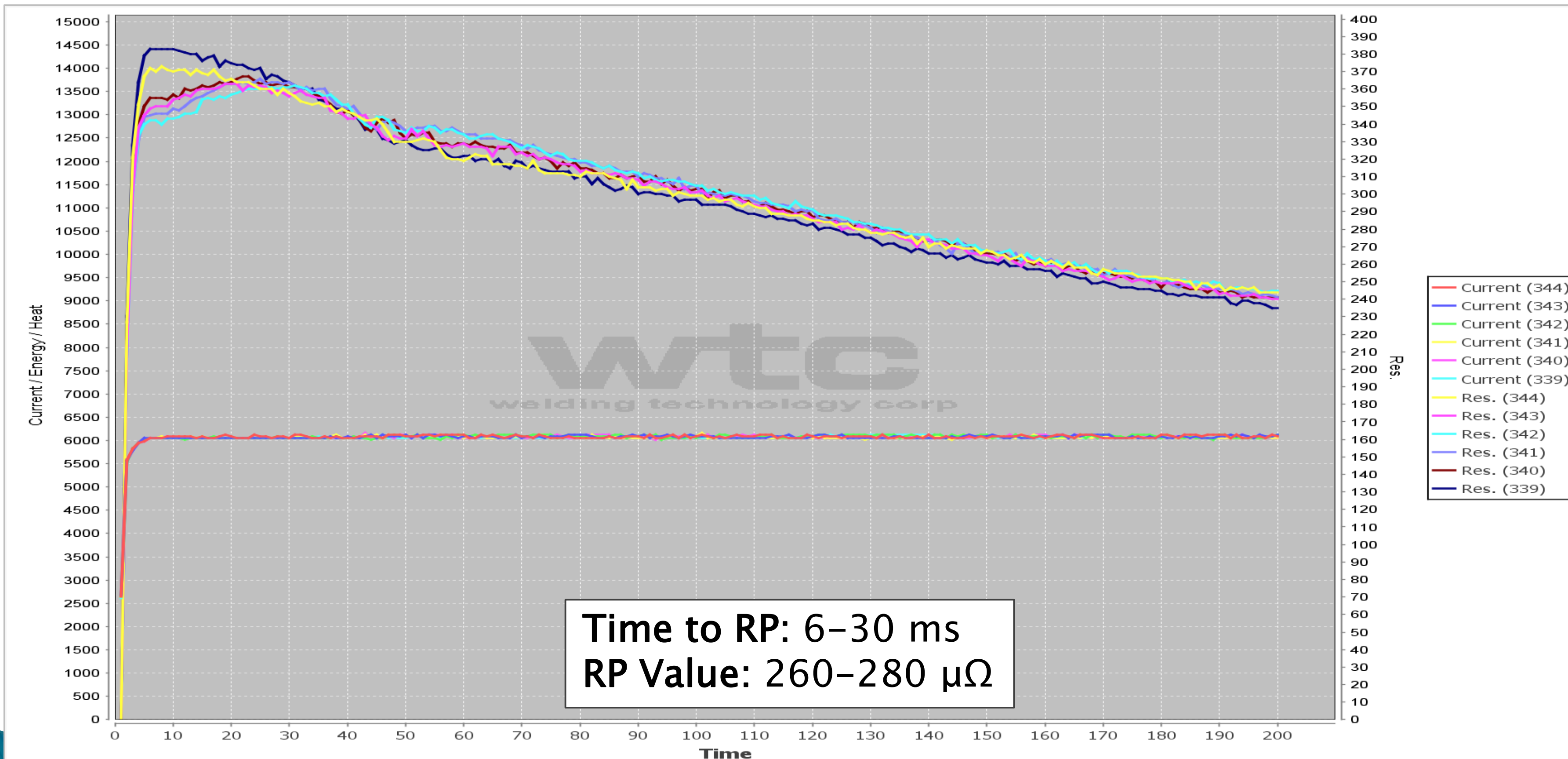
3 impulses (80ms @ 9000A , 20ms cool/off)

**Constant Current Data*

3 Importance of the Resistance Curve

Different weld locations = Different resistance characteristics





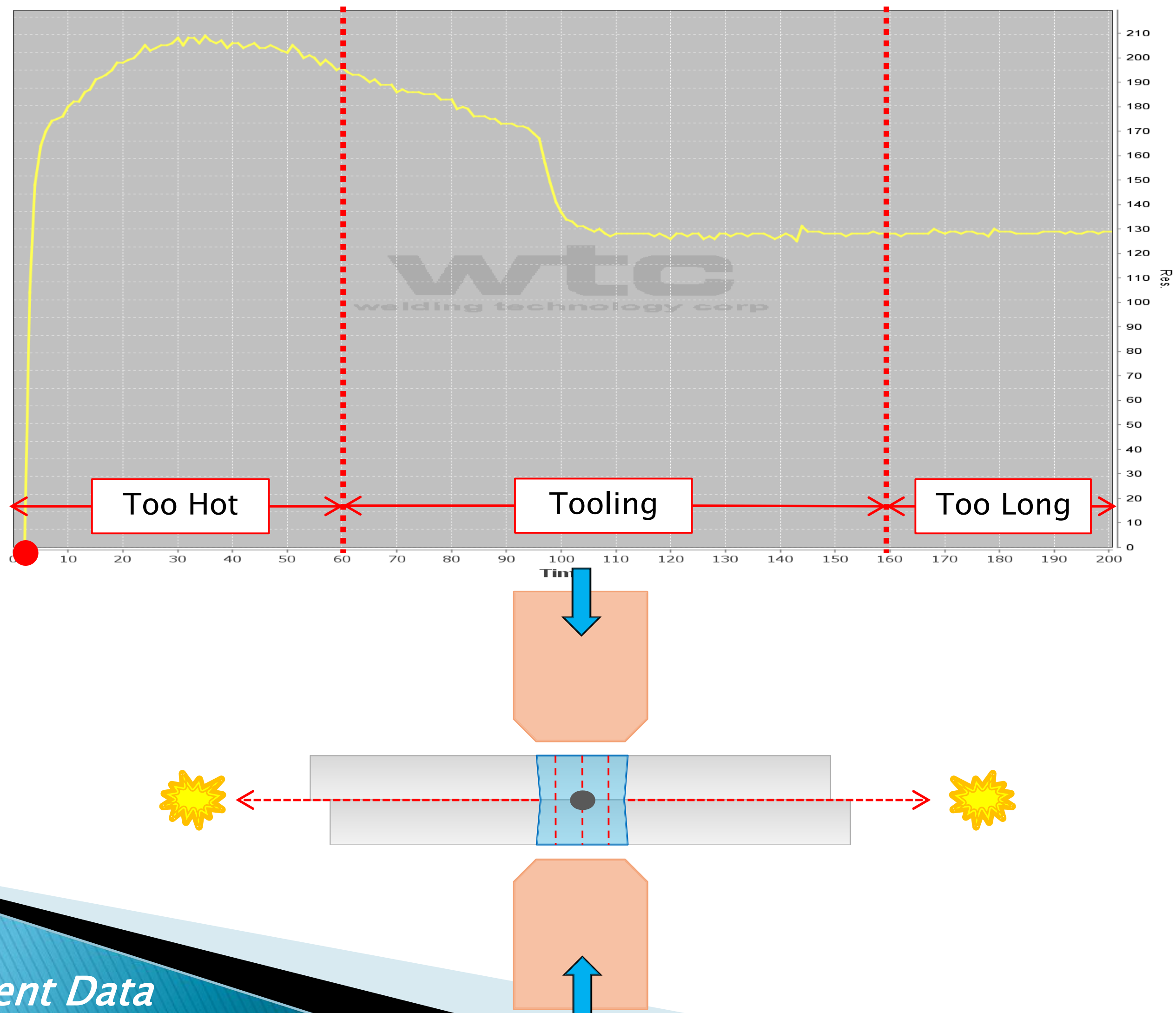
*This drives one schedule for each spot.

