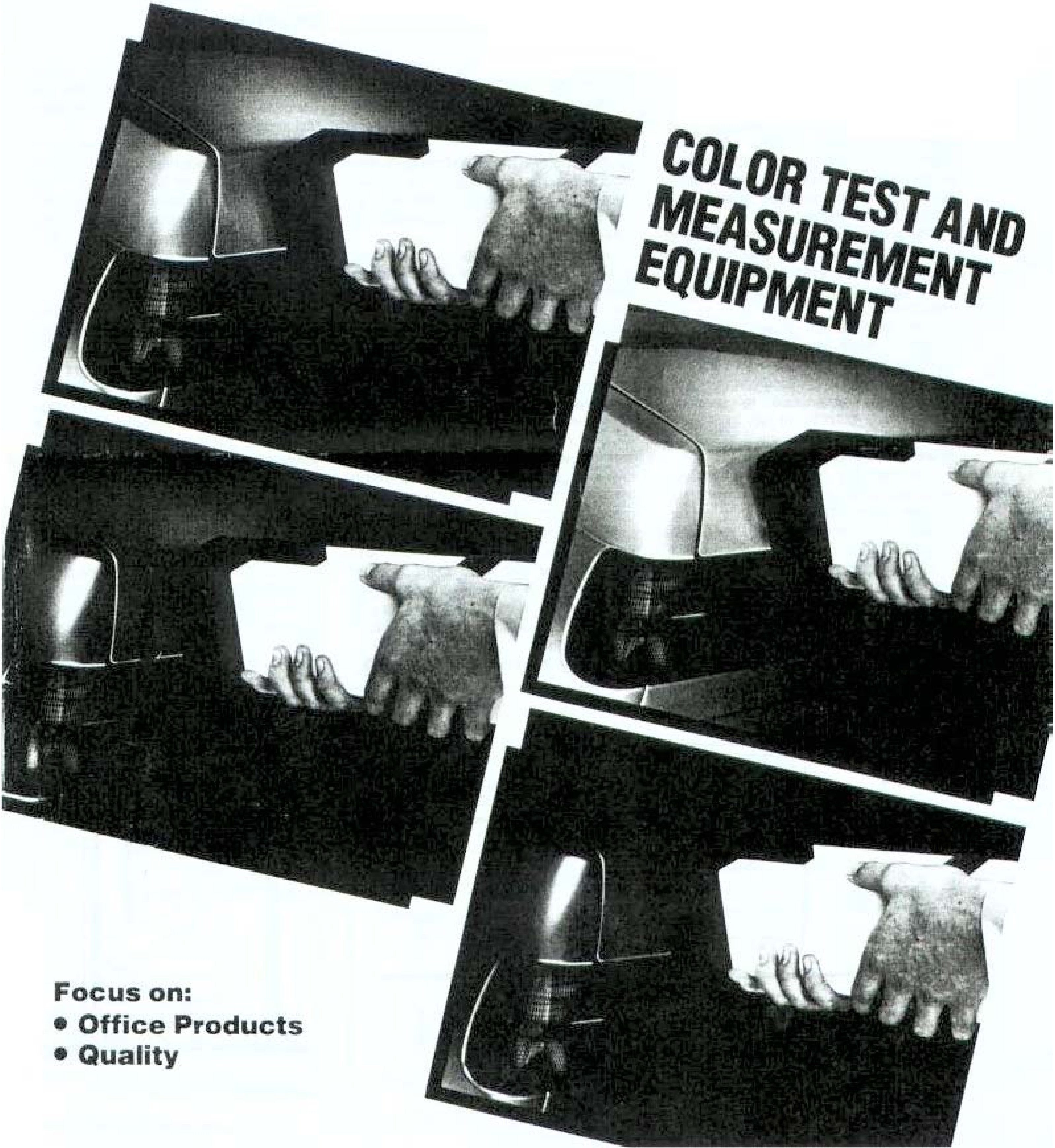
INDUSTRIAL
FINISHING
COATINGS MANUFACTURING & APPLICATION
A HITCHCOCK PUBLICATION DECEMBER 1991



COLOR TEST AND MEASUREMENT EQUIPMENT

Focus on:
- **Office Products**
- **Quality**

Vision System Cuts Armor Plate Overspray

Spray guns turn on and off according to pattern seen. Paint savings of 25% translate into additional benefits

Gary Ettinger and **Donald J. Christian**
FMC Corporate Technology Center
Santa Clara, CA

A unique vision system is bringing a 25% paint savings in the coating of armor plate for U.S. military vehicles. The savings translates into the additional benefits of reduced waste disposal, decreased booth cleaning and equipment maintenance and lowered volatile organic compound emissions.

