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BDX-613-1049 (Rev.)

STEEL-RULE DIE CONTOURING
EVALUATION

PDO 6984752, Topical Report

R. A. Hile, Project Leader

Project Team:
M. L. Wilson
J. J. Mosakowski

Published May 1974

Prepared for the
United States Atomic Energy Commission
Under Contract Number AT(29-1)-613 USAEC

**Kansas City
Division**

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Department 862

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STEEL-RULE DIE CONTOURING EVALUATION

BDX-613-1049 (Rev.), UNCLASSIFIED Topical Report, Published
May 1974

Prepared by R. A. Hile, D/862, under PDO 6984752

Plywood-base steel-rule dies manufactured by the Atlas Steel Rule Die, Incorporated were evaluated as possible alternatives to matched hard dies for flexcircuit contouring. The objectives were to reduce the cost of flexcircuit contouring tools and to obtain shorter lead times in the procurement of production tools. Evaluation of dimensional accuracy and workmanship indicated that these dies are suitable for applications that require contour tolerances no smaller than 0.025 inch (0.62 mm).

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THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission
Contract Number AT(29-1)-613 USAEC

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SUMMARY

The objective of this project was to evaluate the use of laser-produced steel-rule dies for contouring flexible circuits. The advantages of using this type of die are reduced tooling costs and faster procurement. Both of the advantages were realized with the laser-produced die manufactured by Atlas Steel Rule Die, Incorporated. An Atlas die consists of a wood base with a sharpened blade formed to the circuit configuration. The flex-circuit is positioned over the die blade by use of tooling pins, and the contouring operation is accomplished by forcing the die through the circuit material.

A cutting press was purchased to supply the cutting force necessary for the steel-rule dies. The press cutting surfaces were modified to permit inverted cutting, which provides better die accessibility when loading piece parts on the die. The press, a United Shoe Machinery, Series 30, Model B, proved very effective for this application.

Fabrication of a steel-rule die by Atlas is accomplished by laser cutting slots in a plywood base, then hand forming the die blade and installing it in the slot. Manufacturing variables which affect die quality are largely a function of the diemaker's skill. Discrepancies such as butt joint placement and quality, die height variation, and radii-forming accuracy all affect the final contoured piece part. A fabrication specification which was prepared to help reduce the number of variables now accompanies all purchase orders for Atlas dies.

In addition to die inconsistencies, laminate shrinkage during circuit etching contributes to the contour tolerance buildup. A series of tests was run to determine the effect of circuit-panel shrinkage on contour tolerance. Circuits were fabricated with the circuit images turned both in the machine direction of the laminate roll and parallel to that direction. Circuits fabricated parallel to the roll direction shrank approximately 0.003 inch/inch (0.003 mm/mm) compared to very little or no change in the perpendicular direction. Therefore, circuits should be fabricated perpendicular to the roll direction whenever possible.

The evaluation of the Atlas dies showed that a flexcircuit contour tolerance of 0.025 inch (0.620 mm) is necessary to effectively use steel-rule dies for extended flexcircuit contouring. A cost savings of approximately \$1300 would result from use of steel-rule dies for the test circuits.

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DISCUSSION

SCOPE AND PURPOSE

The objective of this project was to evaluate the use of plywood steel-rule dies for flexcircuit contouring applications, particularly the dies produced by Atlas Steel Rule Die, Incorporated, Elkhart, Indiana. The purpose of the investigation was to effect a saving in the cost of flexcircuit contouring tools by using steel-rule dies instead of costly matched hard die sets.

ACTIVITY

Although steel-rule die technology has been used for years in the folding-carton industry, the dimensional accuracy of plywood-base dies was less than desirable for flexcircuit contouring. Metal-rule dies which have close-tolerance machined bases can function adequately, but these dies are more costly because of design requirements and extensive machining. The advent of the laser-cut plywood base die by Atlas Steel Rule Die, Incorporated revolutionized the rule-die industry and made available dies which are both economical and dimensionally satisfactory.