**Constant Current Data*

3 Importance of the Resistance Curve

Expulsion Detection

- Expulsion can be detected from the resistance curve, seen as a sharp drop in resistance:

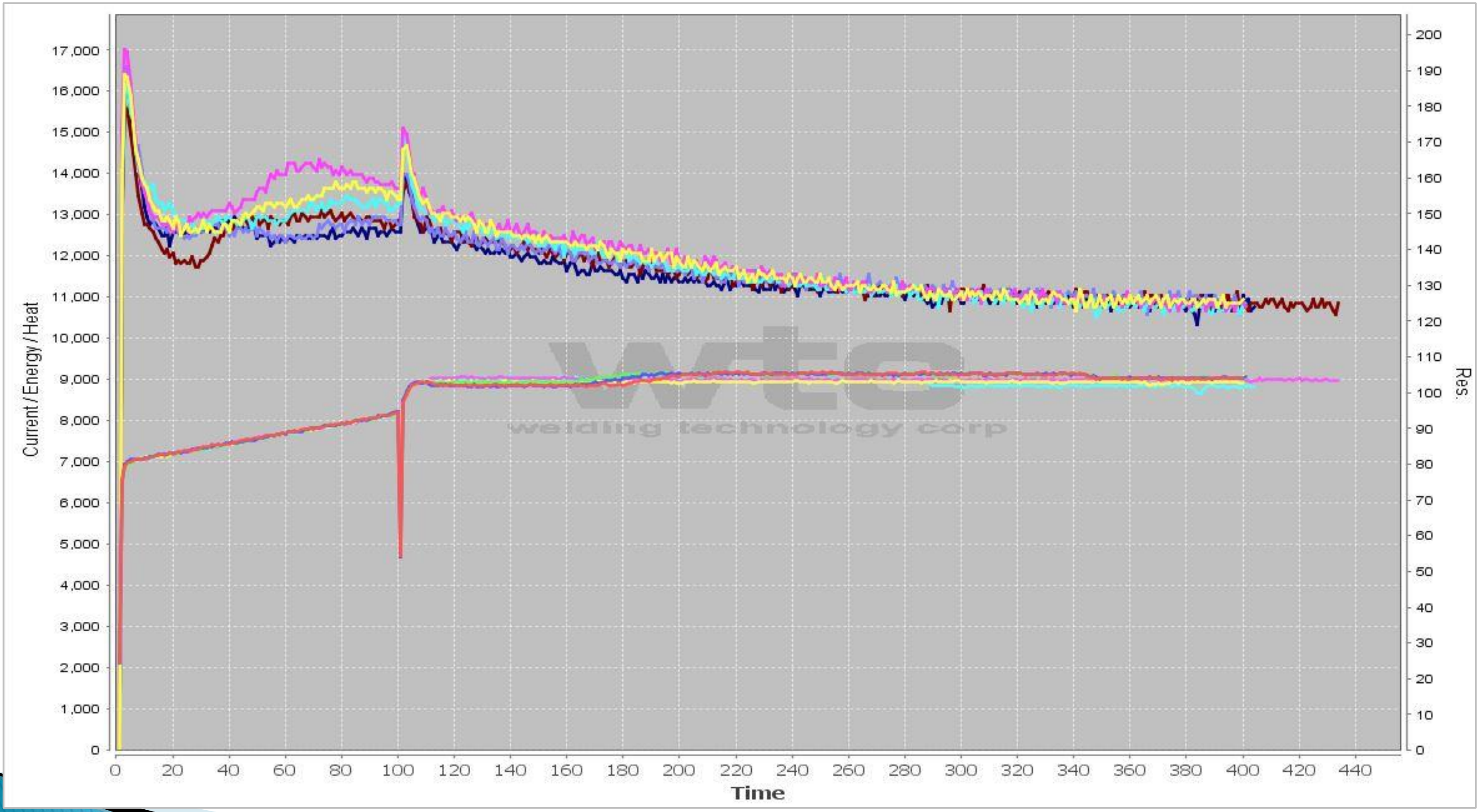


**Constant Current Data*

3 Importance of the Resistance Curve

Adjusting Weld Parameters

- Using Constant Current or Volt/Sec Preheat to stabilize the Resistance curves before the start of the adaptive section of the weld.



4

The Reference Weld

- Later adaptive controls utilize a “reference weld” to enhance the adaptive algorithm.

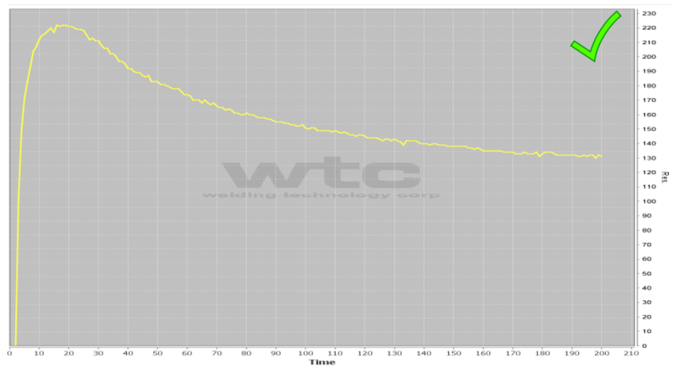
- The reference weld is constant current weld data that is the blueprint for a “good” welding process.

