Industrial Tolerances, Performances of a Colour-difference Formula

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Since 1976 J & P Coats (UK) Limited have employed an instrumental match prediction and pass/fail system in the Dyehouse in Paisley. The system was developed by the Research Laboratory of J & P Coats Limited and, since 1976, a number of modifications to the pass/fail formula has been made on the basis of bulk experience. These modifications culminated in the J & P Coats 1979 Colour-difference Formula. Since the introduction of the JPC 79 formula many thousands of pass/fail decisions have been made and the agreement between visual observer and instrumental decision has been good.

Industrial Tolerances

A pre-requisite to good agreement between instrumental and visual observer decisions is that the limit of acceptability, or borderline between pass and fail, is accurately determined. In J & P Coats (UK) the limit of acceptability, or colour match tolerance, was derived empirically by measuring on a spectrophotometer the colour difference between sample and standard for thousands of visual pass/fail decisions and establishing the visual tolerance. However, the use of the colour-difference value, ΔE, where $\Delta E = [\Delta L^2 + \Delta a^2 + \Delta b^2]^{\frac{1}{2}}$, is ineffective in determining a colour-match tolerance. The non-uniformity of ANLAB colour space gives anomalous results when using ΔE, e.g. $\Delta E = 5$ for a yellow pair could be as visually acceptable as $\Delta E = 2$ for a grey pair. The use of ΔE would therefore be confusing.

To overcome the short-comings of ΔE, J & P Coats Research Laboratory had introduced a modification which was referred to as ΔEa [1]. This modification had the effect of transforming any colour difference to its achromatic (or grey) equivalent. A single number could now be used to compare colour differences in widely differing areas of colour space, e.g. $\Delta Ea = 2$ for a bright red pair is visually equivalent to $\Delta Ea = 2$ for a mid blue pair or a grey pair.

However, despite the obvious advantages of using a single number tolerance value, it was not possible to determine the visual tolerance by use of ΔEa. ΔEa is based on three parameters, ΔL, ΔS and ΔH, where ΔL = difference in lightness, ΔS = difference in saturation and ΔH = difference in hue, and unfortunately the human eye is not equally sensitive to each parameter, e.g. a colour difference of $Ea = 2$ for which the hue difference is large is unlikely to be as visually acceptable as a colour difference of $\Delta Ea = 2$ for which the difference in hue is small. Therefore, although ΔEa is a useful tool for describing total colour difference, it cannot be used as the basis for a colour-difference formula.

It therefore seemed that the most likely way to success would be to derive acceptability limits for each of the three variables of colour – lightness, saturation and hue. To achieve this, the saturation and hue differences, ΔS and ΔH, for each colour match were plotted against saturation, and lightness differences, ΔL, were plotted against lightness [2]. On each graph the line was drawn along the limit of acceptability, i.e. the dividing line between visual passes and visual fails. Thus, one of the pre-requisites to a successful colour-difference formula, that of establishing limits of acceptability, was determined.

Equations which represented the limit of acceptability lines for each variable, ΔL, ΔS and ΔH, were calculated, and a colour-difference formula, which subjected each of the three colour-difference variables, lightness, saturation and hue to mathematical scrutiny, was established. In effect, this colour-difference formula is similar to the logic applied in a visual pass/fail decision. In both systems similar questions require to be answered.

Visual System	*Instrumental System*
1. Is the shade acceptable for fullness/thinness?	1. Is ΔL less than acceptability limit?
2. Is the shade acceptable for brightness/dullness?	2. Is ΔS less than acceptability limit?
3. Is the shade acceptable for tone?	3. Is ΔH less than acceptability limit?

If by either system the answer to all these questions is YES, the shade will be acceptable. If by either system the answer to any one question is NO, the shade will not be acceptable.

Although bulk usage of this colour-difference formula achieved a greater degree of agreement between visual and instrumental assessment than had been achieved hitherto, it nevertheless became apparent that further improvement was necessary. Scrutiny of the results that disagreed suggested that hue tolerance had not been totally defined. After further examination of the available data and visual assessment trials of hue tolerances with changes in hue, it became obvious that the limit of acceptability of hue was dependent not only on saturation, a factor already accommodated in the formula, but also on the hue angle. The hue angle is the angle formed by the *"a"* axis of ANLAB space and the saturation line on which the colour in question lies. This discovery resulted in a pass/fail formula in which a set of three equations defines the relationships between ΔL and lightness, ΔS and saturation and the somewhat complex relationship which exists in the hue:saturation ratio [2]. The relationships can be expressed as follows:

1. Lightness tolerances increase with increasing lightness, i.e. the paler the colour the less sensitive is the human eye to differences *in weight of shade.*
2. Saturation tolerances increase with increasing saturation, i.e. the brighter the colour the less sensitive is the human eye to differences in *clarity of shade.*
3. Hue tolerances increase with increasing saturation, i.e. the brighter the shade the less sensitive is the human eye to differences *in tone*.
4. Hue tolerances vary depending on hue angle.

It was the detection and subsequent evaluation of point 4 which led to the introduction of the JPC 79 colour-difference formula.

Establishing a Colour Match Tolerance

An important condition for establishment of a colour-match tolerance is that the control of the *Dyehouse* variables is such as to enable the tolerance to be achieved without excessive additions. Indeed it can be argued that the tolerance should be that value which is capable of being achieved with each bulk proven recipe on each occasion with no additions. If this concept is accepted, then scrutiny of the data to establish the success rate of first-time-only dyeings in relation to the tolerance will indicate the ability to control sufficiently the process variables. Thereafter decisions can be taken as to whether greater control of the variables is required (or possible) or, indeed, if the colour-match tolerance should be increased.

Performance of JPC 79 Formula

The JPC 79 colour-difference formula has been particularly successful when the standard and the sample have been dyed on the same substrate and the same dyes used. Under these conditions agreement between visual observer and instrumental decision is as high as 92%. Disagreement tends to be borderline and towards visual-observer pass when the instrumental decision has been to fail. Where the above conditions are not met, i.e. use of different dyes on sample and standard, agreement can be substantially worse.

Anomalous results have been noticed in two areas of colour space. At a lightness value of $L \leqslant 20$, the acceptability limits for lightness and saturation appear to interchange in terms of visual appearance. This anomaly is considered to be due to contraction of colour space in this region.

The second area is at or near the neutral grey axis. When the standard shade lies in the first quadrant, i.e. the hue angle is less than 90°, and close enough to the neutral grey axis so that a colour in the third quadrant could fall within the calculated tolerance, then visual observer decisions can disagree with instrumental decisions for colours in the third quadrant.

REFERENCES

1. McDonald, J.S.D.C., **90** (1974) 189.
2. Idem, ibid., **96** (1980) 486.