The painting is being done at FMC's Ground Systems Div. plant (Santa Clara, CA). The system deposits mil-spec epoxy primer and polyurethane topcoat.

The steel armor plates range in length and width from 10 by 24 in. to 72 by 72 in. and in thickness from 0.201 to 1.375 in. They range widely in configuration from rectangular to circular. Some have cutouts of up to 48 in. across. Most have numerous mounting holes of 1 in. in diam or less.

The paint line includes an overhead conveyor, paint booth, primer oven and topcoat oven. Paint application is by automatic electrostatic guns mounted on vertical reciprocators.

Plates entering the paint shop have various surface conditions. Some have been stored outdoors and are rusty; others are new and shiny. Shot blasting prepares the surfaces for painting.

Each plate is hung onto the conveyor by inserting two metal rod hangers into mounting holes. Because lot sizes are usually small in number (even lots of one unit are common), plates are hung in random fashion.

The conveyor makes two passes through the spray booth. Each pass is followed by a bake oven cure cycle. In the first pass the plates are conveyed between opposing reciprocators for the epoxy primer application. In the second pass they are moved between a different set of opposing reciprocators for the polyurethane application.

The vertical up-down motion of the reciprocators carries the spray guns well above and below the upper and lower edges of the plates. The vision system controls paint flow so that each gun cycles off and on automatically at a fixed distance from these upper and lower edges. The vision system and programming also stop paint flow as the guns pass through cutout areas. Paint savings are realized by spraying only when a surface to be coated is in front of a gun.

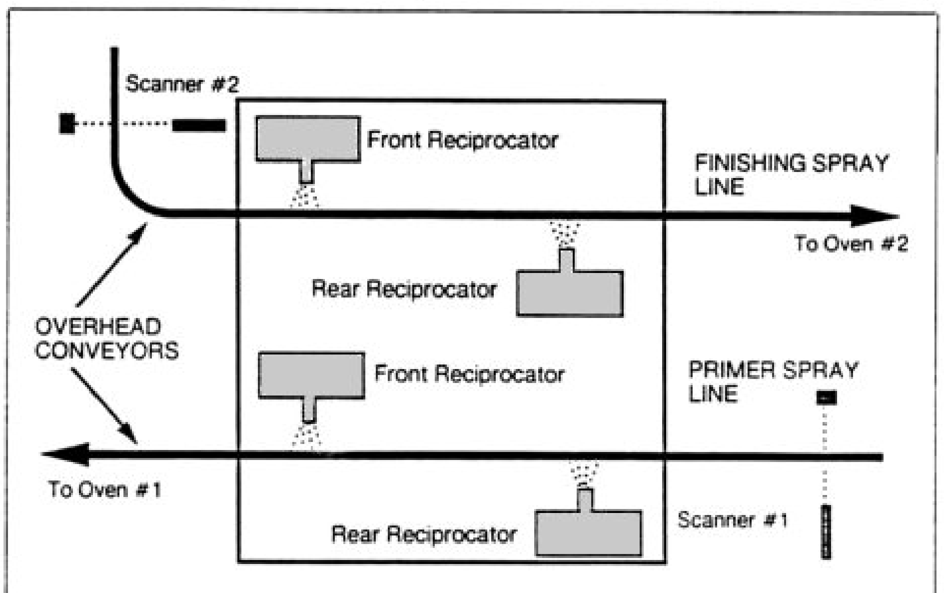
The vision system automatically "ignores" cutout holes smaller than 1 in. It also minimizes paint application on hangers by "erasing" the hangers from vision detection.

