

Poka-yoke designs make assemblies mistakeproof

Products that go together only one way require less worker training, perform more reliably, and repair more quickly. Then the advantages kick in.

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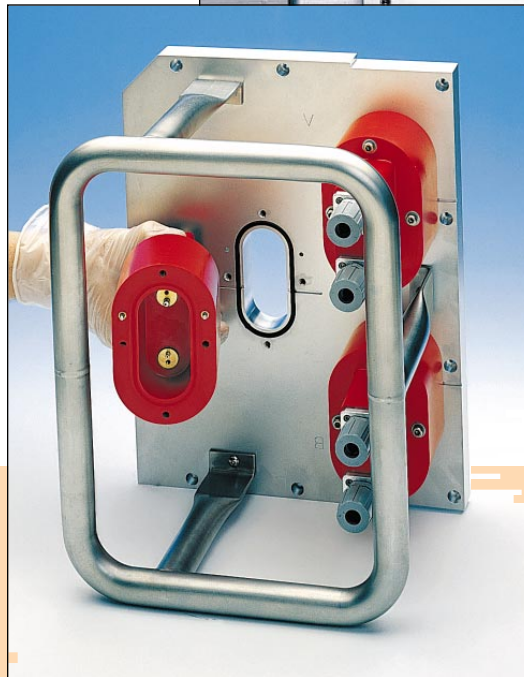
Not long ago Larry Ficarra, an engineer with Varian Ion Implant Systems, Gloucester, Mass., was assembling a vacuum chamber for a 10,000-component particle accelerator used in microprocessor production. A guide pin near an O-ring surface on one component face was supposed to go into a hole on the mating face to ensure proper alignment of critical components. The part with the pin was so bulky it required a little juggling before the pin found the hole. Everything seemed to be working well, but on start up, the critical assembly would not hold a vacuum.

After a lengthy diagnosis, Ficarra discovered that while trying to get the pin into the hole, he had inadvertently scratched the O-ring surface which prevented the chamber from holding a vacuum. Chagrined at how easily the accident happened, he thought of ways to protect the sealing surfaces so anyone putting them together would not repeat his error. Also concerned about such problems was Santo Di-

Naro, formerly the head of R&D and engineering at Varian. He was just instituting a program for redesigning the machine's assemblies so they go together without mistakes. DiNaro says inspiration came from the book *The New Manufacturing Challenge: Techniques for continuous improvement* by Kiyoshi Suzuki. The book discusses a range of techniques for reducing defects in

Mistakeproofing ideas such as this handle make it easy for workers to pick up the assembly for a particle accelerator from Varian Ion Implants Inc., Gloucester, Mass., and set it safely on its side or end without damaging electrodes. Workers must insert the assembly into the vacuum chamber without damaging delicate graphite parts. To do so unerringly, the vertical tab on the foreground plate and notch in the mounting plate make it impossible to incorrectly insert the assembly.

Poka-yoke ideas designed into the scan-plate assembly ensure that it goes together only one way. Alignment pins on the sealing surface of the red part are nonsymmetrically placed as are the bolt holes. Assemblers cannot install this part upside down.



aluminum finish during assembly. The pin may contact the elastomer O-ring, but the compliant O-ring resists damage. Additional pins prevent damage to the sealing surface while a component rests on a bench during assembly or service. Ficarra says the scratched-surface error has not happened since.

Poka-yoke has been around for a long time under different names such as mistake-proofing and goofproofing. And it has been overshadowed by ideas such as designing for manufacturing and assembly. But there are limits to DFM and DFA, and getting back to the basics of mistakeproofing shows the complementary nature of the design philosophies.

