APPLYING RESPONSE SURFACE METHODOLOGY FOR THE MAPPING OF EXPOSURE PLANES

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Abstract

This paper describes the application of a statistical technique , Response Surface Methodology (RSM) for the mapping of exposure surfaces. Use of this method allows a systematic method of testing exposure planes for evenness of illumination, and generates a contour map of the illumination at the plane. The work described here was done with negative acting photo-resist type systems (proofing) but would be applicable to positive acting or film systems.

Introduction

Many types of exposure sources are typically used in the Graphic Arts from high intensity carbon arcs to tungsten filament point sources. The high intensity dis-continuous sources are usually used for plates and proofing and the filament type lights for film application. There is an increasing trend in the film area to expose in a "white" light environment. This typically is accomplished by using a film sensitive in the ultraviolet region of the spectrum and insensitive to the white light region. Two other concurrent parallel trends are evident, an increasing quality awareness in the proofing and plate making areas. These trends and the need for increasing productive capacity by "short exposure times" have necessitated the use of dis-continuous sources of exposing energy. With these sources has come a need for short

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exposing times and consistent results. Lights are being used closer and evenness of illumination is becoming an increasingly important parameter.

There are several considerations in evaluating an exposure system.

Spectrally matched exposure source and film
Consistent exposure energy
Evenness of exposure plane

Exposure systems must be just that, matched systems for optimum performance. Many of the old rules of "thumb" do not allow for maximum performance. As an example a rule of thumb is that height of the light should be the diagonal of the frame. In a typical proofing frame of 30in.X 40in. this would be 50 inches. This would provide even illumination but require unnecessarily long exposure.

The use of several statistical methods can make the optimization of an exposing system an easier task. One such method is RESPONSE SURFACE METHODOLOGY. Response Surface Methodology (hereafter referred to as RSM) is a statistical technique where the relationship between one or several measured responses and several input variables are studied in an empirical way to generate a quadratic equation describing the response's relationship to the input variables. This allows a contour map of responses versus variables to be generated This technique is often used in industry , frequently in manufacturing operations. It is beyond the scope of this paper to provide a detailed analysis of these methods, however a short discussion will help illustrate the usefulness of these techniques.

RSM is part of a group of techniques to generate a model of a system. There are two types of models Mechanistic and Empirical.

Mechanistic modelling assumes a complete knowledge of the process being investigated. The model is described by a series of differential equations.

An empirical model on the other hand is an approximation of reality and is described by a quadratic equation. This is a valid approach as most surfaces can be described this way if the area studied is limited. RSM takes a snapshot of reality. It must be remembered that as such it is an approximation. It is possible to apply RSM and not to be able to construct a contour map from the data. This can occur if the "noise" is as great as the response. The result is that the response could have as easily occurred from random chance as from response change. This could be the effect of no response occurring or from inability to measure the desired response with sufficient accuracy. Another consideration is the choice of the response variable. It must represent the response desired . The choice of the resonse would appear obvious but it is easy to chose a response for simplicity or to choose a response that does truly reflect what you want to measure. As way of illustration suppose you are sent to survey planets for signs of life and you take a picture of earth from the moon. You conclude there are no obvious signs of life. A year later you repeat your experiment (good experiments always being replicated) and you conclude the place is crawling with life. The difference is day and night, quite literally, the second picture taken at night very clearly shows the cities and urban areas aglow with light.

In the measuring of an exposure frame the obvious response to measure is exposing energy. The question is how to measure it. There are two main methods, sensitometric and radiometric. Of the two the sensitometric has much to recommend itself. The main advantages are that the photosensitive material is always available and more importantly is relevant. A radiometric measurement is always going to have to be related to the response of the material. It is of little value to name the difference of illumination at an exposure plane in milijoules /cm^2 when the response of the photosensitive material to this response is unknown. It has been shown that the response of microlines to exposure changes of a photosensitive material follows a parabolic curve and can be described mathematically [1] [Fisch,Cox 1980]. This technique allows illumination to be measured by the photosensitive material itself and in a method that relates to halftone dot images. The use of microlines have been shown to work with plates[2] film and proofing materials. The use of microlines has several advantages as reported by Fisch and Cox [3] [1988]. One of the primary is that a specific microline value can be associated with a given dot range. In the use of RSM it is important that the response measured is a response that is related to the change that is desired to be detected. Grey scales have been used extensively in the graphic arts to measure variations in exposure. In photo-resist systems their use is often contradicted. Many of these systems use a scrubbing action of some sort in development. The action of this scrubbing effect can be quite different between the relatively small area of a dot when compared to the large area of a grey scale.

