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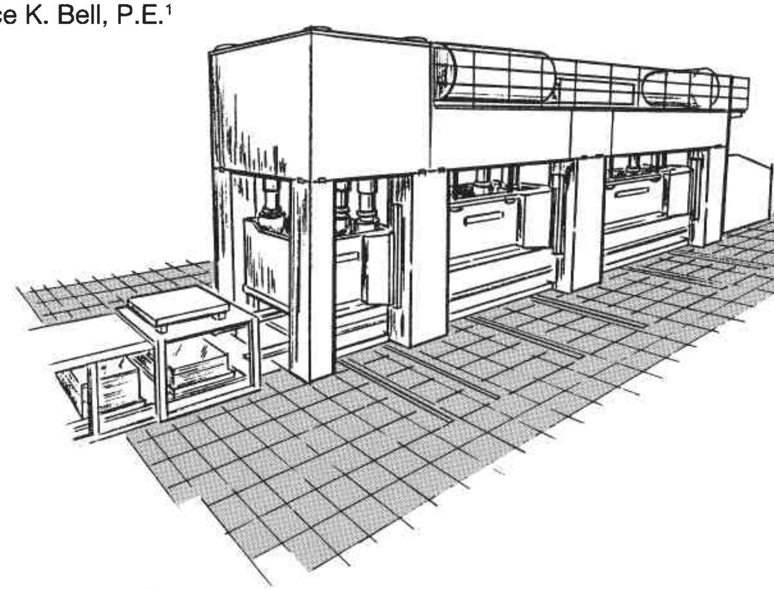
The Care and Feeding of PLC-Controlled* Machinery

OR Everything you've ever wanted to know about PLC's and were afraid to ask concerning their relationship to: Products Liability, Safety/Ergonomics, Documentation, Engineering Design, Hi-Tech, Hi-Speed Machinery, The New Industrial Revolution and TRI-AXIS Transfer Presses

by Lawrence K. Bell, P.E.[1]



Abstract

One of the things that completely surprised the world in World War II was America's ability to convert its industrial system into a seemingly unending stream of war materiel. The backbone of this phenomenom was the mechanical power press. Once the production system was set up, parts were produced in truly amazing quantities with very close tolerances. This concept formed the ***mass production-long run*** *basis of heavy American industry for many years after hostilities ceased. Parts interchangeability was the key factor.*

Technical advances in the field have now paved the way for the first major mass production conceptual change in fifty years. Combining the ideas of progressive dies, moving bolsters, and reliable high tech computer control, the multiaxis transfer feed press line is now a practical reality. Indeed, these technical advances, plus global competitive forces have rendered the old systems obsolete, and adoption of the new concepts are essential for American economic survival in the 1990s and beyond.

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* PLC: Programmable Logic Controller

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*With increasing production rates, closer tolerances, reduced scrap and floor space, and a phenomenal reduction in die changing time (an average of eight to sixteen hours to less than fifteen minutes), the tri-axis transfer feed press line results in a basic operating change in industry: from the old **mass production-long run** basis to **mass production-short run** capability. The probable result of this change is nothing less than a second industrial revolution. Why is this latter idea so revolutionary? Simply put, it reduces costs by an order of magnitude, and increases design flexibility by a similar amount.*

This article, believed to be the first of its kind on the subject, not only discusses the technical concepts underlying the tri-axis transfer feed press line, but also the impact it will have upon machine design and safety, ergonomics, economics, and industrial product liability litigation practices. The article also discusses some of the ways to accommodate these very significant changes that will inevitably come about as this second industrial revolution starts to take hold in this country and elsewhere.

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GENERAL INTRODUCTION

Over the centuries there have been many revolutionary ideas developed in all areas of science and engineering. In very few cases, however, were the long range implications of these ideas immediately and obviously apparent to the public as a whole. Perhaps there were exceptions that proved the rule, such as the printing press, the wheel, the electric motor, machine guns, atomic energy and a few others. Most of the truly revolutionary ideas that were advanced, however, were all but buried in their infancy by generous helpings of scorn, disbelief, and ridicule.

The automobile, for example, was thought fit only to scare horses. The airplane was not exactly seen as a useful, practical development, and the early days of laser experimentation were relegated to the trash heap with the scornful attitude that the laser appeared to be a solution in search of a problem that did not exist. A question was even raised whether the digital computer would ever have any practical utility other than in a few esoteric research labs. After all, it was rather pontifically announced, the computer memory necessary to begin to approach the rudimentary capabilities of the human brain would require a space larger than the Empire State building.

The impact that all of these basic ideas and developments have had on the human condition is now quite obvious to all of us, mostly due to the inevitable technological advances in the field.

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* PLC: Programmable Logic Controller

** Product Liability/Legal Aspects: The transfer feed press/line can be considered a dedicated system, hence susceptible to point-of-operation guarding by the press manufacturer.