When this investigation began it was determined that a suitable press would be required for use in conjunction with the dies. The task of finding a press which would give satisfactory results terminated with the discovery of the United Shoe Machinery, Series 30, Model B. This press was acquired at a cost of approximately \$2500. Figure 1 shows the cutting press, as obtained; however, the press cutting surfaces were altered to perform inverted cutting for flexcircuit contouring. Inverted cutting is accomplished by turning the die cutting edges upward so the cutting action is against the upper pressure plate. This system is more suitable for piece-part cutting because of improved die accessibility when loading flexcircuits on the tooling pins. Press alterations made to facilitate inverted cutting included installation of a 0.125-inch (3.18 mm) thick piece of cork and a 0.250-inch (6.36 mm) flat steel plate on the bottom pressure plate. The cork located underneath the steel plate acts as a shock absorber to provide a smooth cutting action. The upper cutting surface, a flat piece of 0.250-inch (6.36 mm) thick

Figure 1. United Shoe Machinery Cutting Press

6061-T6 aluminum, provides the cutting action against the die blade. This material was chosen to eliminate inconsistencies associated with the conductive rubber surfaces supplied by the press vendor. A rubber surface which is penetrated by the die blade can force the flexcircuit into the die cavity and cause the edges of the circuit to roll or curl. This condition makes the circuits difficult to remove from the die and can result in damage to the circuit. The metal surface gives a snap cutting action that pushes the circuit into the die only far enough to complete the cut. When the operation is properly set up there is no die penetration into the aluminum cutting surface. With proper care of the die, an almost unlimited number of cuts can be made.

The cutting press is electrically controlled to permit automatic adjustment to different die heights. This is accomplished with a system that senses continuity from the die bed through the die blade to the upper cutting surface. When continuity is achieved on completion of the cut the upper head returns to home position. The advantage of this system is that only the pressure required to make the cut is applied, thus resulting in a smooth, low-impact cut which protects the dies and the cutting surfaces from damage. The press is equipped with a time delay which allows higher pressure for cutting, but for flexcircuit contouring with metal cutting surfaces, a minimum time delay setting is desirable.

Atlas Steel Rule Die, Incorporated, Elkhart, Indiana, is the vendor of laser-produced dies used for this evaluation. The Atlas process for die making uses a numerically-controlled CO₂ laser to cut slots in a 3/4-inch (1.91 cm) plywood base. The die blade is then hand formed and pressed into the slots to form the completed die. Since the laser is tape controlled, dies can be reordered by specifying the NC tape program number stamped on the die. Purchase orders for dies are accompanied by a design drawing of the circuit configuration. Atlas programs the NC laser equipment from the drawing to a claimed dimensional accuracy of ± 0.001 inch (0.025 mm).

The laser slotting of the die base is a very reliable process. The only error that can occur at this point in time is in programming. Atlas runs a dimensional check of the laser program tape and corrects obvious errors; therefore, it is reasonable to believe that the laser-cut die base is accurate to within the ± 0.001 -inch (0.025 mm) tolerance claimed.

As with any steel-rule die, the skill of the die maker who installs the blade is the prime consideration in achieving a quality die. The dies obtained for this evaluation showed a high degree of skill, although some differences were noted. The die construction and definition can be controlled by the user;

however, many decisions must be made by the die maker, such as blade hardness for a particular bend and where the butt joints should be placed to have the least effect on the contoured part.

Six dies were purchased for evaluation, all of which were used for contouring the test circuit configuration. Figure 2 shows a typical die purchased from Atlas. Figure 3 shows a typical Kapton flexcircuit contoured by these dies. The test circuit is very thin, with only 0.003-inch (0.076 mm) thickness in the contour area.

Two sizes of die blade were evaluated for this application: a two point, which is 0.028-inch (0.711 mm) thick, and a four point, which is double the thickness of the two-point blade. The blades were standard 0.937-inch (23.9 mm) height. Both side-cut and center-cut blades were evaluated. The two-point center-cut blade has an advantage for flexcircuit contouring in that the thinness and location of the cutting edge enable the radii to be formed more accurately by the die maker.

