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# 편향요크의 컨버전스 조정에 대한 정수계획 해법

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# Integer programming approach to the convergence adjustment of deflection yoke

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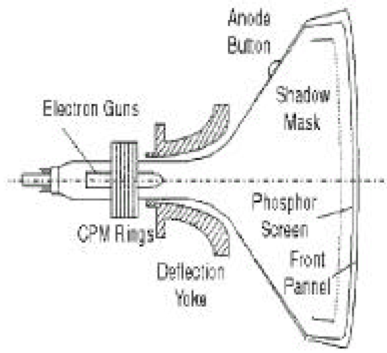
**Abstract**

We consider the adjustment of convergence of Deflection Yoke (DY) in Color Display Tube (CDT). Convergence is a measure of how well the red, green and blue beams are physically aligned with each other to strike the same area of the screen. When convergence mismatch (called misconvergence) happens, one way of compensating it is to attach several ferrite sheets on the interior surface of DY. Since the misconvergence results from magnetic field generated abnormally and it has linearity property, the effects of ferrite sheets can be added also. Under this property, we suggest an optimization model of misconvergence compensation process and test it with random 81 DY samples. As a result, more than 90% of the samples could be made to satisfy the required convergence criteria.

## 1. Introduction

We consider the adjustment of convergence of Deflection Yoke (DY) arising in the manufacturing process of color monitors. The structure of Color Display Tube (CDT) is shown in Figure 1 [1,2]. After three electron beams are emitted from R(red), G(green), B(blue) electron guns, they are deflected by CPM (Convergence and Purity Magnets) rings on the neck and the DY attached to the funnel glass cone. Electron beams which have passed through CPM rings are deflected by horizontal and vertical magnetic fields generated by 2 coils of DY. Then, deflected three beams pass one of the shadow mask holes and collide with phosphor screen and emit lights. Refer to papers [1,2] for more detailed operation and adjustment of CDT.

Convergence is a measure of how well the red, green and blue beams are physically aligned with each other to strike the same area of the screen. Misconvergence causes sharply defined characters or objects to have colored fringes [4]. Convergence can be accomplished by design optimization of coil distributions of DY [3,5]. But minor misconvergence which is generally inevitable when coils have been wound, can be diminished by attaching ferrite sheets to the interior surface of DY. Ferrite sheet has a capability of changing local trajectories of the beams and can be used to improve convergence of the corresponding region of screen.




[Figure 1] Color Display Tube (CDT)

In the factory, convergence adjustment is performed manually by skilled workers and generally, it takes more than a year for a novice to become an expert for this process. In order to improve convergence quality and increase efficiency of convergence adjustment process, we developed a visualized guidance system. Its main function is to read out misconvergence of a DY and indicate visually the locations where ferrite sheets should be attached for misconvergence compensation.

To our knowledge, there have been two studies about adjustment of convergence of DY [1,2,6]. In the studies, (neuro-) fuzzy models were considered to express the relationship between input (location of sheets) and output (convergence change). However, detailed experiment results were not reported in the papers.

In both studies, accuracy of fuzzy models is critical to find attaching locations of sheets that can compensate misconvergence. They used an iterative approach and found the locations considering the axial region and the corner region separately. In this research, we obtain the location (including sheet size)-convergence change combinations by measuring the convergence changes directly and we do not estimate them for other locations using the fuzzy models. By using integer programming model, we can get the minimum number of sheets (with size and location of each sheet) needed to compensate misconvergence in a single step. In order to use the integer programming model, we need to assume that the convergence of a DY has *linearity* property as in the research by Song et al. [6]. Definition and validation of the linearity property will be described in the next section.

## 2. Convergence of DY and Linearity

### 2.1 Measuring convergence of DY

In convergence measuring process, white cross-hatch pattern (called raster) is displayed on the screen and sensing devices such as CCD cameras are used to evaluate the horizontal and vertical distance between red, green and blue lines comprising a white line. Typical test pattern has 5 horizontal lines and 5 vertical lines, offering 25 cross points. In mass-production line, convergence of 17 points is considered to be enough to describe whole misconvergence characteristics of a CDT. An example of raster and such 17 points are shown in Figure 2 (a). The convergence data for each point is expressed by six values which represent the vertical and horizontal relative positions of every beam pair: RGx, RGy, BGx, BGy, RBx, RBy. For example, RGx is the relative position of red beam with respect to green beam in horizontal axis. If this value is positive, red beam is positioned at the right of green beam. Other values are defined similarly. So a convergence data can be expressed by a vector of 102 elements, where every 6 values correspond to each point of measurement. We determine that a DY satisfies convergence criterion if each element of the convergence vector lies within a restricted range. The required range is different depending on the location of measurement. Points 2, 4, 5, 6, 8 of axial region in Figure 2 (a) are categorized as A zone, the rest of points are categorized as B zone. Data in A (B) zone should have their absolute values less than or equal to $T_A$ ($T_B$), where $T_A < T_B$.