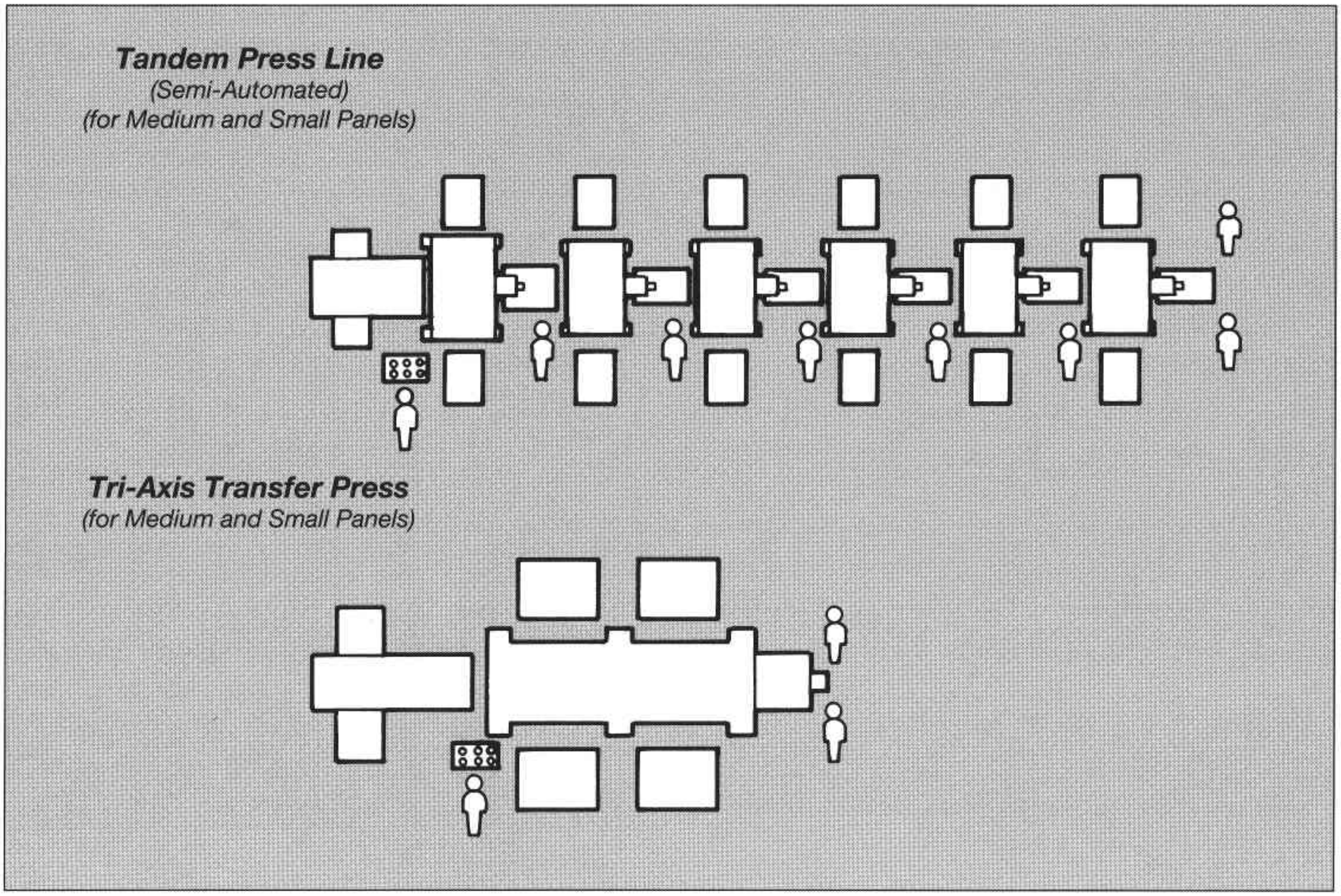

Figure 1. Relative floor space required

Another revolutionary idea that evolved into the subject of this article but which was not initially appreciated nor accepted was the concept of mass production of precision parts. This idea, which had its roots in the Civil War, came into its own during World War II. America surprised everybody by converting to war production in a very short period of time, resulting in an unending stream of war materiel, not only for the American armed forces, but also for their Allies.

The really surprising thing about this vast mountain of goods was that replacement parts for service and even in the original assembly had complete interchangeability with other similar parts and subassemblies. Thus, it was not necessary to have a vast army of skilled machinists to turn out large quantities of precision-made duplicate parts.

The prime player in this scenario was the mechanical power press. Once the press had been outfitted with a die, feeding methods, scrap removal, and operator safeguarding means, precision parts with very close tolerances were produced by the hundreds of thousands. With more complex parts requiring a number of different operations such as blanking, drawing, forming, punching, trimming, etc., a common method of production was to use six to eight individual presses in a line, front to back, each having an individual die reflecting the stage of operation as the part was passed from press to press. This was a typical example of the basic *mass production-long run* concept.

While startling and revolutionary for its time, this concept had a number of very serious drawbacks. First, it was very labor intensive, requiring two to four people per press, depending upon several factors, such as the size and awkwardness of the piece, the production rate, its weight, etc. In an eight-press line there could easily be twenty or more people required to operate at a satisfactory production rate.

Second, with multiple presses in the line, sustaining maintenance requirements were quite significant.

Third, a multi-press production line was a space hog. Room had to be made not only for the presses themselves, but also for loading and unloading at each end of the line, material supply provisions at the front of the line, and appropriate disposition of the finished parts at the discharge end of the line (See Figure 1).

Fourth, and perhaps the biggest drawback of all in terms of downtime and cost, was encountered when a part change was required on the line. Each die had to be changed on each press, with a resulting change (in many cases) in operator safeguarding, as well as in feeding, loading, unloading, etc. The changeover time would vary, but the minimum was usually one

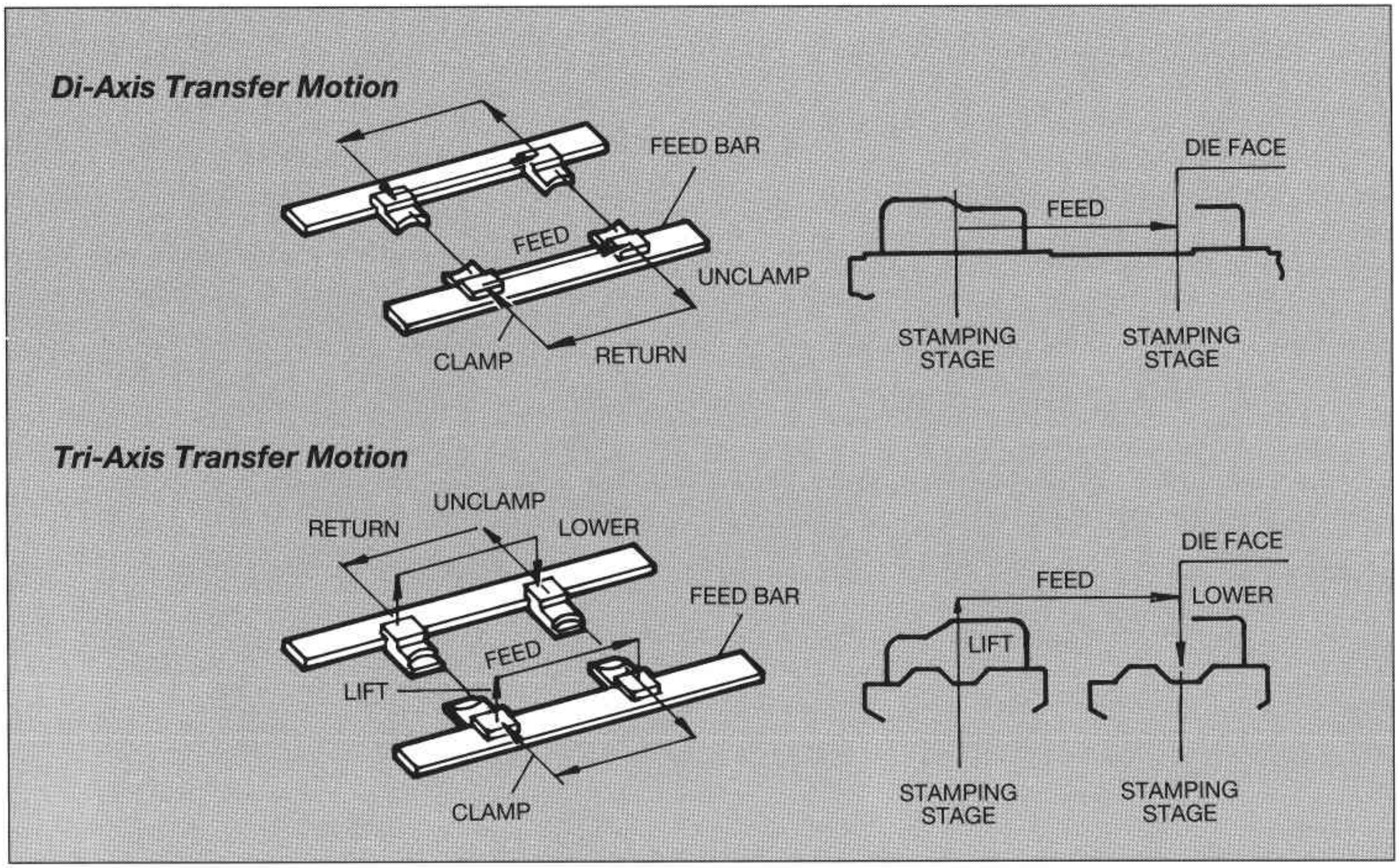

Figure 2. Di-Axis and Tri-Axis Concepts

shift, and in many instances six to eight shifts were necessary.

Over the years, several individual improvements were developed, among them excess and duplicate lines, moving bolsters (where the new dies could be set up ahead of time), progressive dies*, and bi-axis** transfer presses. In addition, the increasing reliability and capability of electronics provided much closer speed and positional control of presses and other machinery, as well as a veritable explosion of diagnostic capability.