The retractable tooling pins produced and installed in the dies at Bendix resulted in a major improvement in the accuracy of the final circuit contour. The tooling pins installed by Atlas were the source of the largest single dimensional discrepancy in the dies. Since the tooling pin locations are part of the original NC tape program and are flashed by the laser during the slotting operation, the real error was being introduced by the die maker in drilling the tooling holes. This problem was eliminated by "bomb-sight" drilling the holes after the dies were received and installing the retractable dowell pin at Bendix.

During the die evaluation, blade height variation was found to cause an incomplete cut. The cutting press, which is electronically controlled, is very sensitive to these variations and will cut through the circuit at the blade high points only. Because the standard die blade has an allowable height variation of 0.003 inch (67.2 mm), additional material must be added to bridge over low areas. This additional material prevents the press from making contact with the blade and retracting before the cut is complete. Kraft wrapping paper was used to minimize these variations and to accomplish complete cutting. Two thicknesses of paper were required on each die, with additional layers added to areas where complete cutting did not occur. The paper not only acts as a bridge over areas of different die height, but also protects the circuit from being damaged by the press cutting surface.

Figure 2. Typical Atlas Steel-Rule Contouring Die

Figure 3. Test Flexcircuit

In addition to height variation, butt joints are a source of die inconsistencies. Before a die is made, the die blade is a straight section of steel with a sharpened edge. The corners of the blade are highly susceptible to handling damage. These areas frequently become part of a butt joint that yields nicked or damaged flexcircuits. Most of these problems could be eliminated with proper care by the diemaker; consequently, a specification was prepared to eliminate problems which are controllable. Dies are now purchased to the following requirements:

- Die shall be made of steel-rule blade pressed into a 0.750-inch (19.1 mm) hardwood plyboard base. The blade slots shall be cut by a numerically controlled laser.
- The die blade shall be two-point center-cut steel rule stock.
- There shall be a minimal number of blade joints. Blade joints are allowed only at outside 90-degree corners when applicable. There shall be no joints in areas where a single length of blade will suffice. All butt joints must be properly aligned. Nicked or damaged blades shall not be used.
- Tooling pin locations and datum targets shall be NC laser-flashed to allow future optical pickup. Tool holes are not to be drilled by the die manufacturer. Bendix will insert tooling holes and pins.
- The die cavity shall be completely filled with open-cell foam rubber- or cork-ejection material. Material also shall be provided outside of the die cavity to support panel overhang.

Because die tolerances are not the only source of contouring discrepancies, an evaluation of the effect of etch shrinkage and lamination on flexcircuit contour dimensions was begun.

Kapton/copper laminate, as received from the vendor, has built-in stresses caused by tension on the material rolls as the layers are laminated together. When the circuit pattern is etched and/or laminated, these stresses are relieved, thereby causing the circuit image to be deformed by shrinkage. The stress in the direction of the roll is different from that perpendicular to the roll; consequently, circuit panels were fabricated with circuits positioned so shrinkage could be measured in both directions. Four laminate panels were cut from 2-ounce double-sided copper laminate which contained two layers of 0.5-mil (12.7 μ m) Kapton dielectric between. The roll direction of the laminate was marked. Two of the panels were press cured at 365°F (185°C) for 20 minutes to determine if the stresses could be removed or stabilized before etching. The panels were then etched to the test cable configuration by standard flexcircuit fabrication

procedures. Half of the panels were etched with the circuits running parallel to the roll direction and half were perpendicular to the roll direction. Measurements taken before and after covercoat lamination are shown in Figure 4 and Table 1. Shrinkage of the image parallel to roll direction was approximately 0.003 inch/inch (0.003 cm/cm), compared to insignificant changes in the perpendicular direction. There was no marked improvement in the press-cured samples as compared to the raw laminate. Although these data apply directly to the test laminate, there is a high probability that this shrinkage trend is uniform regardless of laminate construction. These data indicate that close attention should be given to the direction of shrinkage during processing, and that design of circuits requiring tight contour tolerances consider the effects of shrinkage on minimum conductor-edge spacings.

