

ERRORS IN PROGRESSIVE DIES FOR ELECTRONIC COMPONENTS

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Introduction

Electronic systems contain a variety of small, metal components used for conducting electrical signals between subsystems. Examples of such parts include stamped signal contacts such as shown in Fig. 1 and package lead-frames. These components are manufactured in progressive diesets that stamp the components from a strip of stock material. Stamping operations and dieset elements contribute to the dimensional variation in the finished product and thus affect the quality, performance, and cost of electronic systems.

Dimensional variation is attributable to the compound effect of manufacturing errors in dieset assemblies (Fig. 2) and components, design clearances, operational variability, tool wear, and variation in product

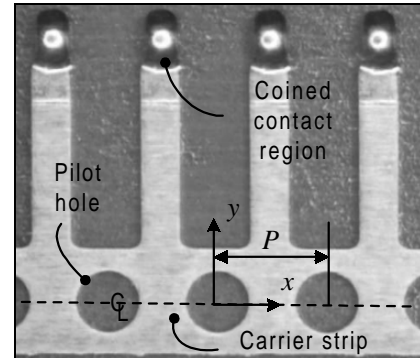


Fig. 1 Stamped electrical contact

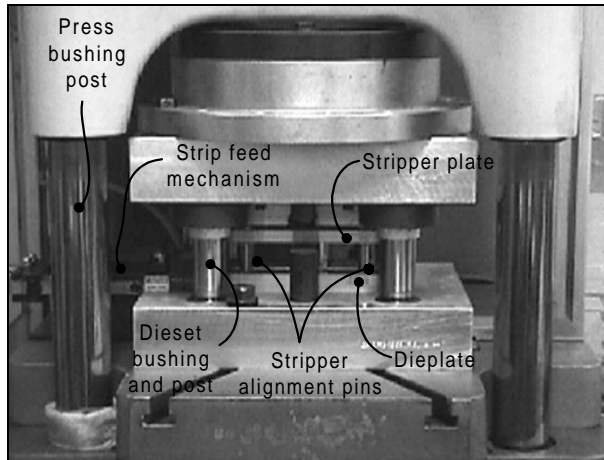


Fig. 2 Dieset for stamping electrical contact

for locating the product strip in subsequent operations like assembly. Pilot holes therefore provide the fundamental datum for a stamped strip and hence constitute a natural place to begin developing precision design methods. In this paper, variation in pilot holes is characterized by pitch (distance between hole centers) and y-errors (distance normal to the pitch). This paper presents a measurement technique, an error model, and a simulation process to characterize and conservatively estimate these errors.

Measuring pilot hole errors

This section presents a technique for measuring errors in the position of pilot holes. The process involves four steps: measurement of the pilot hole locations with an optical gage, fitting the measured points to a circle, calculation of the errors from the best-fit circle, and characterizing the errors statistically.

This technique was used to measure samples from the stamped strip shown in Fig. 1. The x and y coordinates for the center of each hole were measured on a SmartScopeTM FOV from Optical Gaging Products, Inc. of Rochester, NY. Stamped strips often exhibit camber, which is a permanent

material. Complex relationships between these factors make the design of progressive dies difficult to systemize. Prior research on designing progressive dies focused on CAD systems^{1,2,3}, expert systems^{4,5}, and simulation of the forming process^{6,7}. Few investigations into precision aspects have been published^{8,9}. Precision design methods¹⁰ such as error modeling¹¹ and error budgeting¹² that are common for precision machines do not exist for progressive dies, so die design remains an area governed by rules of thumb and diverse opinions¹³.