All of these factors have now come together resulting in a new and extraordinary concept in the manufacturing area known as *mass production-short run* capability. The basic purpose of this article is to discuss not only the underlying technical concepts involved, but also the impact they will have on machine design, economics, safety, ergonomics, and product liability litigation practices.

It must be reported that the above technological factors stated in the prior paragraphs were in place long before American maufacturers initiated implementation of them to achieve the concept of mass production-short run. It was not until global economic competitive forces became significant that domestic manufacturers finally started to convert to the new systems. As recent market conditions so painfully reveal, there is little question that the economic survival of not only the manufacturers themselves are at stake, but also the entire economy of the country.

The basic lesson that this country must learn is twofold:

1. We can no longer afford to let major technological advances and ideas lie fallow for years before recognizing and economically exploiting them.
2. The old dictum that "if it ain't broke, don't fix it" may not be the viable guideline that it once was. It may in fact lead to obsolescence and bankruptcy in a surprisingly short period of time.

In order to follow properly these two lessons it is obvious that the major thrust must come from corporate boardrooms, with a fierce commitment to research and educational programs, as well as a change in corporate thinking to emphasize the long range factors instead of the present short-term bottom line approach.

The machine system that embodies the aforementioned engineering disciplines, and implements the mass production-short run concept is the tri-axis transfer press, controlled by high-tech computer control systems. This machine is essentially one

* Progressive dies: A series of dies mounted on one press. The parts are made from strip stock, and are indexed from die to die with each stroke of the press.

** Bi-axis transfer press: A transfer press moving separated pieces of stock from die to die in a two-dimensional manner (See figure 2).

press, driven by one or possibly two main drives. It is capable of accepting from one to eight dies, which are mounted in groups of two or three on one or more moving bolsters. The transfer press also contains a tri-axis transfer feed which transfers each part to the next die station through a sequence of operations involving three dimensional axes of motion, including clamp, lift, transfer, and their inverse directions of lower, unclamp, and feed return (See Figure 2). An embodiment of this concept is shown in Figure 3, and is discussed in more detail later in this paper.

The transfer press completely eliminates the drawbacks associated with the old multi-press line. It only requires one or two people to run the system rather than twenty, the space required is approximately one quarter of the old line, and an entire die change can be completed in *LESS THAN TWENTY MINUTES!* Additionally, the diagnostic and fault display capabilities made possible by high tech electronics minimizes downtimes. Also, reliability and quality of the part is increased.

The control electronics, while based upon the same microprocessor chips used in personal computers (PCs), are different in that they are designed with a specially dedicated firmware and protocol, and are protected from electrical noise, shock, and severe environmental effects by ruggedized, industrial-type circuits and hardware packaging. Their main function is to solve control logic and implement it to sequence and control the press/line in the desired fashion.

Most control logic designs derive from a specific sequence of operations, and are developed in general from Boolean logic* principles. These electronic control systems are embodied in hardware called PLC's (programmable logic controllers). They contain the system control program, as well as non-control programs such as diagnostic and fault logic.

The impact of the mass production-short run system will also be felt by the smaller component suppliers to the basic users of these systems (e.g., auto makers). One of the downside effects of the tri-axis transfer press is that it is essentially one integrated machine system, replacing an entire production line of presses. Any mechanical or electrical problems which result in downtime will shut down a significant amount of the user's production; therefore, the quality and reliability of the equipment supplied to the users becomes of paramount importance to minimize lost production. It is probable that this will have the effect of decreasing the total number of suppliers to any given user, and in return for more exclusivity the users will be required to increase dramatically their own product quality. Additionally, the suppliers will be expected to provide service information and user personnel training on their product line far beyond anything existing today.

These effects are already being felt by some industrial concerns and in the long run will almost certainly result in a significant change in the way business is conducted in this country. It might be commented upon, however, that the changes likely to occur will be in the right direction to meet the challenges of existing and future global competition.

Finally, the impact of the *mass production-short run* concept upon the conduct of personal injury cases resulting in product liability litigation will be as revolutionary and far reaching as the technical and production changes themselves. The nature of these changes will be discussed in detail later in this paper.

II. DESIGN PHILOSOPHY CONSIDERATIONS

Overall Impact of the Mass Production-Short Run Concept

In the General Introduction some of the *broad-brush* socio-economic implications were presented. The question is now asked "Why is the combination of mass production and short runs so significant?" The answer is cost and design flexibility. In the old mass production-long run systems, high volume, long production runs were required to spread the die-changing, maintenance and overhead costs, as well as the high labor costs, over a sufficient number of parts to make them cost effective. Short runs were therefore prohibitively expensive and very seldom undertaken. This tended to limit parts design flexibility, and pushed up the costs of replacement service parts.

The tri-axis transfer press has changed all that because maintenance, die changing, and operating labor costs are all reduced to the point where the short-run part cost approaches that of the long-run part cost. This is especially true when the initial cost of the equipment has been fully amortized. Design flexibility and therefore product effectiveness will be significantly increased. In addition, the cost savings will ultimately be passed on to the consumer, through marketplace competitive forces.

Since the tri-axis transfer press employs more complex engineering systems and disciplines, the educational and training levels of the machine operators, die setup people, and maintenance personnel will also be increased. This ripple effect will extend to production supervisory personnel, because in order to supervise operations effectively, they must be familiar with the equipment.

The result of the above factors will require a training and educational commitment by users and suppliers far above what exists today. Additionally, because of the tremendous downtime costs incurred when a tri-axis transfer press breaks down, extremely high quality components and sub-assemblies are required. In exchange for demanding high-quality parts from their suppliers, the user manufacturers will give these suppliers a certain amount of exclusivity for their products. The ripple effects of these requirements upon suppliers and their suppliers are obvious.

Finally, the effect the tri-axis transfer press will have on the rest of the user's plant operations is just as major as the transfer press itself. It has a faster production rate than a conventional press line, with tighter tolerances and increased quality. This means less scrap generated. Since the equipment is very fast, adequate means of supplying raw material (usually in the form of blanks) must necessarily be automated as well. On the other end of the transfer press machine system, the discharge of

* Boolean Logic: A form of mathematical analysis originally developed in the 19th century as a tool for logic analysis, but which has proved extremely useful for modern computer programming.

finished parts must also be automated, in order to keep up with the production rate. Since this paper is restricted to the transfer press itself, specific methods of feeding the transfer press as well as removing finished parts will not be discussed in detail.

The foregoing represents some of the ramifications that will follow as the new mass production-short run systems take hold, and come onstream. The magnitude and size of the multi-axis transfer press systems will now be discussed.

Large/Small Systems

A quick review of Figure 3 together with prior discussions in this paper lead to the conclusion that this specific transfer press/line is very large, and so it is. The double-action drawing press can have a pressing tonnage capability of greater than 1500 tons and the six-station transfer press a tonnage capability in excess of 3000 tons on the first slide, and 1500 tons on the second slide. The whole transfer press/line therefore can be rated at over 6000 tons capacity.

It must be recognized, however, that practical realization of the mass production-short run concept can also be achieved in much smaller tonnages. Certainly, as low as 400-500 tons can be used, although in these cases, moving bolsters would probably not be utilized. The die stations would undoubtedly be mounted on a single die carrier, much like a progressive die assembly. The tri-axis feed would be downsized acccordingly.

