Image Clarity (Orange Peel) and Surface Roughness Measurement

Introduction

Metallic and pearlescent paints are standard paint commonly used on car exteriors. As the color and brightness of these paints vary according to the angle they are observing, color control using a multi-angle color measurement instrument (e.g., Spectrophotometer CM-M6) is required to capture the color travel from various angles. However, colorimetric control, on its own, is insufficient for evaluating a car exterior's overall design quality; the image clarity[1] (orange peel) on the painted surface is also an important consideration. For instance, Jet-black luxury sedans with distinctive designs and clear reflected images on their painted surface have high added value.

A wide range of advanced paint colors have been developed in recent years, and they pose the following management problems.

- Conventional measuring instruments need expert knowledge to interpret measurement results.
- Visual and measuring instruments need better correlation.
- It is vital to improve the surface quality, starting from the material, to better manage orange peel. And that means evaluating each process and material from steel plate to electrodeposition and clear coatings.

To solve these problems and satisfy the needs of the market, Rhopoint created TAMS™ (Figure 1), which stands for Total Appearance Measurement Systems. It is an innovative handheld measuring instrument that uses the pattern projection method and visual judgment database to evaluate the quality of painted surfaces. The algorithm used by TAMS™ was developed through the close collaboration between Rhopoint, Volkswagen, and Audi, and Konica Minolta has been appointed its exclusive distributor since 2018. This paper will describe TAMS™'s proprietary core technology: the pattern projection system and algorithm, and also introduce and explain its surface roughness measurement capability.

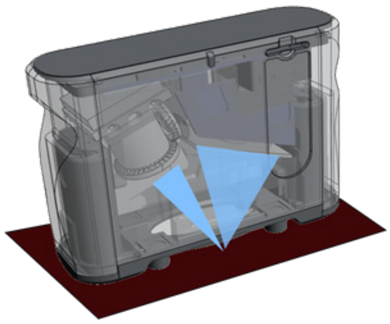

Figure 1 - Illustration of TAMS™ (Total Appearance Measurement Systems)

Basic Principle of TAMS™

One of the primary capabilities of TAMS™ is to quantify the orange peel of a reflected image[2]. This innovative measuring instrument comprises the following components.

- Design that ensures equal distance between the measurement surface and the illumination and sensor
- LCD display for projecting illumination patterns (black and white stripes) on the measurement surface.

Image Clarity (Orange Peel) and Surface Roughness Measurement

- 2D sensor, with an automatic focus adjustment function, for capturing the reflected images of the illumination pattern on the measurement surface.
- Data processing unit computing various appearance quality parameters like sharpness, Waviness, etc.
- Data output that collates with database modelling major automotive manufacturers' visual evaluation know-how regarding orange peel on painted surfaces.

The general approach for visual inspection of advanced paints is to assess the distortion of the reflected image on the painted surface. For measuring instruments to achieve a high correlation with visual evaluation, they must be able to mimic how the human eyes observe the surface closely. TAMS™ evaluates the reflected image using a 2D sensor and an LCD display.

TAMS™ Core Technology: Pattern Projection Method

Traditionally, there are two methods to evaluate the image clarity of painted surfaces, and it is usually done at the final stage of the painting process.

Visual Inspection

Fluorescent light is first shone onto the painted surface before visually assessing the waviness of the reflected image on the printed surface. One issue with this method is that the equipment setup is generally large and costly.

Measuring Instrument

Conventional instruments irradiate laser beam onto the paint surface to measure surface unevenness, and the measurement result is broken down into multiple frequency bands. However, these instruments focus on the surface while our eyes tend to focus on the reflected images, leading to a poor correlation between the measurement result and visual inspection. Furthermore, specialized knowledge and expertise are required to interpret the measurement results.