Programming the vision system to see a slightly enlarged plate facilitates efficient painting of plate edges. This allows the guns to spray "just beyond" surface edges, ensuring good edge coverage. A "zero overspray pattern" would produce poor edge coverage.

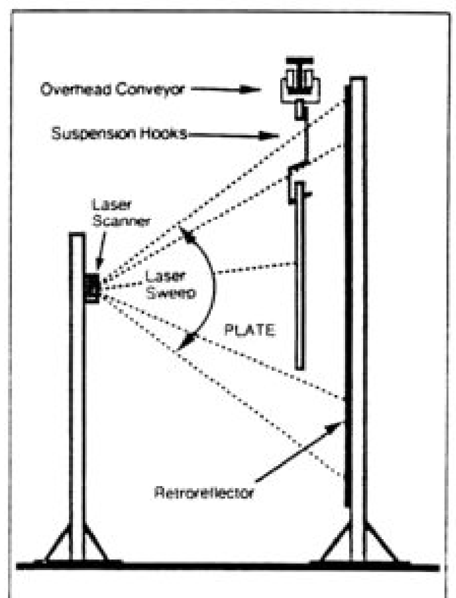
Image information/acquisition

Plates are scanned by lasers before entering the paint booth for priming and scanned again before entering the booth for topcoating. The scanners discern the shape of a plate by firing a laser directly into a reflective strip mounted across the conveyor line. A plate obstructs the view of the reflector, forming the image.

In each scanner a fixed laser beam fires through a beam splitter into a spinning mirror. This rotates the beam through a 360-degree arc, of which only about 113 degrees is emitted from the unit. The reflector returns the beam coincidentally through the rotating mirror, where it passes again through the beam splitter and into a photodetector. A microprocessor digitizes the signal into linear pixels (signals) to form



Floor plan of the spray booth area



Laser imaging station (side view)

a scan line. Rasters (horizontal scan lines) are assembled to form a continuous image of the conveyed stream.

When a portion of the beam is interrupted, the processor sees an object as a dark silhouette against a bright reflection. Surface features on the object have relatively low amplitude and are ignored by the scanner.

Each laser scanner has a glass viewing window to protect the sensor. The reflectors are also shielded with a glass strip. This permits easy cleaning of the assembly without risk of damage to the precision optics.

The helium-neon lasers emit a narrow band of visible frequencies. The received light is filtered before entering the photodetector to eliminate other light. The detected signal is then amplified and clipped to produce a binarized (bilevel) signal indicating "0" (no object present) or "1" (an object present).

On each scanned line 15,360 optical pixels (0s or 1s) are stored. Each pixel requires only 0.006 degree of sweep. Since 20 scans are made per sec, more than 300,000 pixels are imaged per sec. The lines of pixels are loaded into memory serially as a plate passes the sensor and are shifted along to match the moving conveyor. They are removed from memory after a plate passes the last sprayer.

Each run of pixels or a scan line is called a linear blob. After the raster lines are assembled, a two-dimensional blob pattern is apparent that corresponds to the geometry of the plate.

The scanner forms its image in polar coordinate space that is established by an encoder keyed to the scanner rotating mirror. The polar coordinates are converted to cartesian coordinates in order to control the sprayers.

The scanner laser output is less than 0.25 mW. Since the scanner's beam is moving continuously, only 3% of its energy reaches the target, making the system very safe. It could only cause potential eye damage by the deliberate staring into the beam for a long period.

It would have been possible to instruct the control system with a knowledge of each plate shape and specific painting instructions. Such a system was rejected because of the need for continual maintenance of the knowledge base. New plates would require the creation of records in memory before they could be painted.