Figure 4. Layout Showing Locations of Etch-Shrinkage Measurements Listed in Table 1.

The dies were inspected dimensionally when received. Figures 5 and 6 show representative data taken from two of the six dies procured from Atlas. The die measurements were taken from the cutting edge of the blade, and the part dimensions were measured from edge to edge.

An attempt to analyze these data must consider the flexcircuit design requirements of contour tolerance and minimum conductor-edge spacing, as specified on the product drawings. Contour tolerance is defined as the tolerance band around the periphery of the flexcircuit, into which the circuit contour must fall. Minimum conductor-edge spacing is the minimum distance allowed from the conductor to the circuit edge. Steel-rule dies contribute to the tolerance buildup on both of these design requirements.

Minimum conductor-edge spacing is effected by variations in placement of the tooling pins. Figures 5 and 6 show examples of tooling-pin mislocation; however, these dimensions were recorded on dies which had tooling pins installed by Atlas. Bendix tooling pins installed by bomb-sight drilling at the laser-flashed hole locations showed a tolerance variation of ± 0.001 inch (25.4 μm). In the case of the test, this variation shifted the conductor pattern toward the end of the cable and was of very little functional consequence. Circuits of other configurations that have circuit patterns perpendicular to the centerline of the tooling pins could be more adversely effected by reducing the effective high-voltage breakdown distance from the conductor to the circuit edge.

To establish a contour tolerance attainable with steel-rule dies, final part contour dimensions must be compared to the die design requirements. The straight-length sections are the best indicators of out-of-tolerance conditions when using these dies.

The maximum deviation (from Figure 5) is 0.011-inch (0.28 mm) over nominal. Converted to contour tolerance (the deviation from the circuit edge in both directions), the value changes to 0.022 inch (0.56 mm). Assuming some measurement error and including a safety factor for extreme conditions, a contour tolerance of 0.025 inch (0.64 mm) would be acceptable for use with steel rule dies. More than 100 flexcircuits of various configurations were measured during the course of this evaluation, and all fell within the confines of a 0.025-inch contour. One factor that supports a 0.025-inch contour tolerance as being attainable for a production process is that the 0.011-inch deviation was taken to be on one cutting edge rather than equally divided on both sides of the die. This assumption is realistic because of the variability of the butt-joint and the blade-forming operations.

Table 1. Laminate Etch-Shrinkage Measured at Hole Locations Identified in Figure 4

Part and Hole Number	TP X	TP Y	After Etch			
			Measured Dimension X	Deviation From TP	Measured Dimension Y	Deviation From TP
1-1	2.239	0.141	2.2335	-0.0055	0.1486	+0.0076
1-2	1.956	0.142	1.9519	-0.0041	0.1356	-0.0064
1-3	8.739	0.000	8.7133	-0.0257	0.0050	+0.0050
1-4	8.374	0.250	8.3491	-0.0249	0.2436	-0.0064
1-5	10.250	- - -	10.2214	-0.0286	SET	0.0000
2-1	2.239	0.141	2.2342	-0.0048	0.1471	+0.0061
2-2	1.956	0.142	1.9528	-0.0032	0.1372	-0.0048
2-3	8.739	0.000	8.7131	-0.0259	0.0042	+0.0042
2-4	8.374	0.250	8.3480	-0.0260	0.2447	-0.0053
2-5	10.250	- - -	10.2203	-0.0297	SET	0.0000
3-1	2.239	0.141	2.2383	-0.0007	0.1437	+0.0027
3-2	1.956	0.142	1.9553	-0.0007	0.1391	-0.0029
3-3	8.739	0.000	8.7398	+0.0008	0.0006	-0.0006
3-4	8.374	0.250	8.3751	+0.0011	0.2481	-0.0019
3-5	10.250	- - -	10.2509	+0.0009	SET	0.0000
4-1	2.239	0.141	2.2389	-0.0001	0.1431	+0.0021
4-2	1.956	0.142	1.9560	0.0000	0.1390	-0.0030
4-3	8.739	0.000	8.7409	+0.0019	0.0006	+0.0006
4-4	8.374	0.250	8.3759	+0.0019	0.2481	-0.0019
4-5	10.250	- - -	10.2506	+0.0006	SET	0.0000

Dimensions are in inches: 1 inch = 25.4 mm.