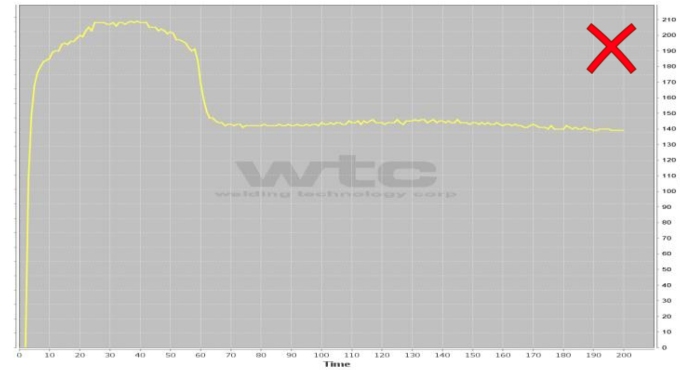
- A good reference weld calls for a process that is:
  - Expulsion free
  - Stable
  - Made with proper equipment (dressed tips, adequate power source, appropriate water cooling etc.)
  - Free of process disturbances
  - Produces quality welds

4

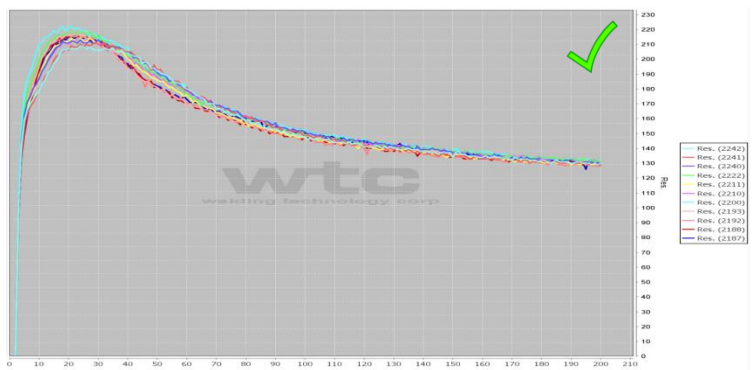
The Reference Weld

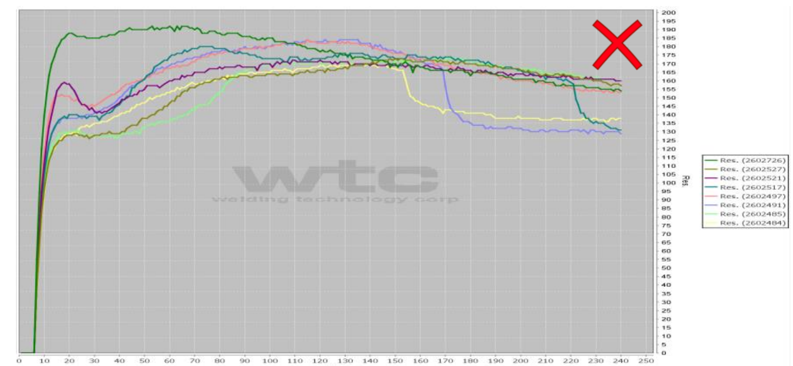
Expulsion Free





Stable