HERE COMES TROUBLE

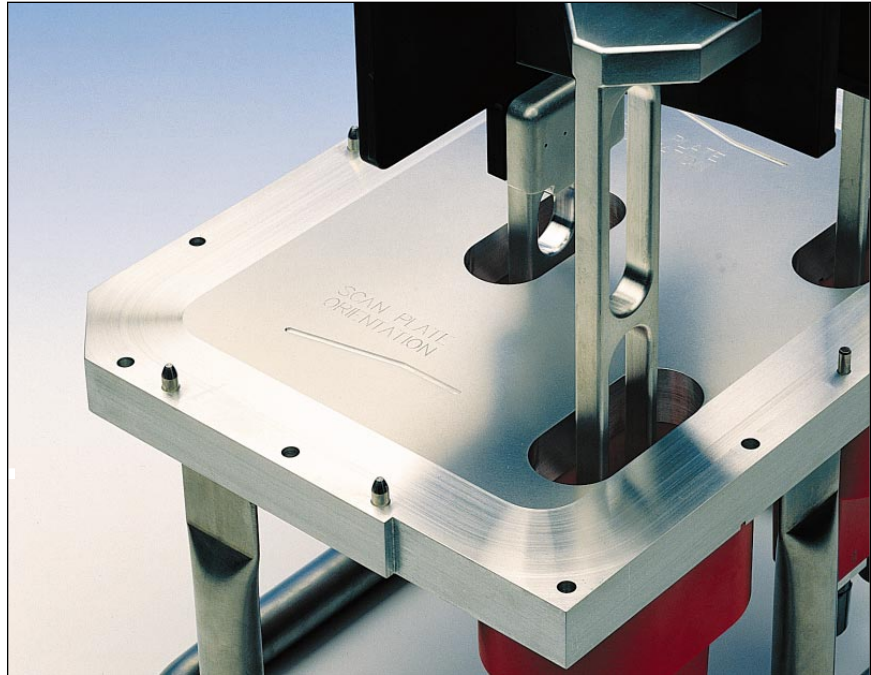
The traditional way of solving assembly and maintenance problems is to spend lots of training dollars instructing workers what not to do. "But when people leave the company, they take their experience and knowledge with them," says DiNaro, and the assembly difficulties stay behind. Training will still be necessary when all designs are mistake-proofed but there will be less of it for all involved. The more critical training will be in store for engineers and designers because there are no formal rules for designing mistakeproof parts. Some solutions will be unique and others borrowed.

One way to find clues for solving assembly problems comes from examining their source. The experts we spoke with provide several guidelines for spotting trouble ahead of time.

One appears to be engineers' innate fondness for symmetry. "Bolt holes in a circle, for example, are almost always equally spaced," says DiNaro. "But picture a motor on a round flange. Its harness probably reaches to one location on the motor. Rotate the motor and the harness cannot reach." The problem is that designers usually mount motors on round flanges with equally spaced holes, thereby providing several ways to orient them. And when something can be assembled wrong, it will be.

Not all parts require mistakeproofing, so focus on those that have a history of misassembly or error. Assembly-line workers and maintenance personnel can pinpoint the most troublesome areas. Companies putting the philosophy to work told us what they see as red flags.

Avoid symmetry when a particular orientation is critical, says Ficarra. Techniques for



Rather than using labels, instructions are machined on the underside of the scan-plate assembly to ensure correct orientation. Also, protruding pins on the shiny O-ring surface let the assembler place the unit face down without marring it. Alignment pins are positioned asymmetrically to define one orientation with the mating assembly.

doing so involve nonsymmetrical hole patterns. Also, use labels sparingly to cure assembly errors because they come off too easily and tend to be excessively wordy.

Beyond symmetry and labels, Brad Flack, an instructor with John Deere Harvester Works, East Moline, Ill., says to look for rapid repetition, environmental problems,

PY ON THE INTERNET

The Internet holds a few sources of poka-yoke information. The best way to find them is to use one of the search sites such as Infoseek (www.infoseek.com). Search first on the general term poka-yoke and then try the name Shigeo Shingo, the guru and most prominent developer of mistakeproofing in Japan. As you come across other authors, try searching on their names.

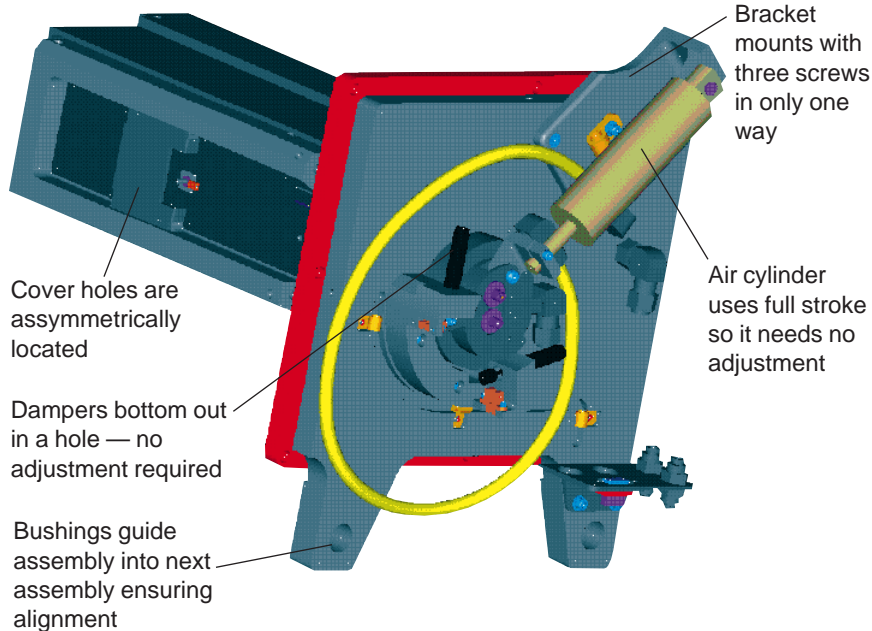
Check out John Grout's site at www.cox.smu.edu/jgrout/pokayoke.html. Grout has compiled the most extensive poka-yoke reading list on the Web along with several papers, and a photo gallery of everyday mistakeproofed designs. The best place to start may be by reading his brief poka-yoke tutorial. After you've read from a few other sites, come back and take his poka-yoke test.