The use of a microline model is described by the following brief excerpt from a previous paper:[Fisch,Cox 1988]

> In independent investigations, Spainhour(10) observed that response curves obtained by the combined response of both negative and positive lines tended to be parabolic in shape and could be expressed as a second order polynomial of the general form $y=ax^2$. Such observations suggested a mathematical model of change in resolution response by exposure could be described; and therefore, modeling could be used to evolve a system for a more accurate determination of the best resolution for a particular exposure level.

This relationship is shown graphically in Fig. 1.

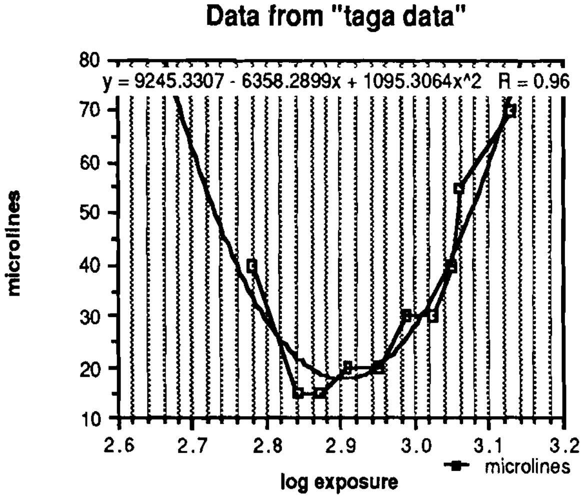

Fig.1 Microline response curve

This graph illustrates the relationship between microlines and exposure. As can be seen it is a simple matter to take any microline value on the Y axis and translate it to it's matching log exposure value on the X axis. The correlation formula shown at the top of the graph could be used to do this mathematically, but in practice it is usually easier to do this directly from the graph. In practice the data for this graph is generated from an log exposure series. In this case the UGRA[4] target was used and microlines were deemed resolved if two thirds of both the positive and negative sides were visible . This is described in detail by [5] Fisch and Cox. The data is then regressed with microlines the dependant variable and log exposure and log exposure squared the independent variables. In this example the correlation is 96% which is very good. In practice Kiekhafer and Stahl[6] have noted that when the correlation is below 90% there is usually evidence of high variability in the exposure system and the relationship is no longer a reliable predictor. It is important that points be distributed evenly about the inflection point for good results.

There are times when microlines may not be the appropriate response. This can occur if a material has excellent resolution and extremely wide latitude. In this case the microline would show virtually no change as exposure was changed. In these cases it is the investigators responsibility to ascertain the correct response variable.

With the microline method previously discussed it is now possible to see how a response map with microlines as a response could be translated to changes in illumination at an exposure plane. The response of microlines in an exposure plane is shown in Fig 2.