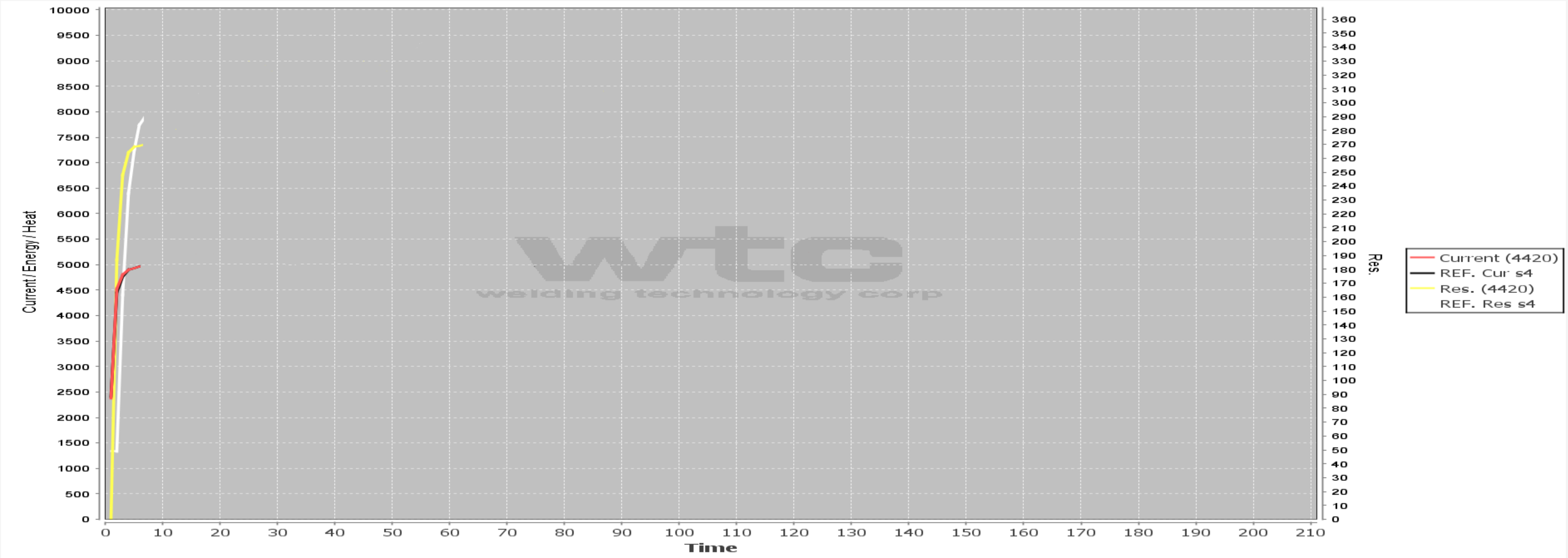
Proper Tooling

**Constant Current Data*

5 Real Time Adaptive Decisions

0-7 msec: Learned Current

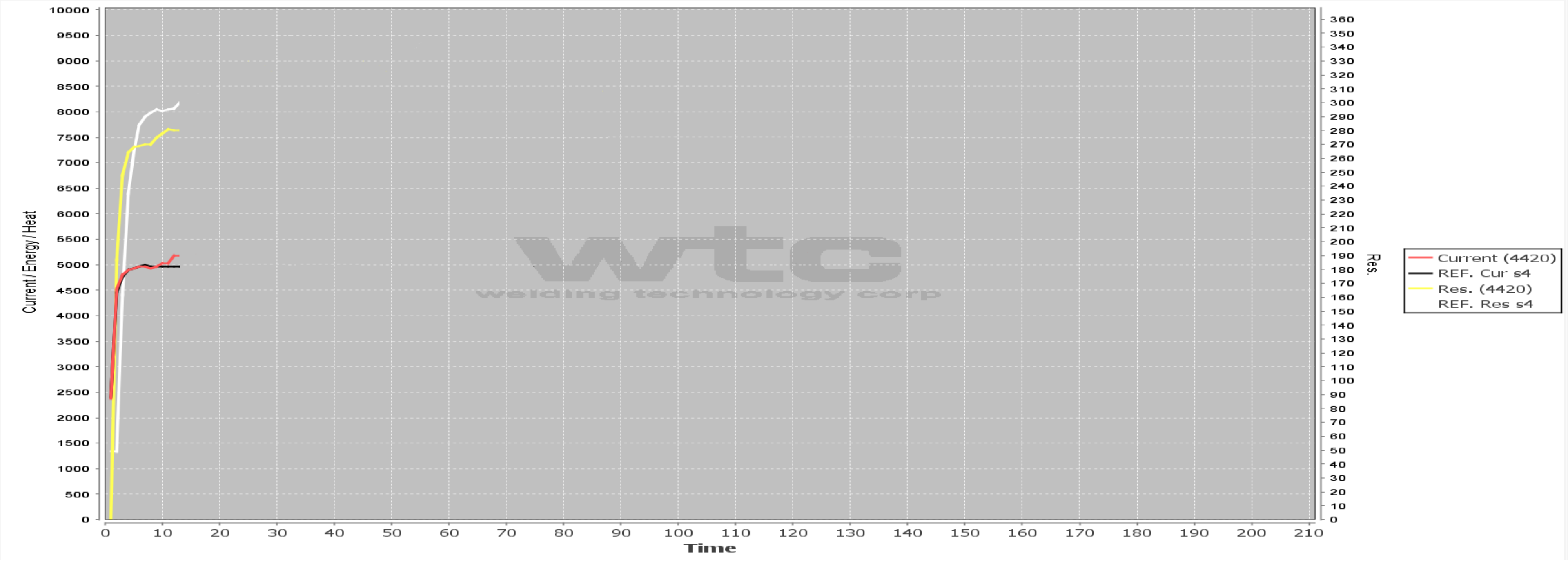
The target current for the beginning of the weld can change based on data analysis.



Real Time Adaptive Decisions

7-16 msec: Auto Adjust

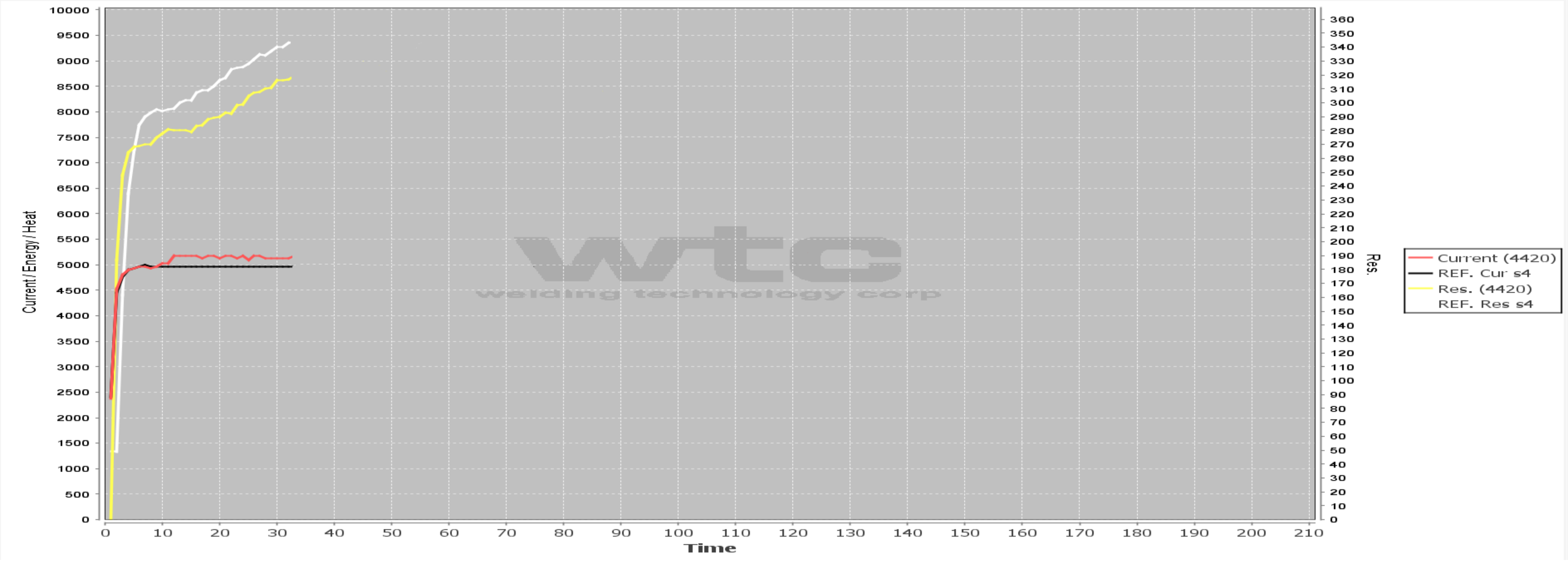
Quick adjustment period to correct initial discrepancy.