Dial up <http://akao.larc.nasa.gov/dfc/toc.html> for Edwin Dean's site at NASA. He's a software developer with dozens of pages devoted to the benefits of improved designs. Several refer to poka-yoke and how it might even be applied to software engineering.

The URL www.dmu.ac.uk/dept.schools/business/corporate/tqmex/shingo.htm takes viewer to a brief history of poka-yoke from Shingo's perspective and a little of the thinking behind his ideas. For example, his driving thought was that eliminating the source of defects eliminates the need for inspections.

The Web site www.mmt-inst.com/otherresources.htm provides a collection of resources that refer to JIT (just-in-time) or lean production ideas. The authors contend that what happens on the factory floor is the core of lean production. Improve manufacturing operations and improvements in customer and supplier relations follow.

3D models let more contribute to poka-yoke designs



and infrequent production. Environmental problem that encourage mistakes include poor lighting, high or low heat, excess humidity, dust, and noise — anything that dis-

tracts workers. And infrequent production stems from serving the different demands of worldwide markets. "For example, there are 17,600 parts in an average combine, throw in

dozens of options and requirements for Europe, and you're bound to make a mistake or two," says Flack.

Sandy Munro, president of Munro & Associates, a consulting firm, suggests investigating at least four areas for potential problems and poka-yoke solutions. "First look for where the product will fail if parts are assembled wrong. Then look for small features critical to proper assembly. For instance, when proper operation depends on a $\frac{1}{32}$ -in. hole, the design is a good candidate for a poka-yoke solution," he says. Relying on subtle differences to determine the top or bottom, or front or back, also signal problems says Munro. "This is particularly true when parts are painted dark colors. Then the eye cannot pick up subtle features."

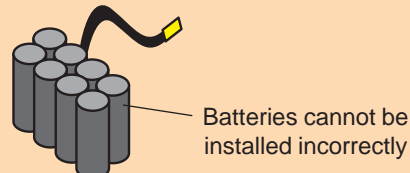
Designs so complicated they confuse inexperienced operators are also candidates for poka-yoke redesigns. "When a lot has to be done at the same time, expect problems," says Munro. "In one instance, assemblers had to drop three parts into a locking mechanism at precisely the same time if the device was to work properly. Most assemblers hated it."

Electrical connectors provide additional examples. Most companies try to standardize for cost savings which often means buy-

A poka-yoked intravenous pump

Counterbores molded into casting are at different depths so assembly uses only one screw size.

Air deflectors install only one way.

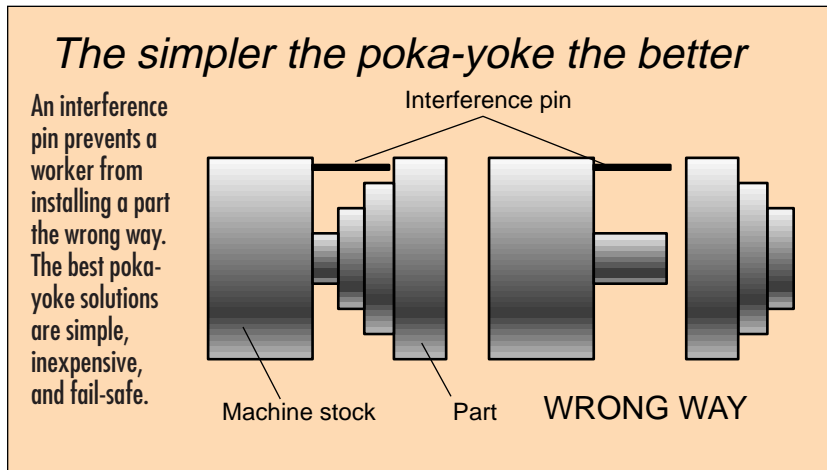


Fastener count trimmed from about 180 to 30

Seal fits only one way between front and rear covers.

