Detection of the Security Feature in the New £1 coin

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How the battle against counterfeiting in the coin industry has driven innovation

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Contents

• The Royal Mint
• The history of coin security
• What makes a secure coin today
• The future of Coin Technology
• First look at the new UK £1 launching 2017
Our History

- **Tower of London**: 1250 - 1812
- **Tower Hill, London**: 1812 - 1968
- **Llantrisant, Wales**: 1968 to present
Our Businesses

Circulating Coins
Producer of all legal tender UK Circulating Coins and the world’s leading export mint

Commemorative Coins
Design and manufacture precious metal coins and medallions to celebrate national events

Medals
Decorations, Awards and Honours including London 2012 Olympic and Paralympic Medals, military service medals, OBEs and MBES

Bullion
Production and distribution of high quality, trustable investment grade gold coins
The History of Coin Security

- The battle between coin minter and counterfeiter has waged for thousands of years
- Up until the 20th Century most coins were made from gold and silver
- The 17th Century was a golden age of coin innovation
- Milling and edge lettering. First widely used on coins from the 1660s when the coining process is modernised and machinery introduced for the production of coins
Isaac Newton makes the point that having the highest quality coin is the best way to deter counterfeiting.

This incorporates the coin as a whole – accuracy of the specification and the highest quality design.

Raises the bar to which the counterfeiter must match.

Independently verified at The trial of the Pyx
# Overt Security Features

<table>
<thead>
<tr>
<th>Edge Lettering</th>
<th>Latent Feature</th>
<th>Fine Engraving</th>
<th>Micro-dots and Micro-lettering</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Edge Lettering" /></td>
<td><img src="image2" alt="Latent Feature" /></td>
<td><img src="image3" alt="Fine Engraving" /></td>
<td><img src="image4" alt="Micro-dots and Micro-lettering" /></td>
</tr>
<tr>
<td>Text impressed into the coin edge</td>
<td>Reveals 2 different images as angle is changed</td>
<td>Similar to the lines used on banknotes</td>
<td>Dots or symbols positioned at precise location</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Beading</th>
<th>Groove Raised Lettering</th>
<th>Bi-colour or Bi-metallic Coins</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image5" alt="Beading" /></td>
<td><img src="image6" alt="Groove Raised Lettering" /></td>
<td><img src="image7" alt="Bi-colour or Bi-metallic Coins" /></td>
<td><img src="image8" alt="Shape" /></td>
</tr>
<tr>
<td>Raised beads in a groove around the coin’s circumference</td>
<td>Raised lettering in a groove around the coin’s circumference</td>
<td>Two composite parts are struck together creating a secure bond</td>
<td>Quick public recognition</td>
</tr>
</tbody>
</table>
Coin Security Features Today

Overt Security
Visible security features

Covert Security
Hidden security features
Covert Security
Electromagnetic Signature

Used in most vending machines
A mixture of high and low frequencies used to determine composition and validity

- High frequencies do not penetrate into the core of the coin and are therefore sensitive to the surface material.
- Lower frequencies penetrate deeper into the coin and are therefore sensitive to both surface and core material.
The next innovation in coin security

- Used in many high security industries such as tax stamps, passports and luxury goods
- The Royal Mint has found a way to incorporate this feature into a coin to create a new generation of 100% machine-readable, coins that offers banknote strength security
The New UK £1 Launched 2017

tick-tock
The High Security Feature

The high security feature is incorporated into the plated layer during the production process.

High security feature clearly visible throughout the plated layer.

Metal Substrate
How Does it Work?

Detected using stand alone optical readers

Readers can be incorporated throughout the cash cycle

The technology is able to check and verify coins at a rate of thousands per minute

Provides a categorical Yes/No answer
The High Security Feature

Patented metal matrix composite deposition process developed by The Royal Mint

Security feature is present only a deposited nickel layer, reducing costs but ensuring validation is possible throughout circulatory lifetime

Deposit retains the ductility, wear and chemical resistance of the nickel matrix

Optically detected in a similar way to banknote and passport validation methods
Electroplating Process

Nickel anode and coins immersed in nickel electrolyte

Application of external potential difference drives thermodynamically unfavourable electrode reactions

Nickel dissolves at anode and is deposited on coins at the cathode
Composite Electroplating

(time $t$)

- $t = 0$: Electrophoresis
- $t = 1$: Weak adsorption onto cathode
- $t = 2$: Strong adsorption to cathode
- $t = 3$: Envelopment by nickel deposition
- $t = 4$: Particle incorporation
Deposition Models

**Inputs**

- **Electrolyte**
  - Temperature
  - Composition
  - pH
  - Additives
  - Colloidal stability
  - Turbulence

- **Electrochemical**
  - Charge transfer
  - Mass transfer
  - Polarisation

**Outputs**

- **Deposit Properties**
  - Ductility
  - Chemical resistance
  - Surface finish
  - Volume fraction
  - Optical properties
  - Wear characteristics
  - Dispersion

**Model**
Deposition Models

All useful composite deposition process models are empirical.

Model requires both inputs and outputs.