The pilot holes within a carrier strip or lead-frame are crucial features in stamped products. The blanking operation that creates the pilot holes is generally the first operation within the dieset. Pilot pins at subsequent stations along the progression use the pilot holes to locate the metal strip. Furthermore, pilot holes are often used

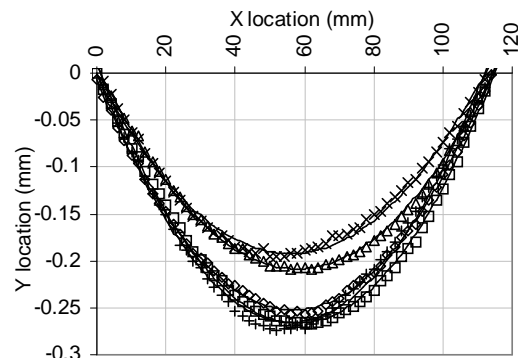


Fig. 3 Measurement of hole centers and fitted circles

strain induced by an imbalance between the residual stresses on opposite edges of the carrier strip. The fixture for the strips of contacts permitted camber but prevented additional strain. Therefore, the strips exhibit a constant radius of curvature (near 6 m).

Fig. 3 shows experimental data for the location of the pilot holes' centers along with circular curve-fits. The errors are measured with respect to the circle as shown in Fig. 4. The curve-fit effectively removes the camber to provide true pitch and y-error information. The y-error is the distance between the point and the curve, measured normal to the circle. The pitch is the arc length along the circle between the normals of two consecutive points. The mean and standard deviation for the pitch were 2.001 mm and 3.4 μm , respectively. The mean and standard deviation for the y-errors were 0.01 μm and 4.8 μm , respectively.

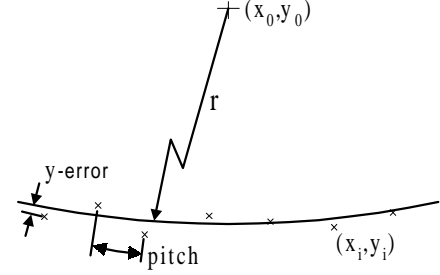


Fig. 4 Errors measured from circular fit

Error model for random variation

An error model that combines the principal error sources to estimate the variance in the pitch and y-errors of the pilot holes is presented. The model is derived by considering two independent operations: locating the carrier strip with several pilot pins and punching the pilot hole. Eq (1) and Eq (2), which express the expected values and variances of a linear combination of uniformly or normally distributed random variables¹⁴, are applied in the model.

$$E(Y) = a_1 E(X_1) + a_2 E(X_2) + \dots + a_m E(X_i) \quad (1)$$

$$\sigma_Y^2 = a_1^2 \sigma_{X_1}^2 + a_2^2 \sigma_{X_2}^2 + \dots + a_m^2 \sigma_{X_m}^2 + \sum_{i < j} \sum_{j=2}^m a_i a_j \sigma_{X_i} \sigma_{X_j} \text{Cor}(X_i, X_j) \quad (2)$$

Fig. 5 shows a pilot pin randomly located inside a hole in the randomly located stripper. The position of the strip and the location of the hole in the strip are random due to feed errors and variation in punching operations. The clearances on the sides of the pin are given in Eq (3) and Eq (4).

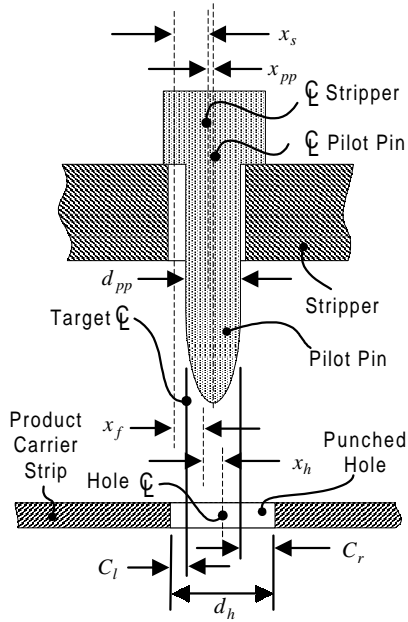


Fig. 5 Errors between a pin and hole

$$C_l = \frac{1}{2} d_h - x_f - x_h - \frac{1}{2} d_{pp} + x_s + x_{pp} \quad (3)$$

$$C_r = \frac{1}{2} d_h + x_f + x_h - \frac{1}{2} d_{pp} - x_s - x_{pp} \quad (4)$$