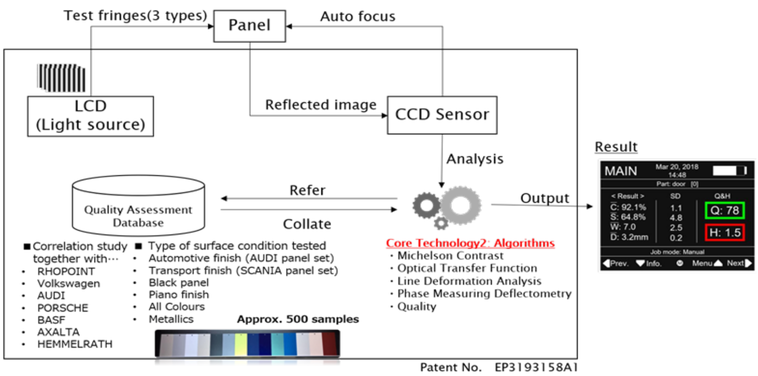

Figure 2 - TAMS™ System Diagram

TAMS™, with and 2D sensor and LCD display, uses the pattern projection method to evaluate the reflected image. It can also measure small areas without the need for scanning. Furthermore, TAMS™ automatically applies the database of major automotive manufacturers' visual evaluation know-how to the measured data to calculate a general index, called quality (Figure 2), that quantifies surface conditions. Continuous development is ongoing for TAM™ to adopt similar operation to DIN6175-2 and Audi2000 by negotiating the threshold values.

TAMS™ Core Technology: Algorithm and General Index

TAMS™ provides four sub-parameters of contrast, sharpness, waviness, dimension, and a single general index, quality. This innovative measuring instrument

Image Clarity (Orange Peel) and Surface Roughness Measurement

is not only capable of evaluating the reflected image on the printed surface but also the surface topography.

Contrast

This parameter focuses on the contrast of the reflected image. The contrast (C) parameter value is obtained using the Michelson Contrast measurement technique, whereby the contrast of the reflected image is quantified using the reflected intensity of black and white stripes.

$$c = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

Figure 3 - TAMS™ Contrast (C) Parameter

Sharpness

This parameter is used to describe the sharpness of the reflected image and is based on the Optical Transfer Function measurement technique. Multiple black and white stripes are first projected across different frequencies. The contrast values of their reflected image are measured and integrated to obtain the sharpness (S) value.

$$S = \int_{f_1}^{f_n} c(f)\, df$$

Figure 4 - TAMS™ Sharpness (S) Parameter

Waviness

Based on the Line Deformation Analysis measurement technique, this parameter is a measure of the reflected image waviness (orange peel). The waviness (W) value is obtained by quantifying the amount of deformation (orange peel) of the reflected image of the projected thin horizontal lines.

$$W = \int_{P_1}^{P_n} F(p)\, dp$$

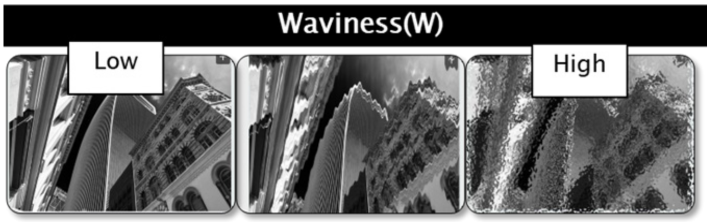

Figure 5 - TAMS™ Waviness (W) Parameter

Dimension

Rather than the reflected image, the dimension (D) parameter focuses on the painted surface and describe the dominant wavelength of the surface waviness. Our eyes are sensitive to the overall amount of waves in the reflected image and the dominant wavelengths. Any change to the dominant wavelength, even when the waviness parameter remains the same, also changes our impression. The difference in the size of the wavelength is generally caused by irregularities on the surface.

Based on the Phase Measurement Deflectometry measurement technique, multiple sinusoidal black and white patterns with different phases are projected and measured to obtain the 3D surface topography for calculating the dominant surface wavelength (Figure 6).