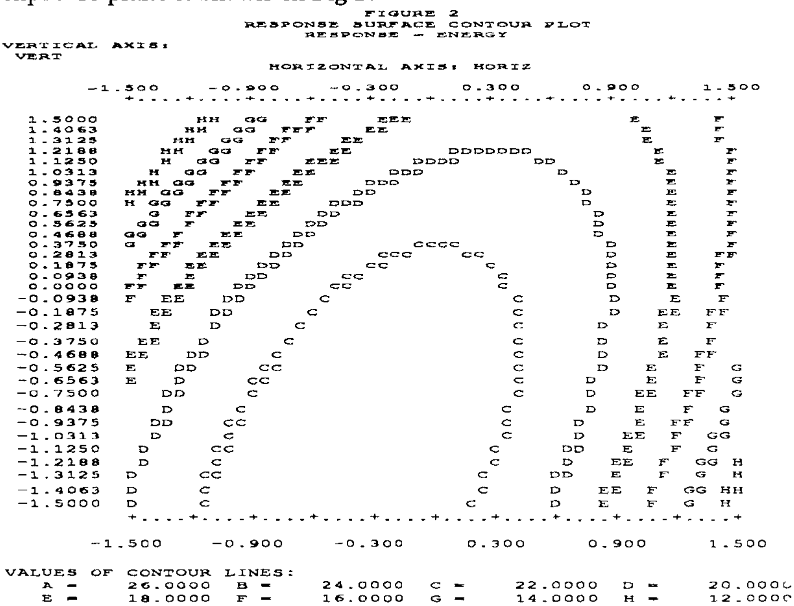

Figure 2 RSM Contour plot

The graph Fig.2 is a contour map generated using RSM. It provides a graphical means of envisioning the illumination across the exposure plane . The map shows response contours in relationship to variables on the axis. In this case the variables are horizontal and vertical distances. In all views shown in this paper the horizontal axis is parallel with the width of the page, the vertical parallel with the vertical. The exposure plane represented is 40 inches horizontal and 30 inches vertical. The contour map is a three dimensional image represented on a flat surface as such there are viewing limitations. The perspective of view is from directly overhead, as if you were viewing the exposure plane from the exposing source. The scaling is in coded units. Coded units are a method in RSM for expressing magnitude of variables. In this case the outside edges of the exposure plane are represented by ± 1.41. This holds true for horizontal and vertical. In the vertical 0 to 1.41 represents 15 inches , in the horizontal 0 to 1.41 represents 20 inches. Throughout the paper this convention applies regardless of the aspect ratio of the figures. The aspect ratios have been changed in some instances to allow figures to be placed side by side for ease of viewing. All values are in linear measurements and have not been transformed. It should be noted in the case of microlines these linear values do not correspond to linear exposure changes as this response is dependent on the response of the phot sensitive material involved.

With the microline techniques previously discussed actual exposure differences for any location on the exposure frame can be determined. This is the true value of this technique. The microline response curve in Fig. 1 can be used to show the latitude of the photosensitive material and by viewing the response surface it can be immediately determined if any value exceeds the latitude of the material. The map also allows the selection of a spot for exposure scales that would be most typical of overall response in the exposure plane. It is also possible to see any sharp discontinuities in the illumination. The usual test of four corners and the center might easily fail to detect a zone of high falloff that did extend to the corners. There are many common surfaces where the center and edges are similar, but where there are local extrema.

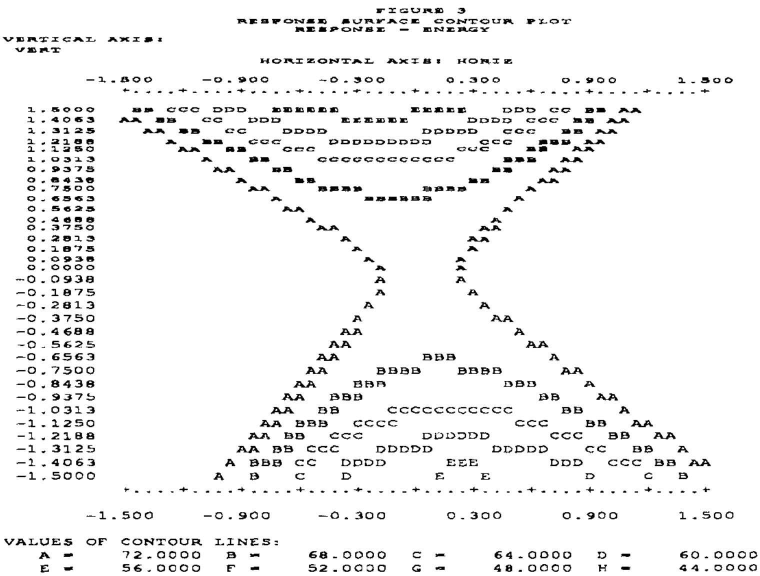

Figure 3 Cosine response detector 365 nm bandpass

The plot of radiometric data Fig. 3 shows the response of integrated energy. It is interesting to note that in both cases the lobes of the contours align themselves with the bulb which runs parallel to the exposure plain horizontal. This radiometer employed a cosine responsedetector that was sensitive in a broad band centered at 365nm.