The clearances are linear combinations of the errors, so applying Eq (1) and Eq (2) yields the expected values and the variances for the clearances:

$$\mu_C = \mu_{C_l} = \mu_{C_r} = \frac{1}{2} (\mu_{d_h} - d_{ppnom}) \quad (5)$$

$$\sigma_C^2 = \sigma_{C_l}^2 = \sigma_{C_r}^2 = \frac{1}{4} \sigma_{d_h}^2 + \sigma_{x_f}^2 + \sigma_{x_h}^2 + \sigma_{x_s}^2 + \sigma_{x_{pp}}^2 \quad (6)$$

Locating the carrier strip with multiple pins is similar to selecting a set of values from the distributions for the clearances. The minimum value within each set represents the clearance between the carrier strip and the entire set of pins. The minimum value is random and called the first order statistic¹⁴. The expected value of the first order statistic, given in Eq (7), is used in Eq (8) to estimate the variance in the uniformly distributed location of the carrier strip with respect to ground.

$$\mu_{C_S} = \int_{-\infty}^{\infty} C_S n \left\{ 1 - \frac{1}{2} \left[1 - \text{erf} \left[\frac{C_S - \mu_C}{\sqrt{2} \sigma_C} \right] \right] \right\} \frac{1}{\sqrt{2\pi} \sigma_C} \exp \left[\frac{-(C_S - \mu_C)^2}{2 \sigma_C^2} \right] dC_S \quad (7)$$

$$\sigma_{x_c}^2 = \frac{(2\mu_{C_S})^2}{12} \quad (8)$$

Fig. 6 illustrates the punch randomly located inside a hole in the randomly located stripper plate. The punch cuts a hole through the randomly located carrier strip. As shown in Eq (9), the position of the punched hole is a linear combination of the location of the stripper, punch, and carrier strip. The variance in the location of the punched hole is found by applying Eq (2), but correlation between the stripper and the carrier strip is expected.

$$x_h = x_s + x_p - x_c \quad (9)$$

$$\sigma_{x_h}^2 = \sigma_{x_s}^2 + \sigma_{x_p}^2 + \sigma_{x_c}^2 - \sigma_{x_s} \sigma_{x_c} \text{Cor}(x_s, x_c) \quad (10)$$

Eq (11) expresses the pitch between two consecutive holes in terms of the nominal pitch and the location of the two holes. From Eq (2), the variation in the pitch is twice the variation in the location of an individual hole.

$$P = P_{nom} + x_{h2} - x_{h1} \quad (11)$$

$$\sigma_P^2 = 2 \sigma_{x_h}^2 \quad (12)$$

The variation in the stripper, punch, pilot pins, and feed are determined from design parameters such as bearing clearances and feed uncertainty. Eq (6), Eq (7), Eq (8), Eq (10), and Eq (11) form a (non-linear) system of equations that can be solved for the variance in the strip location, hole location, pitch, and probable hole clearances. Using conservative estimates for the design parameters, this error model predicts a standard deviation of 6.2 μm for the pitch errors.

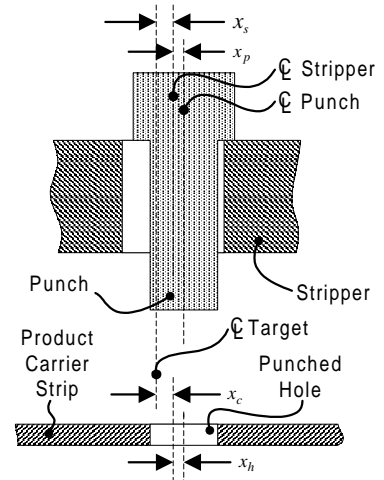


Fig. 6 Errors in punching operation

Error simulation

A simulation for the variation in pilot holes was developed within SciLab¹⁵. The simulation emulates the punching and piloting operations in a sequence similar to a real progressive die. A series of punched holes is indexed through the dieset, so piloting actually depends upon the variation in prior punch operations.