Radial accuracy was somewhat erratic, but measured dimensions show that inside radii are normally smaller than specified. This condition is desirable because the radii are usually specified as maximum values on design drawings.

Contouring the flexcircuits with plywood steel-rule dies has been satisfactory in Bendix development work. Both the usefulness and the dimensional accuracy of these dies are largely

	After Coverlay				
	Measured Dimension X	Deviation From TP	Measured Dimension Y	Deviation From TP	Remarks
	2.2380	-0.0010	+0.1445	+0.0035	Press cured. Pattern paral- lel to roll direction of laminate.
	1.9545	-0.0015	0.1412	-0.0008	
	8.7243	-0.0147	0.0003	-0.0003	
	8.3587	-0.0153	0.2479	-0.0021	
	10.2349	-0.0151	SET	0.0000	
	2.2379	-0.0011	0.1439	+0.0029	Not press cured. Pat- tern parallel to roll dir- ection of laminate.
	1.9525	-0.0035	0.1397	-0.0023	
	8.7215	-0.0175	0.0042	+0.0042	
	8.3568	-0.0172	0.2449	-0.0051	
	10.2323	-0.0177	SET	0.0000	
	2.2395	+0.0005	0.1465	+0.0055	Not press cured. Pat- tern perpen- dicular to roll direc- tion of laminate.
	1.9549	-0.0011	0.1358	-0.0062	
	8.7379	-0.0011	0.0022	+0.0022	
	8.3720	-0.0020	0.2470	-0.0030	
	10.2496	-0.0004	SET	0.0000	
	2.2387	-0.0003	0.1454	+0.0044	Press cured. Pattern per- pendicular to roll direc- tion of laminate.
	1.9544	-0.0016	0.1368	-0.0052	
	8.7372	-0.0018	0.0023	+0.0023	
	8.3713	-0.0027	0.2447	-0.0053	
	10.2464	-0.0036	SET	0.0000	

configuration dependent, but a 0.025-inch (0.64 mm) contour tolerance will handle any worst-case condition. Circuits with contour tolerances as low as 0.015 inch (0.38 mm) have been contoured successfully. A 0.025-inch contour tolerance should be used as a guideline for circuit design; however, with circuits that require a smaller tolerance, development units should be made to determine if plywood steel-rule dies can contour the configuration to the design requirements.

Figure 5. Test Short Cable Steel-Rule Die Inspection Results

Figure 6. Test Long Cable Steel-Rule Die Inspection Results

Atlas fabricated the test dies for approximately \$250 each and delivered them in three weeks. The total cost after installation of Bendix tooling pins was approximately \$300. A matched die set to perform the same job was estimated at \$1500, with six weeks delivery. For this particular application, the total cost savings was \$1300 per die in only this one phase of development. Subsequent design changes would effect similar savings. Eight-flexcircuit configurations were in development when this study was started. All were switched to Atlas dies for contouring operations. The dies proved satisfactory in all cases.

From the data obtained and observations made while using Atlas steel rule dies it is concluded that a contour tolerance of 0.025 inch (0.620 mm) is necessary to effectively use the plywood-construction die in production flexcircuit contouring. Plywood dies are particularly effective for development use where low cost and short lead times are of prime importance.

ACCOMPLISHMENTS

The principal accomplishments of the steel-rule die evaluation are as follows.

- Plywood-base steel-rule dies were proven satisfactory for flexcircuit contouring when a contour tolerance of 0.025 inch (0.620 mm) or greater is allowable.
- A cutting press for use in conjunction with steel-rule dies was purchased and proved in, and the press cutting surfaces were modified to facilitate contouring thin circuit constructions.
- Kapton-laminate etch shrinkage was evaluated to determine the effect on circuit contour tolerance.

FUTURE WORK

Work is continuing to develop other flexcircuit fabrication processes such as plated-through holes, roller lamination, and protective coatings.