Image Clarity (Orange Peel) and Surface Roughness Measurement

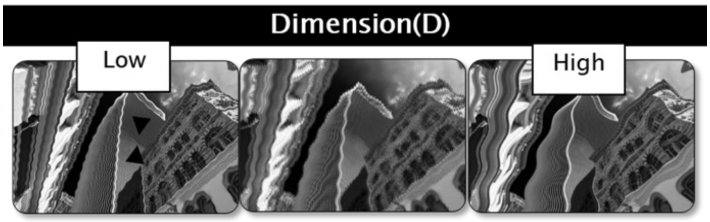

Figure 6 - TAMS™ Dimension (D) Parameter

Quality

The general index quality (Q) is a value calculated by applying the database to the three sub-parameters of contrast, sharpness, and waviness. The quality value describes the paint quality and is expressed between 0 to 100, with 100 representing a smooth finish and high reflected image clarity.

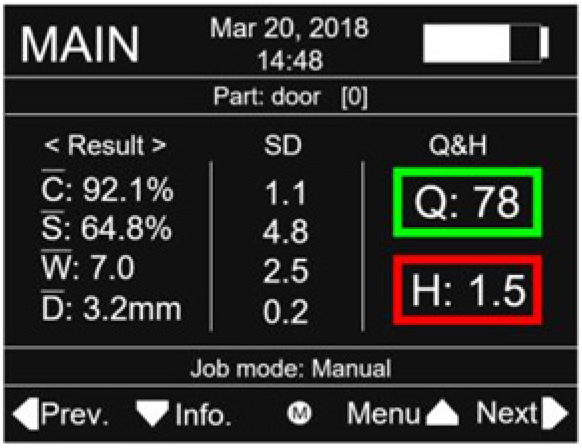

Figure 7 - TAMS™ Measurement Screen

Orange Peel Measurement

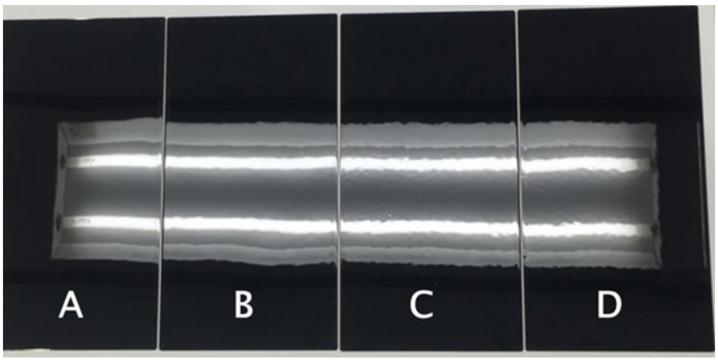

Figure 8 - Coated Panel Samples

Four coated panels (commercial car-level quality), as shown in figure 8, were evaluated visually and by a conventional measuring instrument and TAMS™. Based on the visual evaluation, the surface quality of the coated panels, from the highest to lowest, is in the order of A, B, C, and D. From the measurement results of the conventional measuring instrument, as presented in table 1, it is difficult to express the visual difference using the measured values.

Index	Coated Panel			
	A	B	C	D
Index (1)	2.2	1.9	3.5	3.3
Index (2)	0.6	0.8	1.8	1.8

Table 1 - Measurement Data from Conventional Measuring Instrument

As shown in table 2, TAMS™ offers a more comprehensive measurement result and can express the quality difference between the four coated panels with a better correlation with visual evaluation.

Index	Coated Panel			
	A	B	C	D
Contrast	98.9	99.5	99.1	99.0
Sharpness	100.0	99.7	99.7	99.9
Waviness	0.8	1.8	3.4	4.1
Dimension	0.0	5.3	5.1	5.0
Quality	92.0	84.4	73.5	69.5

Table 2 - Measurement Data from TAMS™

Surface Roughness Measurement

Image clarity, an automotive appearance quality that requires excellence, can be quantified by evaluating orange peel. Many automotive manufacturers are working to improve the final finish quality in the paint and the drying and polishing processes after painting, aiming to reduce orange peel. Aside from

Image Clarity (Orange Peel) and Surface Roughness Measurement

the final finish quality, the surface quality of the base material can also affect orange peel. Base materials like steel plates usually have a low luster and do not exhibit any reflected image on their surface. Therefore, they cannot be evaluated through the usual approach of measuring orange peel.