### 2.2 Test of linearity of convergence

Linearity property is stated as follows: change of convergence due to a ferrite sheet is independent of the current attachment of sheets. In other words, the vector of convergence change due to several sheets can be expressed as the sum of the vectors due to each sheet. In our study, we tested linearity considering two sheets at a time. Theoretically, linearity of three or more sheets holds if linearity of two sheets holds.

In the factory, rectangular sheets are used for adjustment of convergence. Convergence due to a rectangular sheet varies depending on its orientation as well as the location. Later, we test compensation of misconvergence with circular sheets in order not to consider the effect due to the orientation of the sheet. But, in the test of linearity, we use both rectangular and circular sheets.

To test linearity, we calculate the convergence vector $x = y_1 + y_2 - z$, where $y_1, y_2$ are vectors of convergence change due to each sheet, and $z$ is a vector of convergence change when two sheets are attached. We identified that a measurement pair satisfies linearity when the number of elements of which absolute values are greater than 100 $\mu m$ is less than 2. This threshold value was set on the base that each element of the vector has measurement error up to $\pm 50\,\mu m$.

Location of a sheet is expressed by polar coordinate $(r, \theta)$ (see Figure 2 (c)). Depth of a sheet $(r)$ can have values from 1 to 7 in which 1 represents the smallest radius (deepest location). In the linearity test, we considered two values of $r$ and 278 angle pairs, where angles of each pair were selected from [0, 350] with various difference. For selected two angles $\theta$ and $\phi$, we test linearity for the following 4 measurement pairs: $\{(2,\theta),(2,\phi)\}$, $\{(2,\theta),(5,\phi)\}$, $\{(5,\theta),(2,\phi)\}$, $\{(5,\theta),(5,\phi)\}$ when rectangular sheets are concerned. For the circular sheets, we test for the following 2 measurement pairs: $\{(2,\theta),(2,\phi)\}$, $\{(4,\theta),(4,\phi)\}$.

As a result, we found that all measurement pairs satisfied the linearity criterion. As a matter of fact, our linearity test is not complete in that the number of measurement pairs is limited. However, we concluded that the test was sufficient to go further to the next process: modeling and test of misconvergence compensation.

## 3. Modeling

Using the linearity property, we can compute the vector of convergence change due to several ferrite sheets as the sum of the vectors due to each sheet. So, we consider an integer programming model to select the needed locations of sheets among many candidate locations. For the misconvergence compensation, we consider circular sheets of three sizes (they are classified as type 1, 2, and 3). Note that the locations of the sheets can be chosen over the continuous domain (interior surface of DY), and with more locations, the model becomes more accurate. Here, we partitioned the surface of the DY properly and selected a finite number of locations for each sheet type (refer to the next section).

Next are notations and decision variables used in the model.

$N_k$: Set of candidate locations of sheets of type *k*, $1 \le k \le 3$. The same location can be included in more than one $N_k$'s.

$x_j^k$: 1 if a ferrite sheet of type $k$ is attached to location $j \in N_k$, and 0, otherwise.

$a_j^k$: Vector of convergence change when a ferrite sheet of type $k$ is attached to location $j \in N_k$, $a_j^k = (a_{1j}^k, a_{2j}^k, \dots, a_{102,j}^k)$

$b$: Convergence vector of an empty DY, $b = (b_1, b_2, \dots, b_{102})$.

The mathematical formulation of a mixed integer programming (MIP) model can be stated as follows.

$$\text{Min} \sum_{k=1}^{3} \sum_{j \in N_k} x_j^k \tag{1}$$

subject to

$$w_i = \sum_{k=1}^{3} \sum_{j \in N_k} a_{ij}^k x_j^k + b_i \quad \text{for} \quad 1 \le i \le 102 \tag{2}$$

$$-T_A \le w_i \le T_A \quad \text{for } i \text{ in A zone} \tag{3}$$

$$-T_B \le w_i \le T_B \quad \text{for } i \text{ in B zone} \tag{4}$$

$x_j^k$ is binary for $j \in N_k$ and $1 \le k \le 3$

The objective (1) is to minimize the number of ferrite sheets. In constraints (2), $w = (w_1, w_2, \dots, w_{102})$ is the vector of the convergence after needed sheets are attached. Constraints (3) and (4) state that elements of the convergence vector should satisfy the convergence criterion. Note that variables $w_i$ have integer values in any feasible solution, though they are not set as integer ones.