Real Time Adaptive Decisions

16-32 msec: Stable

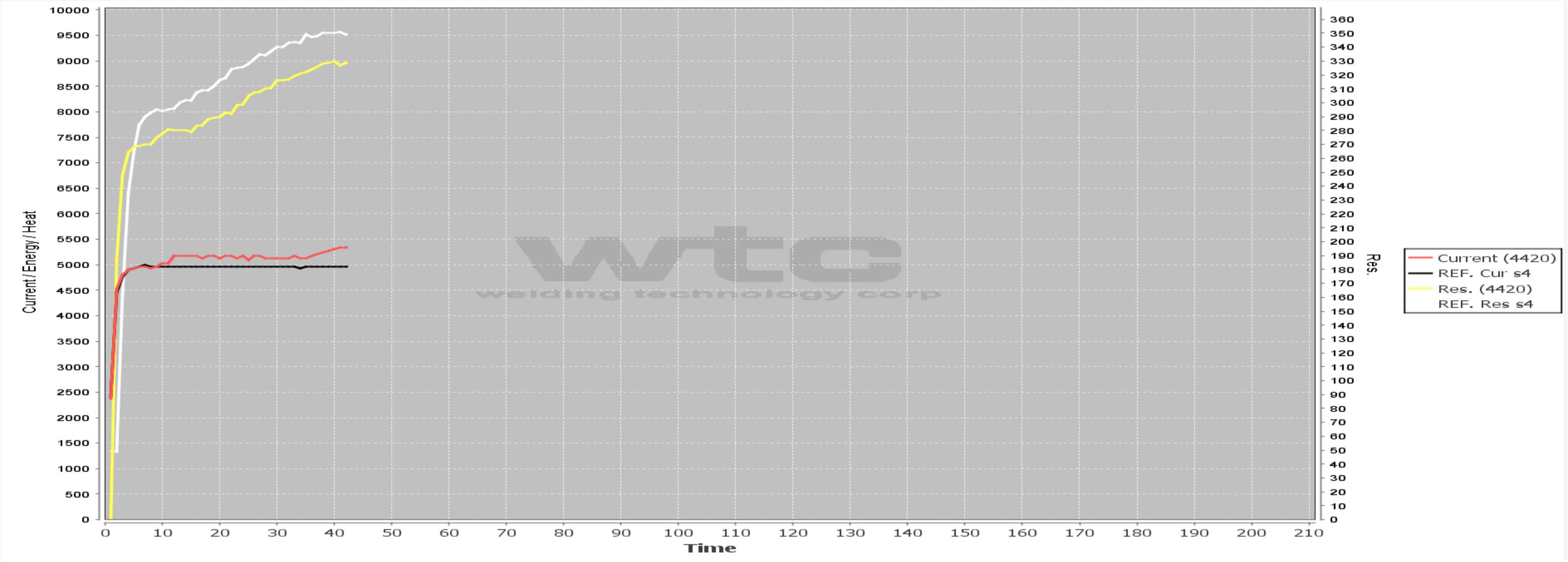
No current changes to evaluate the process.



5 Real Time Adaptive Decisions

32+ msec: Drive to Peak

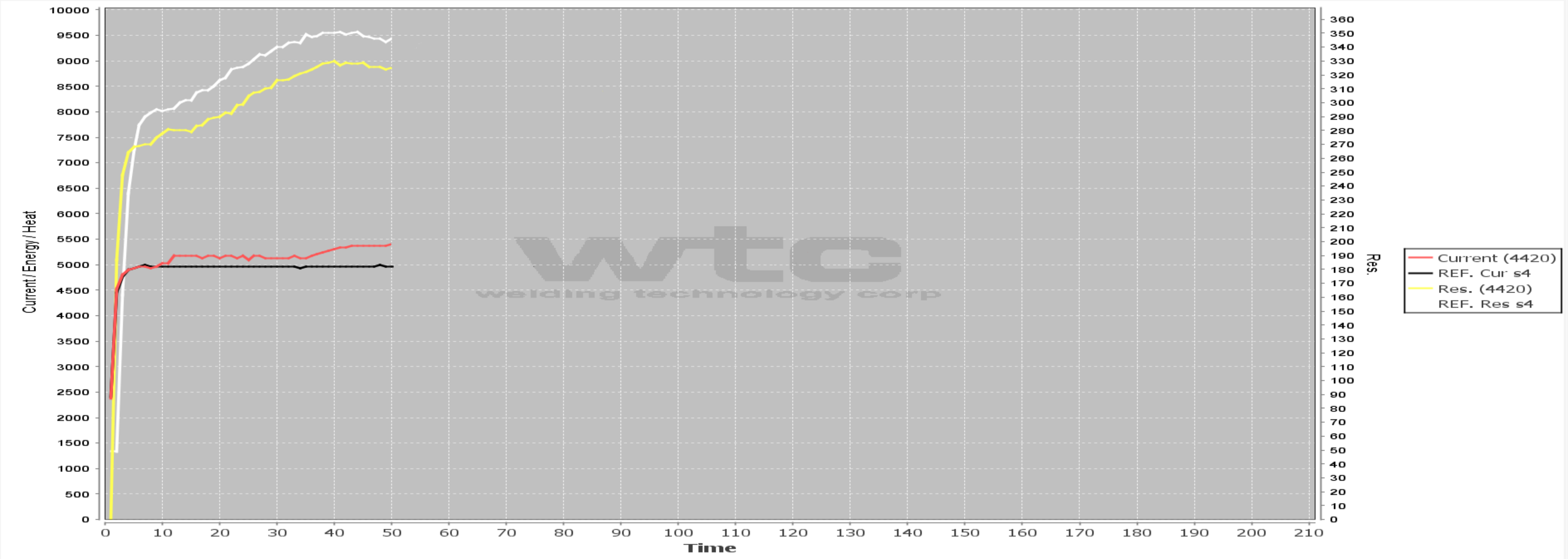
Adjust current to achieve a resistance peak, based on the stable period evaluation.