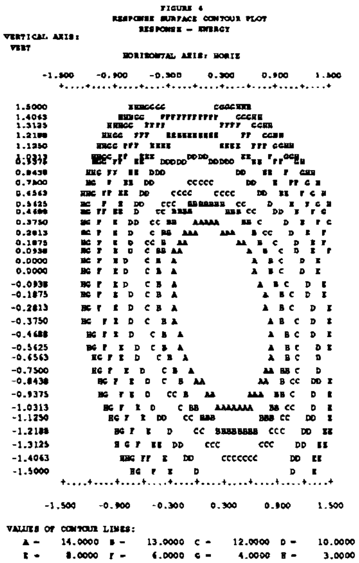

Figure 4 Cosine corrected plot

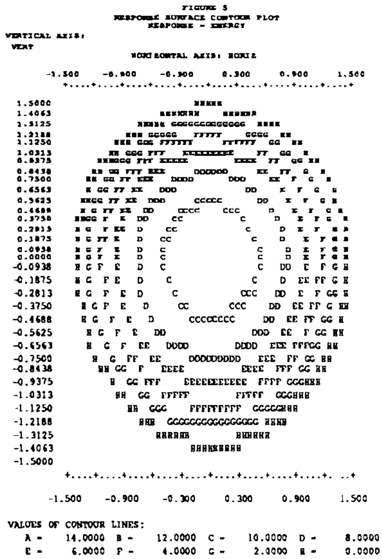

Figure 5 No cosine correction

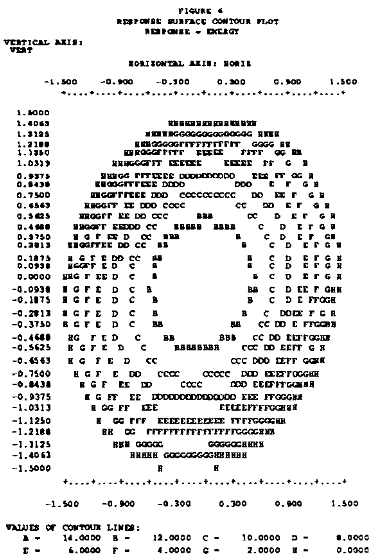

Figure 6 No Barrel

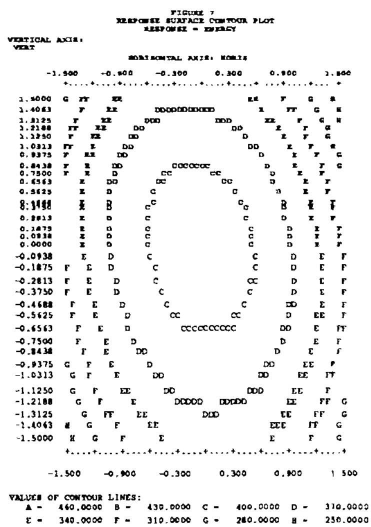

Figure 7 Integrating cosine Radiometer

The contour maps Fig 4,5 & 6 show the response obtained using a radiometer in different configurations. The tests were done using a cosine corrected radiometer in three different modes. The radiometer was cosine corrected and consisted of a barrel with internal stops which had a hemispherical cosine corrector at the top and the detector at the bottom of the barrel assembly . The normal cosine corrected position is shown in Fig.4 . Fig. 5 shows the radiometer with the correcting hemisphere removed and Fig. 6 with only the detector being used. The averaging effect of the cosine corrector can be seen in Fig 4. In all representations the lower left and upper right are represented as having the lowest illumination and their diagonal corners the best. The maps predict an illumination value of zero at some points, this is clearly not possible and is explained by instrument limitations . The readings were taken on one range and the lower readings simply did not have sufficient resolution .

Fig 7 shows the response of an integrating cosine corrected radiometer. The response is similar to the other three maps in that the lower left and upper right corners receive the least amount of illumination. The microline model for this exposure plane predicted a value of .10 log between the upper right and center. This is about 26%, Fig 7 shows a value of 250 units for the upper right corner and 400 units for the center which is 38%. The readings do not totally agree but the cosine corrected radiometer sees more light at the center than at the edges because of its wide acceptance angle.

It has been shown that the response of radiometric readings may give different surfaces due to differing response variables. This situation also applies to microlines. As was shown in the radiometric examples the different surfaces do not indicate a right or wrong answer simply a differing viewpoint. It is similar to a picture taken in color and false color infrared, the views look different but picture the same information but with a different response. The next two graphs help illustrate this point .