This embodiment would allow medium-size manufacturers and stamping houses also to enjoy the benefits of the mass production-short run concept. Indeed, they might even exploit the possibilities better than the larger manufacturers, simply because of the nature of their business, which usually contains a significant amount of short-run jobs.

The electronics would offer the same close control and diagnostic capabilities as that used for the larger systems. In fact, the electronics would yield tighter control for the smaller systems, since there would be less memory required, and therefore the total scan time would be less (See Section III.A.13 for a detailed discussion of scan time and scanning techniques). Additionally, the mechanical factors of the press would be less severe.

Finally, the design techniques used for smaller transfer presses are very similar to those used for larger presses.

Engineering Factors and Design Aspects

PRODUCT DESIGN =

ENGINEERING
+
SAFETY ASPECTS
+
ECONOMIC CONSTRAINTS
+
ERGONOMIC CONSIDERATIONS

Any engineering product design effort for industrial capital equipment must have the above four ingredients included in the design structure. The product design objective may be considered as a four-legged stool, with each of the above parameters as one of the legs. If any one of them is short-changed, overemphasized, or ignored, the stool loses its stability and equilibrium. There must be an exact balance among the four legs to produce a totally acceptable product.

These factors are even more emphasized when a completely new product is being designed. In the case of the tri-axis transfer press, for example, there are five basic components to consider:

1. The power press component
2. The ancillary equipment required to support the press
3. The tri-axis transfer feed
4. The PLC control of the whole system
5. The moving bolsters and die changing systems

NOTE: The dies, loading and unloading methods, and some point-of-operation guards/devices are not considered as part of the transfer press itself.

Each of these areas must be approached with the four design *legs* applied. Finally, the totality of the product is finished by tying together each of the five basic component areas to operate as an integrated whole. Of course, each of the five components is subdivided into many groups; some of these are discussed in Section III, Functional Design Parameters.

The *ENGINEERING* leg of the product design stool contains all of the technical specifications. It is here that the customer's requirements and expectations must be met.The engineering must be done exactly right: if the product is under-engineered, the specs will not be met. If the product is over-engineered, the economics leg of the stool will be larger than it should be, and the product will be a financial failure or the order may not be obtained in the first place.

The *ECONOMICS* leg plays a critical role, particularly in the beginning of the project, during the estimating and quoting phase. If the price is set too high, the order will be lost; if it is set too low, the product will lose money. Again, just as in the engineering phase, there is a delicate balance between too much and too little. If the product is new, without much prior history, the problem of estimating correctly becomes even more complex.

The *ERGONOMICS* leg of the design stool, or human factors engineering of the product, must be very carefully considered, especially in view of the fact that the tri-axis transfer press is to be operated with a minimum number of personnel. Thus, number and locations of critical operating stands and consoles must be evaluated using all of the operating possibilities that could occur. Also, on a transfer-press system such as the one depicted in Figure 1, even though the space requirements are roughly one-fourth of a comparable multi-press line, it could still be over 150 feet long. For this reason, ease of access to various parts of the system becomes a major ergonomics design problem.

Control panel layout, with standard safety colors, must be used to minimize the chances of inadvertently actuating the wrong button in a given operating sequence. Finally, the whole system must be designed so that the operator(s) do not have to perform ergonomically tiring operations; for example, the control panels controlling sequential steps of a procedure must not be physically separated so as to force the operator to hurry back and forth to complete it.

The *SAFETY* aspect leg of the tri-axis transfer press system is very complex, and goes several levels deep. This is particularly true in the overall system interlocking procedures. Naturally each subsystem must contain its own guarding methods, both for pinch points and its own local point of operation. All of these and more must be carefully considered in the overall design.

It must be recognized, though, that however complex the safety requirements for the tri-axis transfer press might be, it is a problem of degree, and not kind. Conventional safety techniques can be and are used very effectively. Warning and *DANGER* signs must be appropriately distributed throughout the transfer-press system, as well as a multiplicity of emergency stop buttons, ergonomically located. For the press component, it must have *SINGLE* stroke control, through two-hand *RUN* button stations, as well as *INCH* and *CONTINUOUS* selections.

Each major component of the system (press, moving bolsters, transfer feed, ancillary equipment, and the PLC control) must be capable of being operated by itself (in a non-productive manner) as well as all together for the productive automatic line mode.

Finally, the press manufacturer must supply a detailed instruction manual regarding the operation of the machine, as well as a safety manual.

Relay, PLC or Hybrid Controls

It was indicated earlier that one of the factors that made the tri-axis transfer press economically feasible was the development of high tech, reliable electronic control systems, including PLC programmable controllers. While this is certainly true, it must not be forgotten that the standard electromagnetic press type relay has achieved a level of operating reliability and noise immunity that cannot even begin to be approached by any solid state system (The author has personally seen a number of original relay control systems at various customer plants still working after over thirty years of hard service).

The question that must be addressed, then, is that considering the high quality and reliability required by the tri-axis transfer press, what type of control system should be used:

PLC exclusively
Relays exclusively
Hybrid system: PLC's and relays

There is little doubt that PLC control does not have the reliability and electrical noise immunity of relays. On the other hand, relays cannot be easily used for mathematical computation, data collection, and diagnostic circuits.

The clear answer is that it would be advisable to use relay systems in very critical areas of control (first level interlocking, and the press clutch/brake control, as examples), and PLC control for almost everything else. In other words, the hybrid PLC/Relay control system should be used for interlocking and the basic press control. Section III.A, B discusses these items in more detail.

Product Liability and Legal Considerations

It was stated in the General Introduction that the tri-axis transfer press would have tremendous impact upon both the users and manufacturers, not only upon production, costs, operations, etc., but also upon product liability and safety considerations. The primary reason for this is that the tri-axis transfer press can be considered as a *DEDICATED SINGLE-PURPOSE SYSTEM, HENCE SUSCEPTIBLE TO POINT-OF-OPERATION GUARDING BY THE PRESS MANUFACTURER.*

To understand the significance of this, it should be emphasized that the press industry, its users, and the government itself (in the form of OSHA) all recognize that the conventional power press by itself is a multifunctional machine, and can accept a virtually infinite number of dies and feeding methods. It is therefore impossible for the press manufacturer to install die-space safeguards that will fulfill all of the infinite die and feeding combinations that can be put on that type of press. Even a perimeter guard would not work in all cases because so many dies and/or parts to be worked on extend beyond the die space perimeter. In other cases, environmental considerations make the development of a *universal* guard impossible.

The responsibility for guarding the point of operation of a press system under the above circumstances very properly falls to the user, since he alone can determine all of the various factors that go into the making of a specific press production system.

The courts have generally agreed with this distinction, while on the other hand, they are tending more and more to assign the responsibility of guarding the point of operation of the machine (whatever kind it might be) to the machine manufacturer, if the machine was produced and sold as a dedicated single-purpose piece of equipment.

While conventional power presses still fall under the multi-functional category and are basically incomplete pieces of equipment as sold, the tri-axis transfer press must be considered as a single-purpose dedicated machine. This places the basic responsibility for guarding the point of operation on the manufacturer of the press.

The reason for this distinction is that by its very design, even though an infinite number of die types can be used, they must all conform to the dimensional constraints imposed by the tri-axis transfer feed system. Clearly this must be done so that the processed parts can be transferred from station to station and ultimately to the finished discharge conveyor (or other discharge means) to be taken to subsequent processing areas.