Real Time Adaptive Decisions

32+ msec: Realized Peak

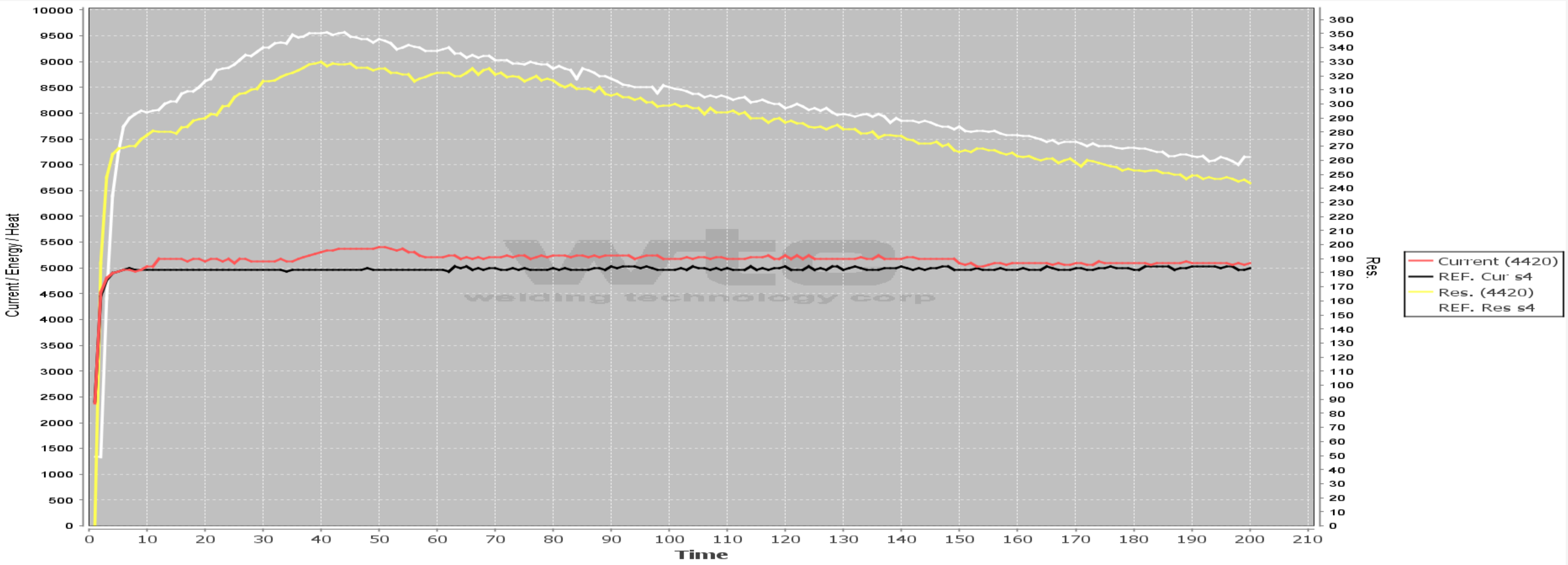
A fixed resistance drop must be observed for a realized peak.



5 Real Time Adaptive Decisions

32+ msec: End

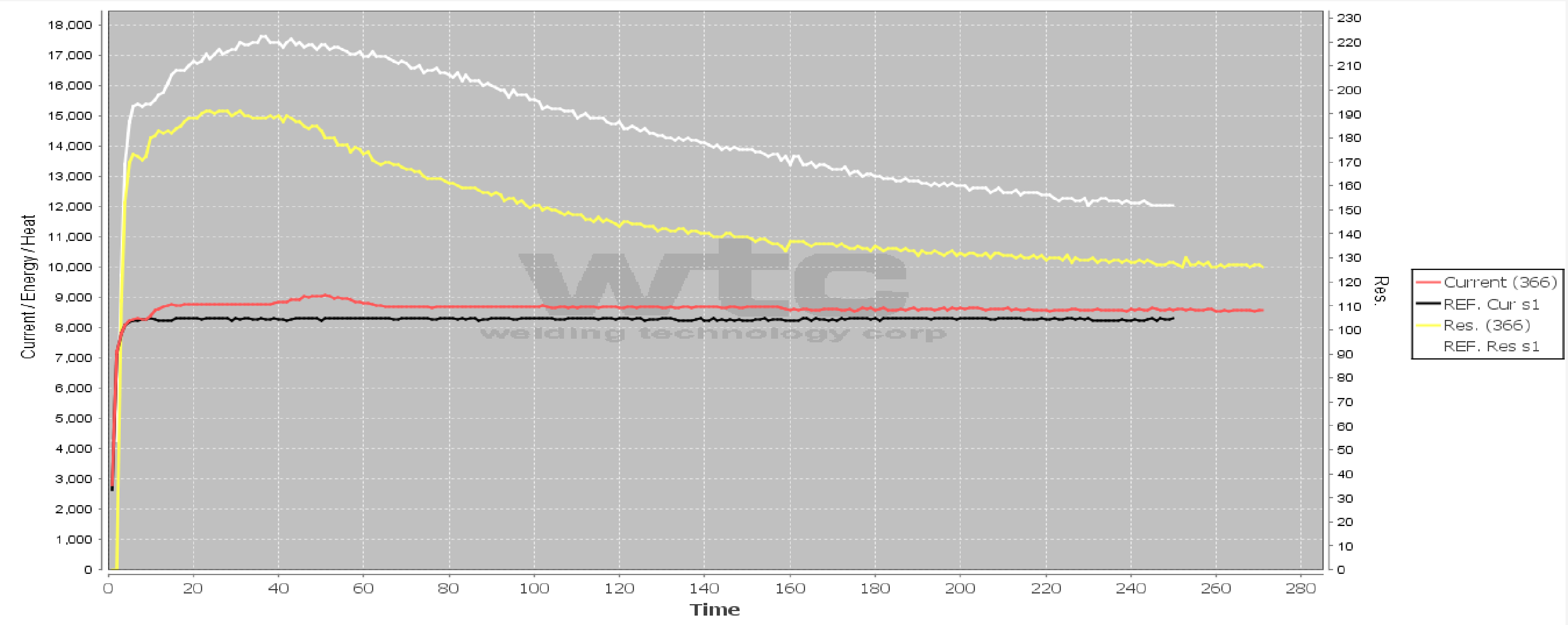
Adjust current after peak is realized, and continue until RD and Energy targets are met.



5 Real Time Adaptive Decisions

Time Extension

If the target RD and Energy targets are not met, time is extended. If time is extended by an excessive amount, the learned current is increased for the next weld.