Complex subassembly uses two screws and the rest snap fits together.

Engineers with Munro & Associates, Troy, Mich., mistakeproofed the assembly for the intravenous pump by cutting the part count to about 73, color coding major assemblies, and using snap fits where possible.



ing many identical items, like electrical connectors. "The PCBs in one machine control needed only three-pin connectors to join each in a series," says DiNaro. "The labels we once used instructed assemblers which boards went where and which connectors should be joined so we color-coded them. But in the field, assemblers connecting and disconnecting them wear or bend the pins, which meant putting on a new plug. Soon the label was gone." Varian's simple solution involved three, four, and five-pin connectors that cannot join others and demand a single assembly sequence. One of Ficarra's solution to labels that come off is to machine them into parts, especially when the function is a correct orientation. On Varian machines assemblers are guided by small machined-in pictures that cannot wear off. "The capabilities of modern NC machines makes it easy to produce machined-in labels," says Ficarra.

MORE POKA-YOKE SOLUTIONS

Many poka-yoke solutions seem like common sense. Take the ubiquitous 3.5-in. floppy disk for example. "The disk goes into a drive only one way and an audible click tells users it's fully inserted," say John Grout, a business instructor with Berry College, Mount Berry, Ga. "That makes poka-yoke an inspection technique that can be used almost anywhere to eliminate human error," he says.

Gary Jones, a trainer and poka-yoke facilitator with Weber Aircraft, Gainesville, Tex., says the best poka-yoke ideas are simple, inexpensive, and fail-safe. He tells of a drill bit suggested by workers in the company's arm-post cell that performs several functions at one time. "It makes a hole to a precise depth and then spot faces or counterbores it, all in

one stroke." Another modification by employees trimmed waste from the way the company had been vacuum forming tray tables. In the original process, table tops and bottoms were formed separately. Now they're formed at the same time from the same plastic sheet, which cuts waste and improves production.

John Deere's Brad Flack says one of the cleverest poka-yoke solutions his teams came up with stemmed from a gearbox that was assembled without oil, mounted on a machine, and required replacement after factory tests. The team streamlined production with a simple proximity switch that opens after all components were loaded into an assembly fixture. The switch prevents workers from using air wrenches to tighten bolts on the assembly until they cycle an oil gun into the gearbox. After filling the gearbox a solenoid releases the interlock sending air to the wrench. Then workers can tighten cover bolts and send the box to the next station.

Munro cites an intravenous pump as an example of a poka-yoked design. "We started by eliminating parts through a technique called Design Prophet and took their number from about 500 to 73 that snap together," he says. Color coding was added to several major components. Color coding is a good idea, he adds, as long as you remember that one in 10 people have some form of color blindness. Thus, colors were selected that could be differentiated by anyone.

Aside from Varian's multipin seal protector, Ficarra points to another impressive poka-yoke design. "The geometry of the vacuum chamber requires a high-pressure water seal adjacent to a vacuum seal, so if water leaks into the vacuum, the leak is almost impossible to find," says Ficarra. A de-

signer's fix used a series of O-rings and deep-drilled holes to allow atmospheric pressure between the water and the vacuum. "There were space constraints and bearings in the way, but good visualization software lets the engineer solve the problem," Ficarra says.

Several poka-yoke solutions involve jigs and fixtures that required workers to install components in a particular sequence to avoid errors. Munro cautions, however, that fixtures are only one way to solve troublesome designs and that the real fix may be upstream. "Fixtures help get around bad designs, but they add cost," says Munro. "We recom-

mend going to the engineers and designing out the need for fixtures by designing parts that fixture themselves one to another."

THE PAYOFF

So how does all this effort benefit a company in hard dollars? Berry College's John Grout says Lucent Technologies (formerly AT&T Power Systems) has reported that half of their 3,300 mistakeproof devices cost less than \$100. However, they estimate a net saving of \$8.4 million, or about \$2,545/device. Other participating companies also report impressive figures.

Varian's DiNaro made the commitment to overrun his budget and hold the first 100% mistakeproofed machine off the market for seven months while design work was completed. For that investment, DiNaro says the company got a product that is easily the single best it had ever produced. Costs for installation, start up, and warranty have been lower than for any machine before it. "All the dollars set aside for those contingencies, a figure that approaches \$1 million, now go to the bottom line," he says. ■

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