This means that any part made by the tri-axis transfer press system must *NECESSARILY* fit within the perimeter of the die space areas of the transfer feed system; therefore it is a dedicated single-purpose system, and is susceptible to guarding techniques to be supplied by the press manufacturer which will accommodate any die configuration that can be utilized by the transfer press. This guard must be part of the press design, and of course the cost must be figured into the original price quotation to the customer.

While this aspect of tri-axis transfer press systems certainly relieves the user employer from a good deal of safeguarding responsibility for his particular job runs, he is not freed in any way from the responsibility of developing and implementing an effective employee safety program. Additionally, some states now require that if a

Tri-Axis Transfer Press/Line Block Diagram

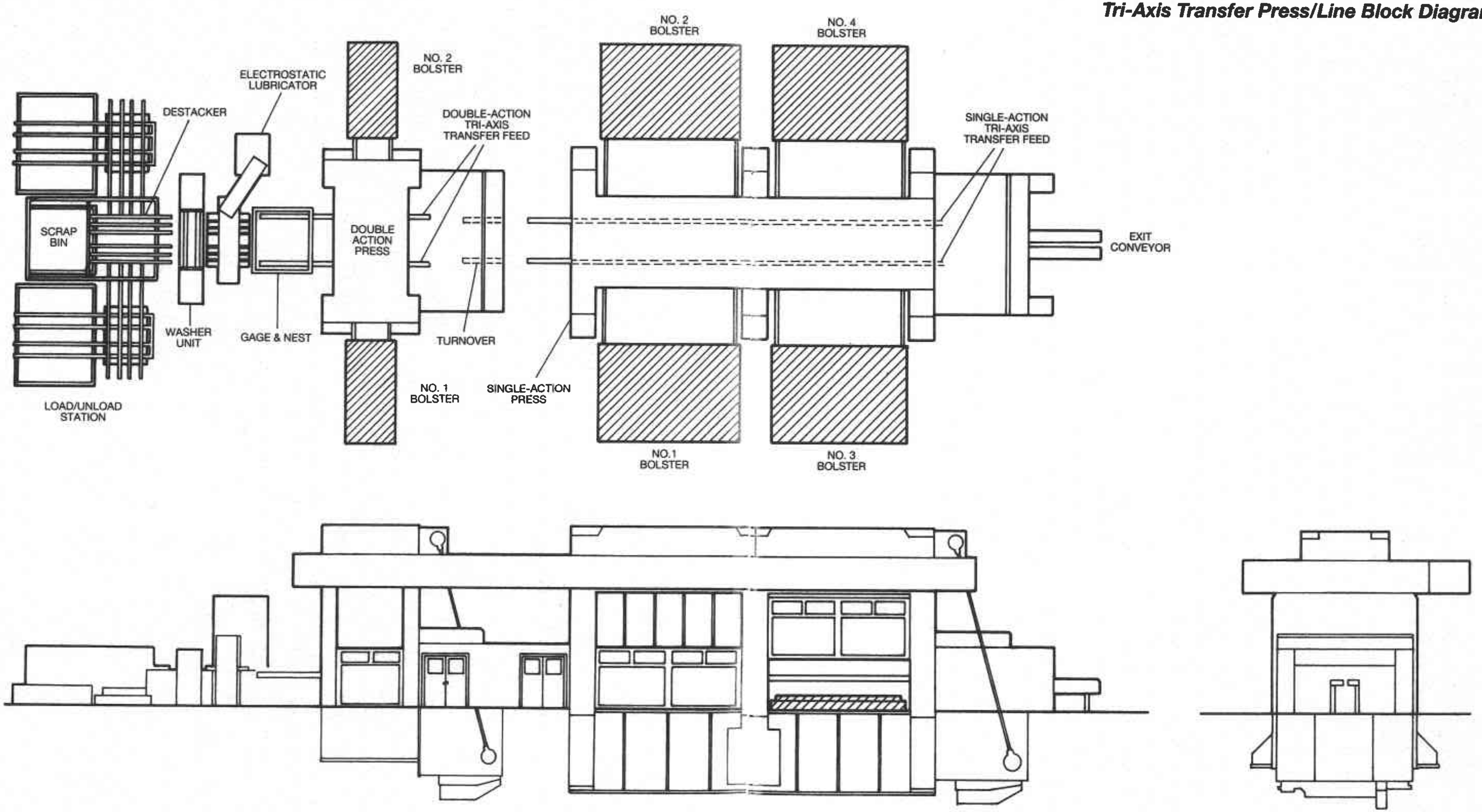

Figure 3. Tri-Axis Transfer Press/Line Block Diagram

user removes or otherwise negates the effectiveness of a safety guard furnished by the press manufacturer, the protection afforded to the user by worker's compensation laws is withdrawn, and he may be brought into the suit by his injured employee.

In summary, since most presses in the future will undoubtedly be of the bi/tri-axis transfer type, every facet of all the areas touching this equipment will affect the engineering, costs, safety methods, ergonomics, the users, their suppliers, the operators, and litigation procedures in cases of personal injury. The impact of all of these factors will be more fully discussed in this paper.

III. FUNCTIONAL DESIGN PARAMETERS

Introduction

This section is a thorough discussion of all phases of the technical design techniques and general implementation of those techniques necessary to achieve a balanced product design in the form of the tri-axis transfer press system illustrated in Figure 3.

Section III.A discusses design techniques while Section III.B goes into the actual implementation of those techniques. Detailed design formulas and programming practices are not given, however, primarily because to do so would turn this paper into a design handbook, and that is not the intention. The objective of this section is to illustrate the technological complexity involved in bringing the mass production-short run concept into practical reality, together with the resulting impact that it will have on all areas of the manufacturing sectors of the economy (the impact upon the non-manufacturing areas, particularly product liability, is discussed in Section IV of this paper).

Certainly one of the non-manufacturing areas is that of documentation and training. The necessity for initiating and maintaining good records cannot be overemphasized. Section III.C discusses this aspect of design in some detail. Finally it might be noted that the other *legs* of the product design stool (See Section II) are not explicitly broken out and discussed in Section III. This is because all four of the legs are treated simultaneously as integral parts of the product design process by the members of the various design teams involved. Hence, when one talks about stopping and interlocking levels, or power and control wiring techniques, for example, it is assumed here that these items are looked at from the point of view of the guidelines required by all four legs of the design stool. It can also be concluded that while the quality and reliability performance are not mentioned explicitly either, they are both spelled out in detail in the customer specifications, and are factored into the design.

The above are all design details and as indicated at the beginning of this introduction, are simply not within the scope of this paper. If a need arises and sufficent interest is shown in the future for a design textbook for the tri-axis transfer press, it would be published and distributed as a separate entity.

A. DESIGN TECHNIQUES

1. The Transfer Press Line Block Diagram (See Figure 3)

It will be recalled (See Section II) that the system can be broken down into five basic areas:

1. The power press component(s)
2. The ancillary equipment to support the power press component(s) operationally
3. The tri-axis transfer feed
4. The PLC control system
5. The die changing system and moving bolsters (Dies are not included in this category)

The major subcomponents of each of these areas will now be explored.

Power Press Component(s)

In this particular embodiment of the mass production-short run concept (See Figure 3) there are two individual tri-axis transfer presses. Going in the direction of the material flow, which is left-to-right in Figure 3, the first press is a double-action power press, with a mechanically driven tri-axis transfer feed system. There are two slides, an outer blankholder slide and an inner slide, which performs the actual drawing operation on the blank part. The tonnage ratings of the press refer to the dynamic force capable of being exerted on a die set approximately one-half inch up from the bottom of the stroke of the inner slide. The holding or clamping force on the piece part is exerted by the outer slide. The press is driven by a separate main motor drive, using D.C. (Direct Current) operation, which lends itself to extremely close speed control capability.