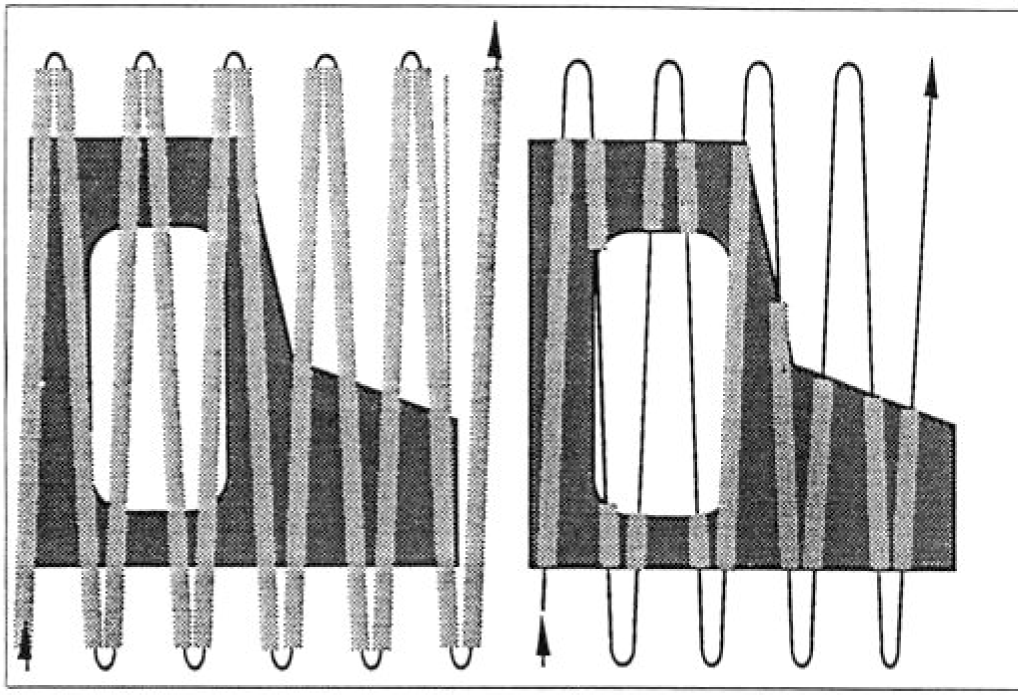
The system is completely sensor-based. All necessary instructions are derived from the incoming stream of sensor data. Once a plate has passed through the system, all knowledge about its shape is gone. Only certain statistics are retained.

As each raster line is formed, the laser scanner transmits the encoded pixel stream to the host programmable logic controller (PLC). The PLC assembles the rasters into a two-dimensional image. Each 1 in the image represents a section of the plate. Each 0 represents empty space. A cutout in the middle of a plate will be visible in a binary map, as will the plate's hangers and mounting holes.

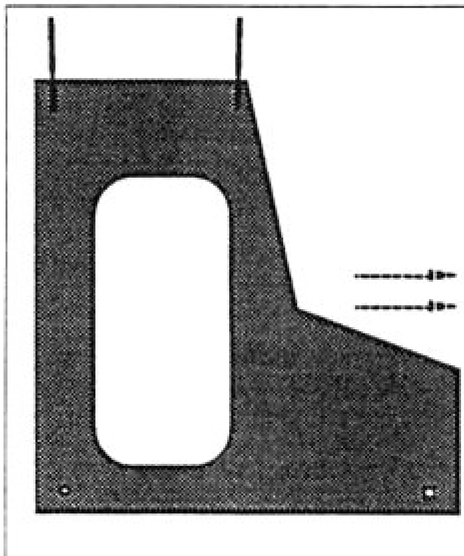
Mounting holes are filtered out by the laser scanner processor. It is set to ignore holes less than 1 in. in diam by removing all white blobs shorter than a few pixels. This does not disturb the highly precise edge locations of the plate. The hole data are eliminated from the run-length code and therefore never communicated to the host PLC.

A nonlinear filter is applied across the top edge of a plate to eliminate the hangers. The filter monitors peaks within a 5-in. structuring element on the top edge and triggers the filter when a value exceeds a threshold.

The raw plate map of pixels is modified slightly to add the overspray zone around perimeter and cutout boundaries. This is accomplished by changing perimeter and cutout border 0s to 1s. This swells the image slightly.



Drawing (left) shows theoretical reciprocating spray pattern across a moving conveyed object. Drawing (right) shows same spray pattern with spray gun turned off when no target is present.