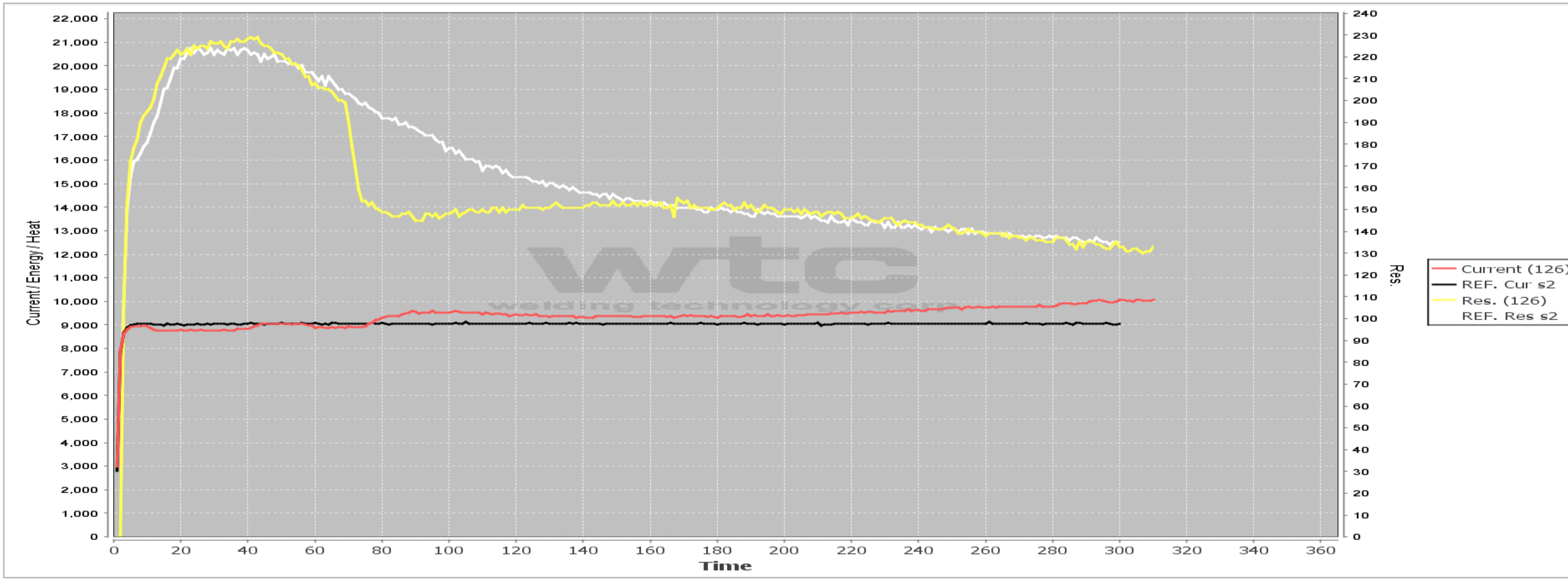


5

Real Time Adaptive Decisions

Expulsion Event

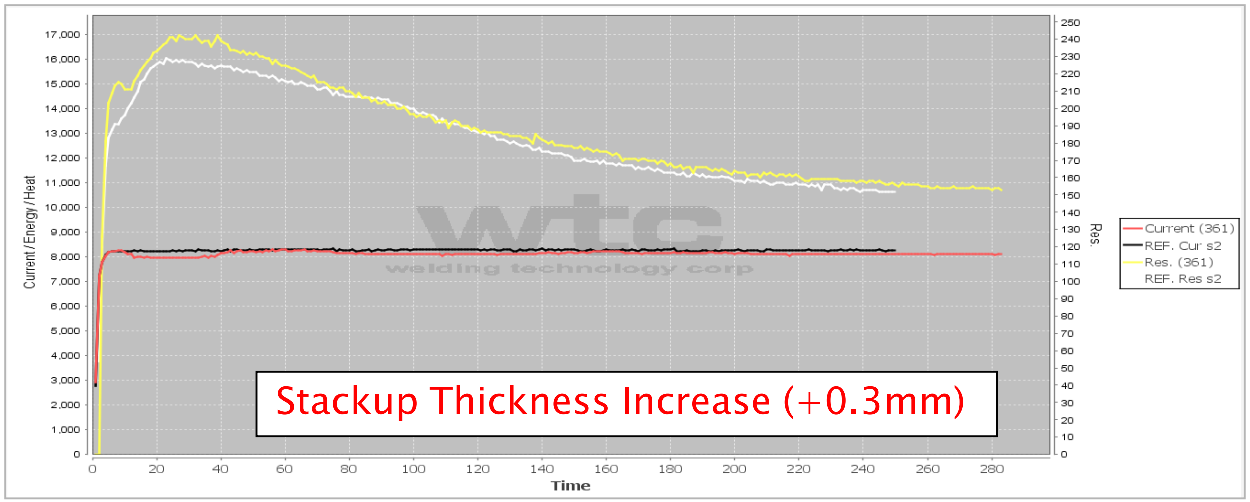
Current is increased after an expulsion to add heat & regain the lost nugget material.

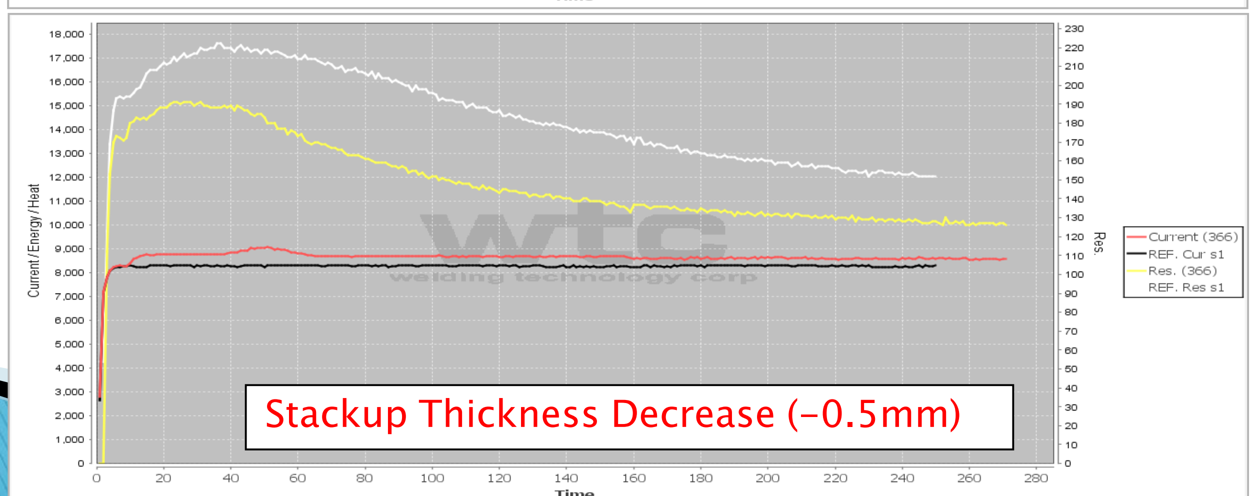


5

Real Time Adaptive Decisions

- Disturbances to the RSW process have major implications on the weld quality.
- The ability to detect <u>and</u> adapt to these disturbances can enhance the reliability of RSW.





5

Real Time Adaptive Decisions

- The decision making algorithm can be adjusted to account for a variety of applications.
  - Type of production – high volume (robot) vs. low volume (portable gun)
  - Type of material – high strength vs. mild metals; coated vs. bare metals
  - Constraints – cycle time; secondary current limits
- This allows the user to fine-tune the system to make better decisions in every situation.
- More flexibility = more complexity
  - This increases the time/knowledge required for proper setup.

6 Implementing Adaptive Control

- An adaptive control system requires:
  - Sensors (voltage leads)
  - Training
  - Setup
- The extra time/cost provide an opportunity to enhance the product quality, especially when a process becomes unstable.
- The amount of setup may vary for different applications.
  - In high volume production, stability/repeatability is key. This is not necessarily true for small scale applications.