Specific experiments must be performed to determine operating parameters.

MATLAB was used extensively to develop and apply models at laboratory and pilot scale and to solve process issues at production scale.

Over 500 experiments were performed at the laboratory and pilot scale to characterise the system.
Example Applications

Inputs

- Electrolyte
  - Temperature
  - Composition
  - pH
  - Additives
  - Colloidal stability
  - Turbulence
- Electrochemical
  - Charge transfer
  - Mass transfer
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Outputs

- Deposit Properties
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Model
Volume Fraction

The volume fraction of the security feature incorporated into the electrodeposit was quantified using the Image Processing Toolbox.

Electron micrographs were produced from coin cross sections.

Over 4000 cross sectional micrographs were analysed during the development phase.

Automated methods were developed to speed up the analysis process.
Volume Fraction

Mounting resin

Nickel deposit containing security feature

Nickel brass substrate
Volume Fraction

Micrograph was cropped to reveal only the composite coating.

Image imported as a grayscale numerical array with values between 0 and 1 for each pixel.
Volume Fraction

Threshold value applied to convert numerical array into a logical array:

\[ \text{img} = \text{img} < \text{threshold} \]
Volume Fraction

The surface area fraction of the cross section occupied with particles is approximated to the volume fraction.

The volume fraction can be determined with knowledge of the sum of the logical array and the size of the array:

\[ vf = \frac{\text{sum}(\sim \text{img})}{\text{numel(img)}} \]
Volume Fraction

Over 400 laboratory and pilot scale electroplating experiments were performed.

At least ten micrographs were produced from each plating cycle, microscopy and image analysis took approximately 1hr per cross section.

Originally volume fraction analysis was performed manually using image manipulation software.

Automation with MATLAB reduced measurement time by over 50%.
Volume Fraction

Rapid comparison of process treatments with other measurement methods

Reproducible comparison metrics

Automated report generation using MATLAB + LaTeX

Signal (a.u.)

$R^2 = 0.88$

Volume Fraction (%)
Example Applications

**Inputs**
- Electrolyte
  - Temperature
  - Composition
  - pH
  - Additives
  - Colloidal stability
  - Turbulence
- Electrochemical
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**Outputs**
- Deposit Properties
  - Ductility
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**Model**
Phase Dispersion

A good dispersion of the security feature throughout the nickel matrix is critical for a good quality product.

Clustering will produce a product with a variable authentication signal throughout the lifetime of the coin.

Phase Dispersion

Edge detection methods provided by The Image Processing Toolbox were used to logically define the perimeters of the security feature inclusions.

Each centroid was then determined, again using image processing functions.
Phase Dispersion

From the centroids, the level of clustering can be determined by applying statistical methods.

Ripley’s K function was applied to the data to determine the degree of spatial clustering.

Phase Dispersion

Treatment 1

Treatment 2

Clustering

\[ \tilde{K}(r) \]
Analysis of the dispersion was only performed infrequently due to the lengthy analysis time.

Dispersion analysis, and other validation methods, could be performed with each automated volume fraction measurement - incurring less than a 5s increase in processing time.

Statistically significant clustering, not visually discernible was unexpectedly detected from some process treatments.

Provided an important metric to analyse treatments that would have otherwise not have been performed.
Example Applications

**Inputs**

**Electrolyte**
- Temperature
- Composition
- pH
- Additives
- Colloidal stability
- Turbulence

**Electrochemical**
- Charge transfer
- Mass transfer
- Polarisation

**Outputs**

**Deposit Properties**
- Ductility
- Chemical resistance
- Surface finish
- Volume fraction
- Optical properties
- Wear characteristics
- Dispersion

**Model**
Detection of the Security Feature

Over 100M new £1 coins were manufactured before launch

Security feature detectors were not achieving predicted pass rates

Over 50% failure rate after 50M £1 coins were produced!
Detection of the Security Feature

Each of the 50M coins were validated through a coin sorter as part of the telling process.

Data recorded includes thickness, gauge, EMS parameters and the high security feature signal data.

Historical data was imported into MATLAB.

Oscilloscope readings were performed as the coin moved through the detection window and analysed using the Signal Processing Toolbox.

As the coins moved past the security feature detector changes in the measured signal were observed.
Detection of the Security Feature

A larger signal near the edge of the nickel plated inner was discovered.

Measurement was performed at the centre of the coin.

A narrower detection window was the cause of the unexpected failures.
Detection of the Security Feature

Pound coins without the security feature were compared to coins with the security feature.

Data was imported and 100% authentication was achievable using basic signal processing methods.
Detection of the Security Feature

Pass/fail logic was controlled by an embedded system installed in the coin sorters.

Alternate functions, mimicking the capability of the embedded controller, were prototyped offline.

Accurate pass rates were determined using historic data without reprogramming controllers.
Detection of the Security Feature

Once a suitable detection method was determined it was rolled out into production.

Problem was solved in only a few days with no downtime of the telling machines.

100% of the 25M rejected £1 coins were reclaimed and 100M £1 coins were produced on time in anticipation of the launch!
Thank you for listening
Any questions?