With TAMS™, it is possible to evaluate the paint finishes and also the roughness of the base material surface, even surfaces with little reflection (1 GU or more). It measures the 3-D surface profiles using the Phase measuring deflectometry to calculate the roughness curve.

Furthermore, the surface roughness (Sa) and linear roughness (Ra) can also be calculated in accordance with the ISO standards. The roughness curve is obtained by superimposing numerous frequency components on a wave before applying bandpass filter processing (ISO 16610[3]) to extract only the frequencies to be evaluated. Sa and Ra are standardized by ISO 25178[4] and ISO 4288[5], respectively, and surface roughness measurement by TAMS™ is carried out following these standards.

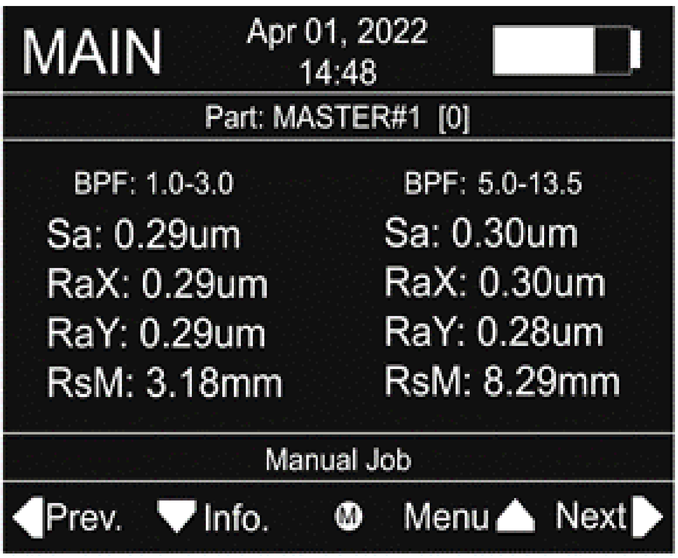

Figure 9 - TAMS™ 's Surface Roughness Measurement Screen

Three coated panels made from the same materials but with different surface roughness, from the roughest to smoothest in the order of 5A, 4A, and 1A, were evaluated using TAMS™ (figure 10). The Sa value obtained from TAMS™ is the surface irregularities difference average and an index in the depth direction. As shown below, TAMS™ can easily discriminate between different surface roughness.

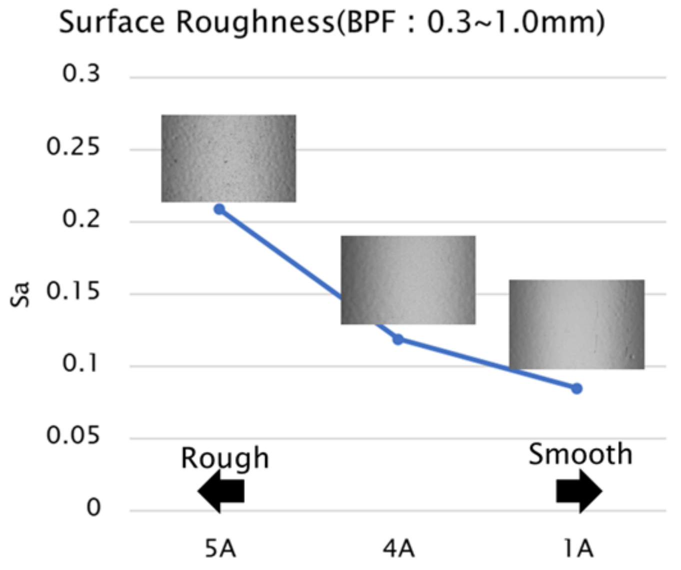

Figure 10 - TAMS™ Surface Roughness Measurement Results

Measurement of TAMS™ also corresponds closely with the measurement of a white light interferometer (Wyko), as presented in Figure 11 and Figure 12.