The simulation consists of three nested loops. The primary loop operates the stripper plate. Each time the die cycles, a random location for the stripper plate is generated. A simplification for the presence of multiple bearings in the plate provides a conservative estimate. The next loop randomly locates all the pilot pins in the stripper and then shifts them by the stripper position. This gives the locations for all pilot pins relative to the global coordinate system. The third loop recursively adjusts the position of the carrier strip until it fits within the range of clearance for the entire set of pilot pins. The punch is then randomly located within the stripper and offset by the stripper position to obtain its location relative to the global coordinate system. Finally, the hole is punched through the carrier strip. The entire process is repeated for the desired quantity of die strokes.

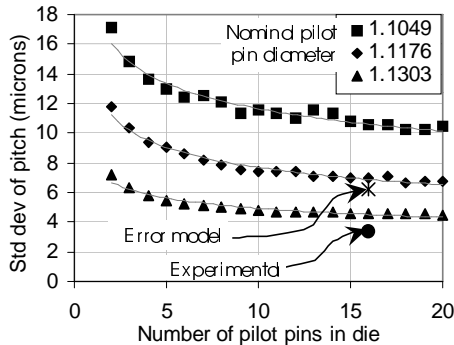


Fig. 8 Pitch error as a function of the number of pilot pins

The pitch errors in Fig. 8 decrease as the quantity of pilot pins in the die increases. The pitch error asymptotically approaches a minimum value set by the geometry and clearances in the dieset. A change in the diameter of the pilot pins (which changes the clearance between the pilot and pilot hole), therefore results in a different minimum limit in the pitch error.

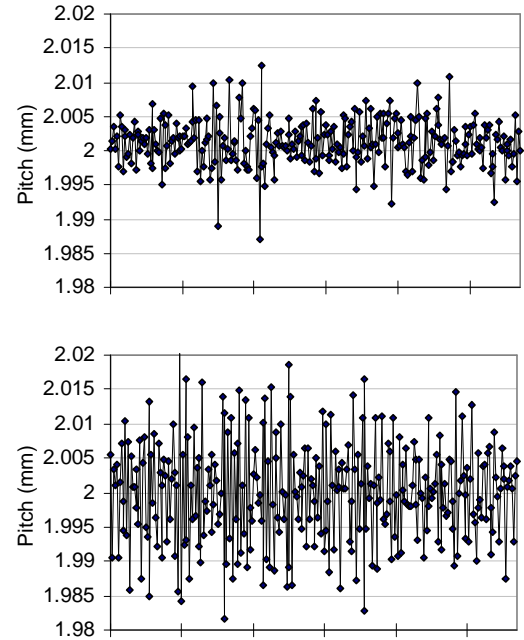


Fig. 7 Pitch per cycle, experimental (top), simulation (bottom)

Fig. 8 shows the results of the simulation for various numbers of pilot pins and three different pin diameters. Two additional points identify the value predicted by the analytical model and the measured value. The simulation was configured with the same geometry as the test die, and clearances and means matched those used in the analytical model (nominal manufactured values). Both the measurements and the simulation exhibit an alternating cycle of short and long pitches. Thus, the nature of the simulation follows closely with the real die. Like the error model, the simulation yielded larger errors, but this is expected due to the conservative nature of the stripper bearing assumptions.

Conclusions

This paper presents a technique for measuring pitch and y-errors in stamped pilot holes of carrier strips or leadframes. An error model is developed that considers design parameters of the progressive die such as punch clearance, stripper bearing clearances, pilot pin clearances, and the quantity of pilot pins in the progressive die. Solving a system of non-linear equations provides an estimate of the pilot hole pitch. In addition, the error model offers input in to a complete system simulation that reproduces the characteristic output of the experimental data. Using this approach to design the piloting system for a progressively stamped product provides knowledge of achievable pitch repeatability. These methods help the designer achieve the quality requirements at minimum cost, by minimizing wasted material in the carrier strip.

This exploration has shown that predictive error models and simulations can be created for stamping operations such as the blanking of pilot holes. Extending these models by providing design optimization and incorporating manufacturing tolerances, is the next step. This methodology may also be applicable to additional stamping operations such as trimming, coining, etc. This provides additional opportunities to develop more precision design tools that help reduce or eliminate the dependence on opinion and rules of thumb common to progressive die design.

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