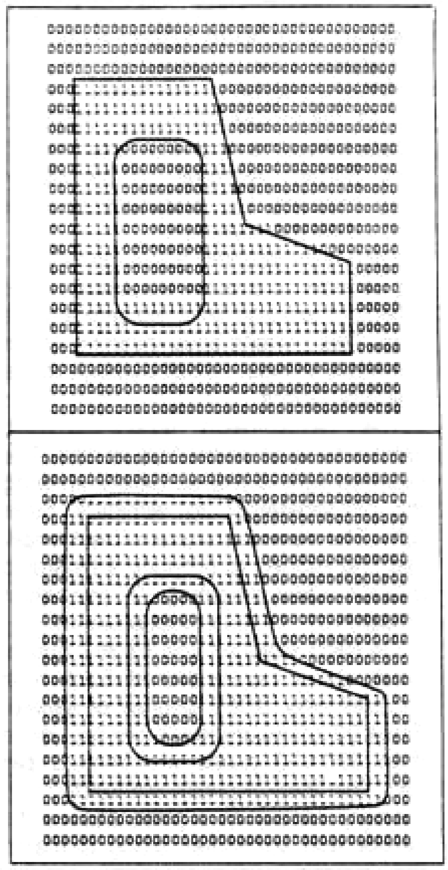
000010000000000000100000000000000000000
000010000000000000100000000000000000000
000111111111111111100000000000000000000
000111111111111111100000000000000000000
000111111111111111110000000000000000000
000111110000000001110000000000000000000
000111110000000001111000000000000000000
000111110000000001111000000000000000000
000111110000000001111100000000000000000
000111110000000001111111100000000000000
000111110000000001111111111111000000000
000111110000000001111111111111111100000
000111110000000001111111111111111100000
000111111111111111111111111111111100000
000101111111111111111111111111101100000
000111111111111111111111111111111100000
000000000000000000000000000000000000000
000000000000000000000000000000000000000

As each raster line of a part is scanned, the laser scanner transmits the encoded pixel stream to the host PLC. The rasters are assembled into a two-dimensional image (right). Each "one" in the image represents a section of the part; each "zero" is empty space. Note that the cutout in the middle of the part is visible in the binary map. The suspension hooks show up as lines at the top of the map; two small mounting holes appear as zeroes near the bottom corners.

The plate map is used to synthesize the control commands fed to spray guns. A spray gun's predicted up-and-down "triangular wave" travel path is plotted against the plate map, and the intersections with plate edges are computed. These intersections are converted to time coordinates, representing the estimated time of arrival of the spray carriage at a plate's edges. Commands to turn the spray on or off are generated and applied to the guns.

The PLC control program is written in "ladder logic." The program contains more than 1000 rungs, each corresponding roughly to one line of code in a procedural language.

In a normal PLC scan cycle all rungs to be executed would take about 100 msec, yielding a scan rate of 10 Hz. This would not be sufficient to maintain adequate control over the reciprocating sprayers. To reduce the scan time, the software is segmented into 52 subroutines that are conditionally executed. The main program is executed



Raw part map (top), and part map after "morphological dilation" (bottom). Expanding the spray pattern slightly ensures good part edge coverage.

every scan, generating two to six subroutine calls per scan. The various subroutines are specialized to perform operations such as:

- monitoring the operator console
- communicating with laser scanner
- receiving/assembling plate map
- dilating the map for overspray
- filtering out hangers
- shifting the plate map in sync with the conveyor motion
- updating the spray gun commands based on gun and conveyor position.

This tree of conditional execution reduces the typical scan time to 6 msec and a scan rate of 167 Hz. The most time-sensitive device is the spray gun timer controlling the time that the gun is turned off and on. These times correspond to the position of the gun as it reciprocates. Gun timer commands are updated on every PLC scan.

Some of the major hardware components include: Allen-Bradley PLC 5/25, 1771 digital I/O modules, Allen-Bradley Basic module with serial port, Namco Lasernet LN110-30001 laser scanner and Namco converter.

For more information about the hardware components, circle the following numbers on the reader information card. Allen-Bradley (Milwaukee, WI), **Circle 48**; Namco Controls Div., Acme Cleveland (Mentor, OH), **Circle 49.** △