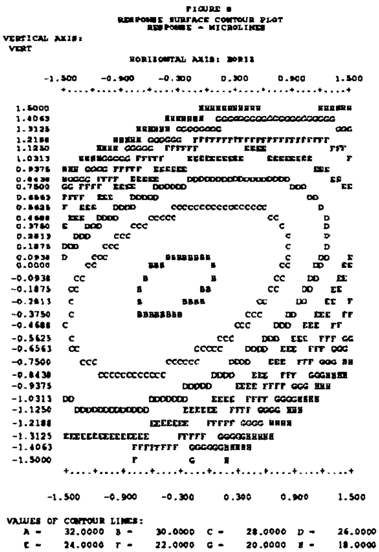

Figure 8 Half height

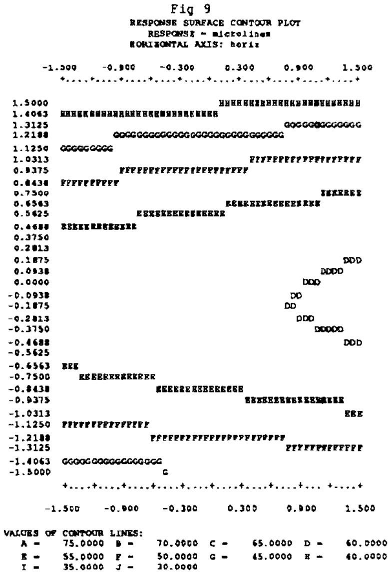

Figure 9 Full height

Microlines are effected by many of the variables in a system, if they were not microlines would not be the useful tool that they are. Some of these factors are latitude of the photosensitive material and overall system latitude. The many variables in a exposing system are highly interactive and often difficult to separate. In any event the final response is usually the critical one. In Fig 8. and Fig.9 the same source and plane has been used. In Fig 9. the exposure used was well above optimum at twice the normal exposure value. This was done to put the microline response on a portion of the response curve that had a high slope in order to have a smaller change in exposure produce a larger response. This does not change the final result, only the reference points change. This result shows the same as when the optimum exposure (not shown) was used. There is no differentiation in values. The test statistics Fig 10 clearly show this. Fig. 8 shows the same plane as Fig 9 but with the height reduced by half. This is in effect causing much more severe falloff ,which is of course easier to detect. The same effect can be caused by changes in system latitude. The extreme cases, infinite or zero latitude give similar results. In the case of infinite latitude changes in exposure can not be detected, in the case of zero latitude changes occur so rapidly separation of actual change from noise becomes impossible.

Multiple Regression Y_1 :microlines 5 X variables

DF:	R:	R-squared:	Adj. R-squared:	Std. Error:
11	.635	.403	-.095	10.495

Analysis of Variance Table

Source	DF:	Sum Squares:	Mean Square:	F-test:
REGRESSION	5	445.442	89.088	.809
RESIDUAL	6	660.808	110.135	p = .5829
TOTAL	11	1106.25		

No Residual Statistics Computed

Note: 12 cases deleted with missing values.

Multiple Regression Y_1:microlines 5 X variables

Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	58.824				
horizontal	1.136	3.729	.096	.305	.7709
vertical	-2.652	3.729	-.224	.711	.5037
horix*vert	0	5.247	0	0	•
x^2 of horizonta	-.018	4.207	-1.342E-3	4.175E-3	.9968
x^2 of vertical	-7.671	4.207	-.586	1.823	.1181

Figure 10 Full height test statistics

There are several statistics that indicate the "goodness" of the model The R^2 is a measure of how well the data fits the model The closer the number is to one (1) the better the fit. The statistic R^2 adjusted is an indicator if the number of terms used in the model are appropriate ,that is does this coefficient really influence the model. It is possible to fit terms which do not explain noise yet increase the R^2 In the second part of Fig .10 is the Beta coefficient table. This table shows the coefficients for the model and their significance. The probability column shows where the t statistic becomes significant. Simply put if we say the effect is real and it is not how often are we wrong? In the parameter column horizontal has a t value of .305 and a probability of .77. This indicates it becomes significant at 77 percentile In statistics significance is usually desirable at .05 or .10 the best this model does is .12 with the $X^2$of vertical parameter indicating this is the only relationship effecting the model.

In the next example the microlines used were the positive microline scale on the Matchprint[7] test element. The exposure was adjusted to 1.25 times normal. The exposures are adjusted above normal so the positive microlines are used, if the exposure fluctuated plus and minus of optimum a microline would have a positive and negative value. Exposing past the optimum allows only one value for the microline and simplifies the analysis.

Multiple Regression Y_2:half height 5 X variables

DF:	R:	R-squared:	Adj. R-squared:	Std. Error:
9	.934	.872	.712	2.562

Analysis of Variance Table

Source	DF:	Sum Squares:	Mean Square:	F-test:
REGRESSION	5	178.637	35.727	5.441
RESIDUAL	4	26.263	6.566	p = .0629
TOTAL	9	204.9		

No Residual Statistics Computed

Note: 14 cases deleted with missing values.