7 Adaptive Control vs Constant Current Control

- It is crucial to have realistic expectations of an adaptive system.
  - Modern adaptive controls are not perfect.
  - Poor setup results in improper adaptive decisions.

- GSI SLV Duisburg study:
  - 10 tests comparing adaptive and CC performance using a variety of materials and disturbances.
  - These disturbances are common in production environments.
  - Adaptive control provided noticeable improvement in weld quality.

7

Adaptive Control vs Constant Current Control

GSI SLV Duisburg Report: Percent of normal nugget size achieved for 10 disturbances [4]

			Diameter Compared to Normal			
Test	Description	Step	**CC (Upper)**	**CC (Lower)**	**Adaptive (Upper)**	**Adaptive (Lower)**
VW01	3-sheet stackup	NSSP upper interface	**49%**	**51%**	**98%**	**91%**
		NSSP lower interface	**3%**	**64%**	**75%**	**100%**
VW02	2-sheet stackup	HDG Z100 -> uncoated (+NSSP)	**120%**	-	**100%**	-
		HDG Z100 -> Z140 (+NSSP)	**42%**	-	**100%**	-
VW03	Weld with adhesive	Adhesive + NSSP	**70%**	-	**90%**	-
VW04	Variation of electrode force	Force 50%	**99%**	-	**87%**	-
		Force 150%	**75%**	-	**86%**	-
VW05	Shunting effect in a 3-weld specimen	NS3, 30mm from anchor	**67%**	-	**93%**	-
		NS3, 15mm from anchor/weld 2	**37%**	-	**88%**	-
VW06	Functionality of multi pulse weld	Multi pulse weld, NSSP upper int.	**50%**	**52%**	**50%**	**65%**
		Multi pulse weld, NSSP lower int.	**10%**	**62%**	**10%**	**77%**
VW07	Shunting effect + bad fit up	NSSP 40mm, +Z material	**61%**	-	**99%**	-
		NSSP 25mm, +Z material	**52%**	-	**92%**	-
VW08	Misalignment of parts/electrodes	10°	**43%**	-	**20%**	-
VW09	Welding at the edge of the specimens	8mm / 4mm	**54%**	-	**58%**	-
VW11	Electrode life test	thin mild steel , HDG	**550 Welds Before Undersized**		**410 Welds Before Undersized**	

7 Adaptive Control vs Constant Current Control

GSI SLV Duisburg Report : Comparison of 7 Adaptive Controls for 10 disturbances [5]

			Evaluation Based on Result (Diameter)								
Test	Description	Step	**CC**	**MAX**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
VW01	3-sheet stackup	NSSP upper interface	**1**	**5**	**5**	**3**	**5**	**3**	**3**	**5**	**1**
		NSSP lower interface	**1**	**5**	**3**	**5**	**1**	**1**	**1**	**1**	**1**
VW02	2-sheet stackup	HDG Z100 -> uncoated (+NSSP)	**5**	**5**	**5**	**5**	**5**	**3**	**5**	**5**	**5**
		HDG Z100 -> Z140 (+NSSP)	**1**	**5**	**5**	**3**	**3**	**3**	**5**	**1**	**1**
VW03	Weld with adhesive	Adhesive + NSSP	**1**	**5**	**3**	**3**	**3**	**1**	**3**	**1**	**1**
VW04	Variation of electrode force	Force 50%	**5**	**5**	**3**	**5**	**3**	**3**	**5**	**5**	**5**
		Force 150%	**1**	**5**	**3**	**3**	**3**	**5**	**3**	**1**	**3**
VW05	Shunting effect in a 3-weld specimen	NS3, 30mm from anchor	**1**	**5**	**5**	**3**	**5**	**3**	**3**	**3**	**1**
		NS3, 15mm from anchor/weld 2	**1**	**5**	**3**	**1**	**5**	**1**	**1**	**3**	**1**
VW06	Functionality of multi pulse weld	Multi pulse weld, NSSP upper int.	**1**	**5**	**1**	**-**	**1**	**1**	**1**	**3**	**1**
		Multi pulse weld, NSSP lower int.	**1**	**5**	**1**	**-**	**1**	**1**	**1**	**1**	**1**
VW07	Shunting effect + bad fit up	NSSP 40mm, +Z material	**1**	**5**	**5**	**3**	**5**	**3**	**5**	**3**	**3**
		NSSP 25mm, +Z material	**1**	**5**	**3**	**3**	**3**	**3**	**5**	**3**	**3**
VW08	Misalignment of parts/electrodes	10°	**1**	**5**	**1**	**3**	**3**	**5**	**1**	**5**	**5**
VW09	Welding at the edge of the specimens	8mm / 4mm	**1**	**5**	**1**	**1**	**1**	**1**	**1**	**1**	**3**
VW11	Electrode life test	thin mild steel , HDG	**3**	**5**	**3**	**3**	**-**	**-**	**-**	**-**	**-**
		sum:	**26**	**80**	**50**	**44**	**47**	**37**	**43**	**41**	**35**

8

Conclusion

Advantages	Disadvantages
• Real time adjustments provide weld quality enhancements (avoid post-production corrections) • Automatic response to expulsion events • Detection and response to unknown disturbances • Detection and response to expected wear/tear • Flexible programming for a variety of applications • Weld data for quality analysis is automatically generated • Alerts/faults to previously undetected production disturbances are provided	• Additional equipment is needed for resistance feedback (voltage sensors) • Sensors may require additional maintenance • Proper setup requires resources (training/knowledge, time, trial parts) • Difficult to implement during line building stages due to the lack of welded components to establish a reference weld.

References

[1] WeldCor Supplies Inc. “Resistance Welding.” *Weldcor*, 2013, www.weldcor.ca/encyclopedia.html?alpha=R&per_page=3.

[2] Ho, C Y, and T K Chu. *Electrical Resistivity and Thermal Conductivity of Nine Selected AISI Stainless Steels*. 1977, p. 40.

[3] Wang, S. C., and P. S. Wei. “Modeling Dynamic Electrical Resistance During Resistance Spot Welding.” *Journal of Heat Transfer*, vol. 123, no. 3, June 2001, p. 576., doi:10.1115/1.1370502.

[4]* Schreiber, S. (Ed.). (2016). *Test of "intelligent" weld controls for resistance spot welding (VW-Test)* (p. 21-59, Rep. No. 2015 661 0759-V).

[5]* Schreiber, S. (Ed.). (2016). *Test of "intelligent" weld controls for resistance spot welding (VW-Test)* (p. 65, Rep. No. 2015 661 0759-V).

*www.slv-duisburg.de / widerstand@slv-duisburg.de