## 4. Experiments

We consider circular sheets with diameters of 6*mm*, 8*mm* and 10*mm*. In the factory, rectangular sheets are preferred since they provide more degree of freedom: location and orientation of a sheet. Since attaching circular sheets requires only finding the accurate locations of sheets, they seem to be more suitable for the automatic attachment indication system.

### 4.1 Getting convergence change data

In order to get convergence change due to single sheet, we place a sample DY without sheets at the measuring system and read out convergence. Then we attach a sheet to one of the candidate locations of the DY and get the changed convergence data.

Convergence change becomes larger as sheets are attached to deeper location or as larger sheets are attached. If the value of change is too large (more than 200 $\mu m$) or too small (less than 50 $\mu m$) it may causes unexpected side effects. So we do not consider such sheet-location combinations here. Consequently, 370 combinations that result in resonable amounts of convergence change were prepared

### 4.2 Test of misconvergence compensation

After the data of convergence change are prepared, we find sheet locations for misconvergence compensation using real DY samples and check if convergence criterion can be satisfied. The procedure is similar to two-step procedure described above except that the locations of sheets are obtained by solving the optimization model. If convergence cannot be accomplished by a trial, we repeat the procedure.

### 4.3 Results

Total 81 DY samples were tested. Among them, five DYs satisfied convergence criterion initially, so they were excluded from the test. Thresholds in convergence criterion for A and B zone are 200 $\mu m$ and 300 $\mu m$, respectively.

We succeeded the adjustment of convergence for 71(93%) DYs within three trials. The numbers of success for the three trials are 60, 9 and 2, respectively. Thus we can find that two trials of adjustment are sufficient for most DYs. More than three trials, however, were not helpful for misconvergence compensation. Figure 2 shows an example of convergence adjustment of a sample DY. We succeeded the adjustment at the first trial.

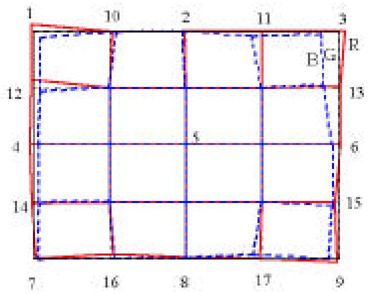
Among five DYs for which we failed to compensate misconvergence, two of them are identified as inadequately prepared samples. For such DYs, the difference of sizes between red and blue cross-hatches was too big and misconvergence could not be compensated enough. For the rest of three DYs, we could not reveal the reason of the adjustment failure.

The optimization model was solved by CPLEX 6.5 and it took at most 3 seconds to get optimal solutions for an adjustment trial.

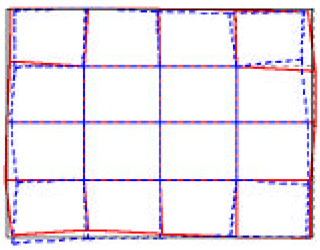
## 5. Conclusions

We suggested and tested an optimization model for the adjustment of convergence of DY and succeeded the adjustment for more than 90% of DY samples. The success seems to result from the following factors.

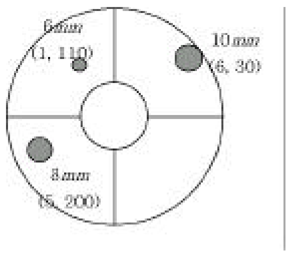
First, the automated measuring system of DY developed recently was very useful in data acquisition process, while specially designed fixture for ferrite sheet attachment made the experiment very efficient. Second, optimization package CPLEX solved the optimization models in short times. The optimization model aimed to minimize the number of sheets not to minimize misconvergence ($\sum_i |w_i|$). With the second objective, we may be given more sheets. Since error between expected convergence change due to a sheet and true one is accumulated as the number of sheets increases, final convergence performances due to optimization model and real adjustment may not be matched. Moreover, the time to get optimal solution is much less with the first objective than the second.




(a) Raster of an empty DY



(b) Raster after three sheets are attached.




(c) Attachment of sheets

[Figure 2] An example of convergence adjustment

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