There are also two moving bolsters associated with the double-action press, each capable of carrying one die set. In Figure 3 both bolsters (shown in crosshatching) are shown outside the press die space area. Normally, during production running, one bolster is in the die area with the dies currently in use. The other bolster has been equipped with the next die to be used for the next production run.

The second tri-axis transfer press is a single-action press with two slides mechanically tied together longitudinally parallel with the axis of the line material flow. Both slides are driven by a D.C. drive. Again, there is a mechanically driven tri-axis transfer feed, which services both in-line slides. The first slide is rated with the higher tonnage capacity, and the second slide is approximately half of that.

It is noted that there are four moving bolsters (see cross-hatching), all of which are depicted as being outside the press die space area. Each bolster contains three die stations. During normal production running, two bolsters are in the press die space, each containing three dies of the current job running (for a total of six). The other two bolsters have already been set up with the six dies required for the next job to be run.

Ancillary Support Equipment

In addition to the two main presses, there is a number of ancillary support equipment, which is required to support the primary presses properly. From left to right on Figure 3, the description of the support equipment is as follows:

a. Load/Unloader Station
b. Destacker Unit
c. Washer
d. Electrostatic Coater
e. Gage and Nest Station
f. Parts Shuttle
g. Parts Turnover

h. Height Compensator
i. "Smart" Exit Conveyor

These nine pieces of support equipment to the two primary tri-axis transfer presses each have different and necesary functions to serve in order to ensure smooth parts flow. It should be emphasized that while all the basic functions that these pieces of ancillary equipment serve are necessary, there are of course different means to implement them for different applications. This particular embodiment does have the nine separate pieces of equipment, and each of them are briefly described as follows:

a. Load/Unload Station. The raw material for this line comes in the form of precut blank sheets of steel, which are piled in stacks. Depending upon material thickness and size, each stack could contain 200 or more blanks. Each stack is loaded by the line feeding system unto the destacker unit. If a blank is unsuitable for some reason, it is rejected by the station and unloaded into the scrap bin.

b. Destacker Unit. The loader positions the stack of blanks under the destacking mechanism, which picks up one blank at a time and inserts it into the next unit in line; in this case, the washer.

c. Washer. This equipment cleans and scrubs each blank with a special fluid, to clean off any accumulated dirt, rust, and other flaked particles.

d. Coater. The washer ejects the blank into an electrostatic coating machine, which uniformly spreads the lubricant onto the blank. In any pressing operation the die/blank must be properly lubricated to ensure proper processing and efficient die operation.

e. Gage and Nest Station. The part travels from the coater to a gage and nest station, the function of which is to position the blank properly for pickup by the double-action tri-axis transfer feed unit.

f. Parts Shuttle. This unit accepts the part from the double-action tri-axis transfer feed unit (the drawing action is performed by the double-action press). After the press has cycled, the transfer feed unit removes the part from the die, and deposits it on the parts shuttle. The shuttle, which is mechanically driven in this case by the double-action press, transports the formed part to the turnover unit.

g. Parts Turnover. This unit accepts the part from the shuttle, and in this case is also mechanically driven by the double-action press. Some operations require that the part be turned over for further processing and some do not require this turnover. If turnover is called for, the mechanism is electromagnetically clutched in by a programmable selection.

h. Height Compensator. This equipment receives the part from the turnover unit, and its purpose is to position the part for proper pickup by the tri-axis transfer feed unit of the dual-slide, single-action press.

i. "Smart" Exit Conveyor. After the part has been transferred and processed through the six die stations of the single-action transfer press, it is deposited upon the Final exit conveyor, which is electronically programmed to start, stop, accelerate and index to transfer each finished part properly to the stacking and discharge conveyors.

The Tri-Axis Transfer Feed Systems

As indicated in Figure 3, there are two tri-axis transfer feed units associated with this particular embodiment of the mass production-short run concept. They are completely separated from each other, one being mechanically driven by the double-action press, and the other mechanically driven by the dual-slide, single- action press.

The basic tri-axis feed movement is the same for both transfer feeds and is shown in more detail in Figure 2. A study of this figure will illustrate the interlocking complexities involved. See Section III.B.I.d, for a more detailed presentation of interlocking parameters. The clamping and unclamping mechanisms are also mounted on the feed rails. For overload protection, the entire feed mechanism is driven through a torque releaser unit.

The PLC Control System

As indicated earlier in Section II, the PLC control with relay and contactor control for critical areas of the transfer feed/line ties all of the various components of the line together. The control system is broken down into a number of basic operating areas:

a. Overall transfer line control
b. Component Control (i.e., double-action press, single-action press, the transfer feed units, and all of the ancillary equipment previously listed).
c. Interlocking techniques for personnel and machine guarding
d. Diagnostic monitoring
e. Fault, prompts, and tutorial message
f. Production data collection
g. PLC Communications. Some of the design techniques used to implement these areas are discussed in the rest of Section III, parts A and B.

The Die Changing System and Moving Bolsters

This system, which does not include the actual dies (they must be furnished by the employer/user) involves two complete sets of bolsters; one set is normally in each of the transfer presses and is running current production; the other set has been set up by the user with the dies for the next production run. A complete explanation of the automatic die change is contained in Section III.B.I.b and III.B.2.c, d.

III. A.

2. Electrical Noise
3. Grounding
4. Shielding
5. Power and Control Wiring and Voltages

These four items interact with each other, and therefore, while each one has to be considered as a separate area, the effects of each upon the others must also be recognized. Consequently, they will be discussed as one general item. In any industrial process involving high power components, electronic controls and devices, and large physical areas with long electrical runs required, as well as other industrial environmental factors, electrical noise must be very carefully evaluated. In the transfer press/line embodiment considered in this paper, the following sources have a very significant effect upon electrical noise and its probable negative impact upon overall transfer press operation:

a. Shock
b. Vibration
c. High horsepower motors, both A.C. and D.C. (Nearly 2,000 horsepower total for the tri-axis embodiment illustrated in this paper).
d. Long cable runs
e. Lubricant spray (effects upon electrical connections and circuits)
f. Low voltage electronic cables and connections
g. Power line disturbances, and "dirty" power
h. Transient disturbances created by high-power, high-voltage thyristor converter and inverter sets
i. Outside electrical noise sources such as welders
j. Environmental effects upon the control equipment such as temperature, humidity and atmospheric contamination.

The major concern regarding electrical noise is that if it gets into the electronic control systems it could (and does) generate spurious signals. These in turn create improper commands to the machine and equipment, which could endanger personnel and cause damage to the machinery. Minimizing the effects of electrical noise is therefore an extremely vital design objective.

Whatever the source of the noise is, it is of one or two basic types:

Electromagnetic interference (EMI)
Electrostatic interference (ESI)

Whenever current is flowing, it sets up both electromagnetic and electrostatic fields. Obviously the larger and stronger the current the more powerful will be these generated fields. If other wires are nearby, currents will be induced in them from the primary current-carrying wire.

This phenomenom can be either good or bad, depending upon the design objective. For example, in a transformer this field coupling action is essential to the operation of the device. This is a *good* or positive use. A *bad* or undesirable use is an electronics communications cable, where such coupling action could cause a disruption or garbled information message in the communications.