Multiple Regression Y_1:half height 5 X variables

Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	30.063				
horizontal	-.934	.911	-.184	1.026	.3628
vertical	-.758	.911	-.149	.832	.4522
horix*vert	3	1.281	.419	2.342	.0792
x^2 of horizontal	-2.106	1.214	-.342	1.735	.1578
x^2 of vertical	-5.422	1.214	-.881	4.467	.0111

Figure 11 Half height test statistic

The statistics in Fig 11 show a good adjusted R^2 of .71 and the t values of $X^2$of vertical and horiz*vert become significant at <.10. This was accomplished in two ways The effect of falloff was intensified by moving the light source closer, and secondly a microline target with more closely spaced increments was used. The same effect can occur with changes in latitude of the photosensitive material. An increasing latitude makes exposure differences increasingly difficult to detect. In a statistical sense the model depicted in Fig.10 has failed. It cannot detect changes in response from practical sense this is the desired result. Assuming the system noise is at a reasonable level it is desirable for the photosensitive material not to be able to detect changes in illumination.

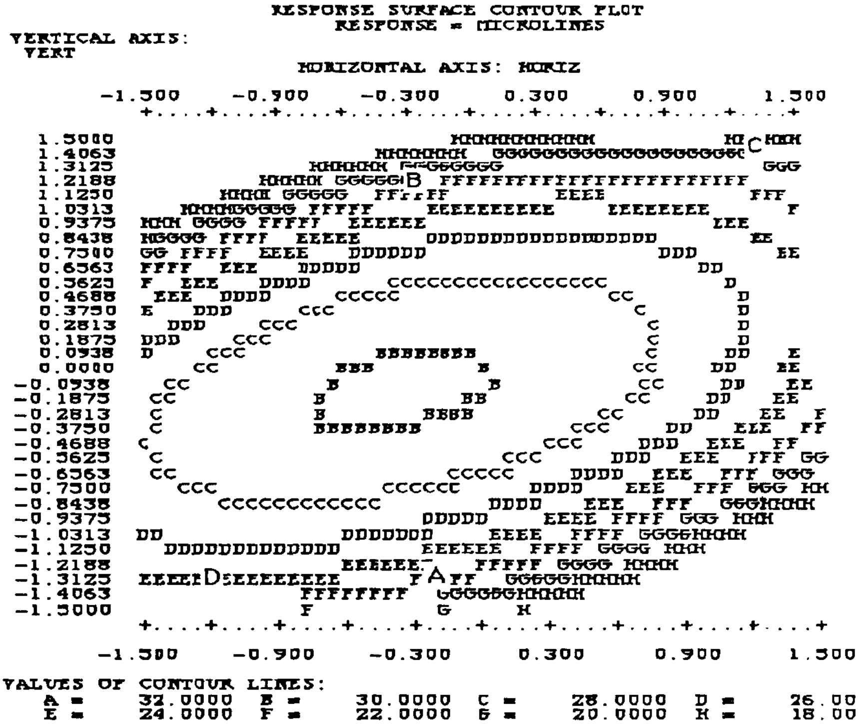

Figure 12. Predictive contour map

Figure 12 shows a response contour map with four points labelled A,B,C, and D. These points were tested to see if the model could predict the values actually obtained. To make the test more rigorous the model was developed on a Friday and the predicted points were tested the following Monday. The material and processor were constant. The results are shown in Table 1.

POINT	PREDICTED MICROLINE	ACTUAL MICROLINE
A	22/24	24
B	20	21
C	20	21
D	24	24

The values obtained in actual practice match very closely with those predicted by the model. The actual ability of a model to predict is greatly effected by the variability of the system. It is possible to predict the range of estimated values for a given value. In the case of exposure plane modelling it is desirable to detect general contours and to find grossly atypical areas

Conclusion

It has been demonstrated that the use of RSM can be a valuable tool in the Graphic Arts for the mapping of illumination level at exposure planes. The use of RSM when coupled with the appropriate response can provide a contour map of the chosen response and also be used to predict this response. The techniques presented in this paper allow a much increased knowledge of the true nature of the exposure plane This increased knowledge can result in increased productivity and quality in the finished product.

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