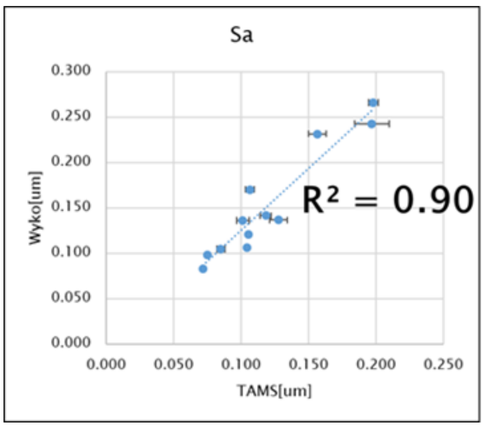

Figure 11 - TAMS™'s Surface Roughness (Sa) Measurement

Image Clarity (Orange Peel) and Surface Roughness Measurement

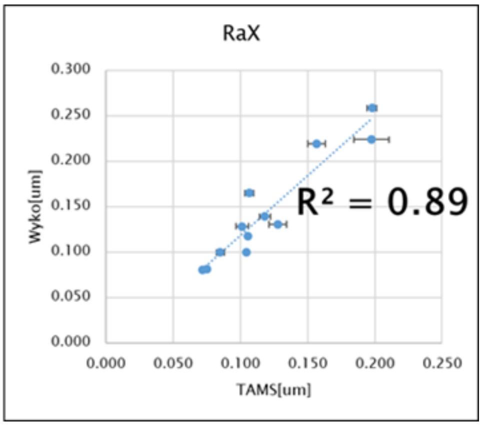

Figure 11 - TAMS™'s Liner Roughness (Ra) Measurement

The measured values of TAMS™ and white light interferometer (Wyko) plotted on the horizontal axis and vertical axis, respectively, show a high correlation of about R^2=0.9 on both the Sa (Figure 11) and Ra (Figure 12) values.

TAMS™ is capable of quantifying orange peel and surface roughness as a single unit, without the need for multiple measuring instruments, providing objective and consistent quality control throughout various processes.

Conclusion

The paint finish and surface quality of the automobiles are vital to their aesthetic appeal and can help manufacturers differentiate from the competition.

While the visual evaluation method is still relevant, it has several drawbacks like high cost, subjectivity, etc. Rhopoint TAMS™ is a revolutionary appearance measuring instrument that can provide orange peel evaluation with good visual correlation and also measures surface roughness.

Watch this webinar to learn more about the optical measurement methodology for automotive surfaces.

Konica Minolta Sensing, together with group company Radiant Vision Systems and Partner Rhopoints, offers various leading technology and turnkey solutions for the appearance, color, light, and display evaluation throughout the R&D, manufacturing, and quality control of automotive. Check out our range of testing and measurement solutions here.

Interested to find out more about TAMS™ or need help with your measurement challenges? Contact us for a free consultation now.

References

1. JIS K 7374, Plastics - Determination of image clarity

2. Christen, Klaus; Weißberg, Dirk; Roths, Klaus; Burrows, Anthony David; Morandi, Pierre; Dauser, Thomas EP3193158A1, 2017.

3. ISO 16610-61:2015, Geometrical product specification (GPS) — Filtration — Part 61: Linear areal filters — Gaussian filters

4. ISO 25178-3:2012, Geometrical product specifications (GPS) — Surface texture: Areal — Part 3: Specification operators

5. ISO 4288:1996, Geometrical Product Specifications (GPS) — Surface texture: Profile method — Rules and procedures for the assessment of surface texture