A number of methods are used to minimize the effects of unwanted electrical noise generation. Several of these are listed below, although it must be emphasized that the variables for noise analysis are extremely complex, and non-linear as well. Consequently, only the mere mention of some of these techniques can be made in a paper of this type. The primary ones are:

a. Grounding
b. Shielding
c. Isolation
d. Wiring configuration
e. Component location

It should be noted that aluminum or copper braiding used around wires or cables is effective only for ESI type of noise. Only magnetic materials are effective against EMI. Finally, cable runs should be grouped as to all A.C. or all D.C. voltages, at approximately the same voltage levels, since their respective fields, being approximately the same, tend to cancel each other out.

Some common voltages used for equipment of this type are:

D.C. Volts
5-low volt. Electronics
12-low volt. Electronics
24-Power Supply-Electronics
100-Power Supply-Motors
500-Power Supply-High hp Motors

A.C. Volts (60 Hz)
120-Single phase
Utility power
480-Three Phase
Motor power

III. A.

6. Hardware, Software, Firmware
(With respect to PLC's)

These items are all part of the PLC control systems, although each have a different role to play. They are definitively described as follows:

a. Hardware. All of the PLC components such as circuit boards, the microprocessor itself, the packaging, I/O boards, various connection ports, the power supplies, and all of the myriad electronic parts used to assemble these items are known as hardware. With respect to the PLC, it may be considered as the physical body of the controller.

b.Software. If hardware is the body of the PLC, then the software has to be the brain. This is where programming comes in. Each PLC is very similar in form, but does widely different things depending upon what instructions (or programs) are loaded into its memory ("brain"). The capabilities of software programming are virtually unlimited, being constrained only by the memory capacity of the PLC. It is basically the detailed set of instructions to the PLC to solve a particular group of logic functions in such a way as to command the machine being controlled to perform in the prescribed manner.

c. Firmware. This is a type of programming that limits the range of instructions that are available. It is used where a number of repetitive actions are frequently required from the PLC (called sub-routines), that are substantially the same in nature. Rather than rewriting the entire subroutine program each time it is needed, the firmware allows the whole set of instructions to be called up by a single command. The big advantage to firmware is that it saves memory and therefore processor scan time.

Another example of a firmware program is what is called a *soft* pushbutton. A button of this type is loaded with a number of different unalterable functions, with choice of function selection being left to the operator or user. In general, firmware utilizes a type of computer memory known as ROM (Read Only Memory), whereas software programs use RAM (Random Access Memory). A discussion of memory types can be found in Section III.B.1.e.

III. A.

7. Contactors, Relays, Hardwired Components

Section II discussed relays vs. PLC Techniques. This section analyzes relays in somewhat more detail. There is no question that the relay will continue to be a viable element in electronic control systems for years to come. The three hardware components listed in the title are defined as follows:

a. Contactor. A contactor is quite similar to a conventional control relay in that it is an electromagnetically operated device, with an armature that is part of the solenoid assembly. Upon energization of the solenoid the magnetic field forces the armature in such a direction as to close the contacts of the device, which then act as switches (there are many different contact configurations). The difference is that the contactor is a high-power device as opposed to a control relay, which serves as basically a logic solving device only.

b.Control Relay. As indicated above, the relay is also an electromagnetically operated component and finds its greatest uses in today's designs as part of critical control circuits.

c. Hardwired Electronic Components. This is a classification of device that is designed to fulfill one specific function, and while possibly containing processor chips, it cannot be user-programmed, and therefore contains no software programs. Some examples are electronic sensors and transducers, digital thermometers, special devices (such as rotary encoders), standard pushbuttons and selector switches, etc. This is the reason such components are described as "hardwired" as opposed to "soft" devices.

The standard machine tool (and in particular the press control) relay has been used in a wide variety of machine tool applications for well over seventy years. If a relay suitable for press application is used (basically a common armature type of construction for the contacts) and the control system is built as per JIC (National Machine Tool Builders) and NEC (National Electric Code) standards, the control will perform satisfactorily for literally decades (a fact to which the author can personally attest). This presupposes proper care and maintenance, of course.

The control relay has a number of advantages that solid state and computer control can never achieve. The primary ones are:

a. The most reliable electrical/electronic control component available today, proven over decades of use.
b. Completely impervious to electrical noise
c. 100% isolation between control contacts and power.
d. Can operate at 120 volts to prevent contact contamination buildup.
e. Operates over an extremely wide range of environmental conditions, including temperature, pressure, humidity, and atmospheric contamination.
f. Used within their application constraints, they are more economical than any other type of control.

The relay's primary disadvantages are:

a. It must be hard-wired, thereby limiting its flexibillty.
b. It is too bulky to be used in sufficient quantities for efficient data collection and diagnostic circuits.
c. Its contacts sometimes create electrical noise due to contact *bounce*. This requires special design techniques when they are used with low voltage electronic inputs (such as special debounce circuits).
d. Because it is hard-wired, a relay system must be debugged each time a new system is built, whereas a software program need only be debugged once.

Contactors, control relays, and hardwired electronic components may all be looked upon as building block control elements to be used as desired and/or required in control design.

III. A.
8. Sequence of Operations

Any machine system, as far as control is concerned, consists of four basic parts:

a. The input elements
b. Logic manipulation
c. The output elements
d. The Power Supply

The machine itself has been designed to operate in a particular sequential manner, in a number of operational modes such as automatic, semi-automatic, manual, inch, jog, etc. As it progresses through its operating cycle, it performs the work for which it was designed and built. The sequential steps of the machine cycle, when broken down into the exact manner in which the machine is required to operate during the cycle, is known as the *sequence of operations*. Section III.C.6 discusses this area in greater detail.

Once the sequence of operations has been developed, a set of instructions for the logic section may be designed, either with a relay logic circuit, a software program for the PLC, or a hybrid PLC/relay design.

Input elements are defined as those control components that deliver data information to the logic area, such as when to start the cycle, what operating mode it is required to operate in, speeds (feed and cycle rates), feedback information that will tell the logic control where the machine is in the cycle, where it would like to be, if it is going through the cycle without any perceived malfunctions, when to pause, when to restart, when to stop, et cetera.

Typical examples of input elements would be pushbuttons, selector switches, pressure switches, flow switches, limit switches, rotary encoders and limit switches, strain gages, programmable limit switches (PLS), input keyboards, hard-wired electronic devices, temperature transducers, feedback commands of all types, input commands from other, separate equipment, etc.

The logic section of the control system receives the data from the input elements, and evaluates and solves this information in a sequential manner, according to a set of specific instructions (software) which had been programmed into the logic elements earlier, and then proceeds to give the appropriate commands to the machine to move in the desired manner, speed, position, etc. The logic section may consist of control relays, contactors, PLC controllers, and internal interaction between the sub-parts of the PLC.

Once the logic section has determined the desired status of each of the movements, speeds, positions, etc. of the machine, it actuates (or de-energizes) the output elements to accomplish this. It is the job of the output elements to carry out the commands of the logic section, and while doing that, provide instantaneous status information to the input section (feedback).

Typical examples of output elements would be solenoid valves, pneumatic and hydraulic cylinders, motors, motor-activated potentiometers, linear motors and solenoids, pilot lights, CRT's, printers, contactors, relays, scoreboard displays, horns, bells, throttle commands, pressure and flow adjustments, temperature adjustment commands, mechanical and hydraulic clutches, etc.

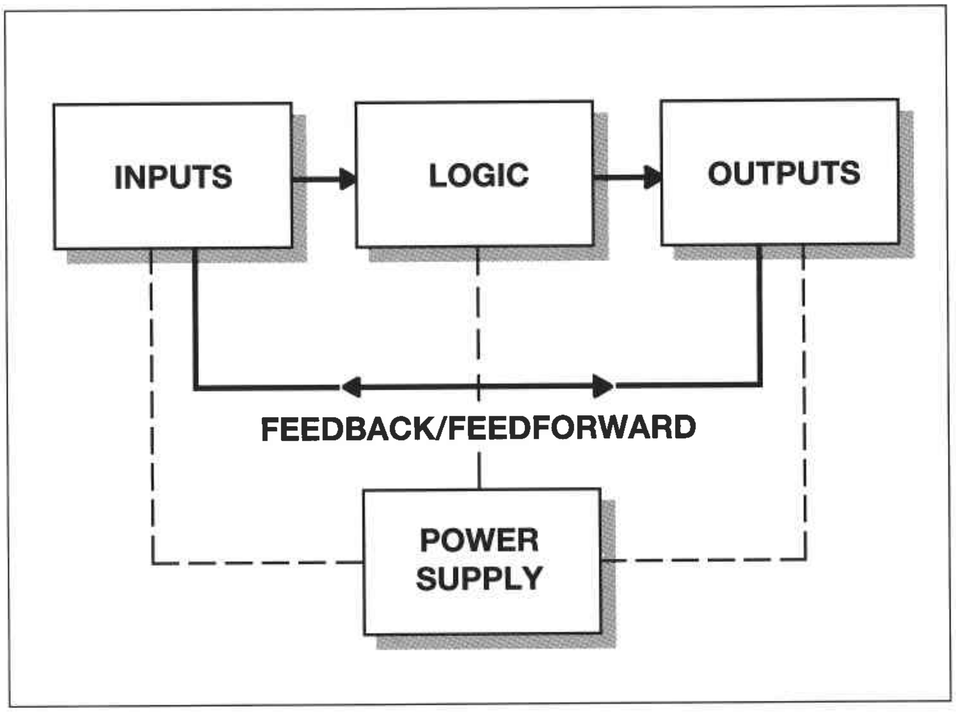

Figure 4. Basic Control System Block Diagram

The fourth basic section of the control system, the power supply, while not in the direct line of control flow, nevertheless is extremely vital in that it furnishes power to the hardware sections of the inputs, logic, and outputs. The basic control block diagram would be as shown in Figure 4.

III. A.

9. Fault Messages
10. Diagnostic Messages
11. Tutorial/Instructional Messages

Just as in the earlier discussion (III.A.2, 3, 4, 5) on electrical noise, these three categories, while each serving a different purpose, are all part of of the non-control portion of the overall PLC program. A message of some kind is displayed when a control condition exists (such as a limit switch malfunction) that it is deemed desirable for the machine system operators to know about. Depending upon the seriousness of the triggering condition, the message might be displayed only, or displayed and acts additionally to stop the operation until the matter is investigated.

Whatever types of message are called up to the display screen, they all are triggered by a similar mechanism: an abnormal or special condition exists that will call up a previously stored message by proper comparison, and then displays it on a screen. In some cases, it will also affect the control, such as stopping the cycle until the triggering condition is removed. The usual types of messages are as follows:

Fault Messages

This type of message is triggered by a perceived malfunction of some type: low or loss of pressure, loss of feedback, overtemperature of some element (e.g., a bearing), the cycle getting out of the correct sequence or timing due to failure of feedback or logic, low voltage, loss of voltage, failure of interlock circuits, unscheduled depressing of emergency stop buttons, dropping of the part by the feed mechanism, double blank destacking, failure of the turnover to operate when it should, any number of internal PLC faults, and literally hundreds of other types of messages.

The number of possible and significant fault messages obviously increases with the size and complexity of the machine system. In the case of the tri-axis transfer press/line discussed in this article, there could be over 1,000 fault messages stored in the PLC. Each of these messages is triggered by some malfunction that is sensed by pressure switches, limit switches, temperature sensors, and the like.

Depending upon the seriousness of the fault, the message may also trigger a stop command to the control program. For example, if a interlock fault occurred, the message would also trigger an emergency stop command to the machine system.

If the fault were of lower priority, such as a lube fault in a noncritical area of the press, the control might be allowed to continue operating, but when the machine was shutdown (for lunch, etc.), it could not be restarted until the lube fault was cleared. It is obvious that the type, number and priority of each fault message must be approached with as much care as the control design itself.

Diagnostic Messages

These types of messages, while similar to fault messages, are different in that, in addition to displaying the bare fact of the fault itself, they contain information that is helpful in determining the cause of the fault. For example, if a fault message appeared on the screen "72LS did not close," the supplemental diagnostic message might be triggered: "This is the scrap hopper door cylinder; Check status of 71LS to determine if cylinder has bound up in midstroke or if it did not move on the command." In this case, if 71LS has actuated, that would indicate that the cylinder started to move, but did not finish its stroke *OR* that 72LS is faulty. If 71LS did not change status, it would indicate that the cylinder did not receive a command to move or that perhaps the controlling solenoid valve was malfunctioning. In any event, the cause of the problem can be determined more rapidly.

Another type of diagnostic message is that of early warning. For example, if the oil level in a tank is getting low, a sensor would recognize this and perhaps trigger a message: "Oil in Tank C-4 is low; please refill."

Tutorial/Instructional Messages

While these two types of messages are quite similar, nevertheless there are differences and they are used differently. Tutorial messages are similar in intent to *Help* messages on PC programs such as Windows and Word Perfect. Their purpose is to make the viewer acquainted with some of the basic objectives of a particular operation of the machine system. For example, if an operator wanted to become more acquainted with the automatic die change operation, he would call up the tutorial messages on the description of that operation.

Instructional messages, on the other hand, are actual instructions or prompts to the operator when he is performing an operation such as a manual die change, or for some semi-automatic operation. Even in full automatic mode, certain messages are a propos, such as "Blanks running out," or "Increase coating lubrication on blanks." In a manual type of operation, the instructional messages may be more in the form of prompts, as the program walks the operator through the cycle.

The concept of message utilization in minimizing downtime as well as in preventive maintenance is extremely effective in maintaining on-line productivity. This is especially true if the messages in each category are stored and compared as part of the production data collection process (See Section III.A.15).

III. A.
12. Clutch Control/Dual Processors

In Section II, it will be recalled during the discussion on relays/PLC hybrid systems, that this type of control should be used in very critical parts of the machine system, and the term *clutch control* was used as an example of this. In press design, anything directly connected with the energization and deenergization of the main clutch is a critical area, since if the clutch is inadvertently actuated or commanded to actuate from a spurious command, the press slide(s) will come down, and the transfer feed mechanism will operate. If the movement is unexpected, and/or out-of-cycle sequence, both personnel injury and machine damage can occur.

As a matter of fact, the clutch/brake areas are so critical that they are usually designed with their own special, dedicated PLC's, completely separate from the rest of the press PLC control. The control concept is described in more detail in Section III.B.1.a; the objective in this section is to emphasize the design philosophy used, particularly why dual processors are used.

It is a well known control design concept that one of the techniques used to maximize the operating reliability of a circuit is to employ redundancy for critical components. Years ago, the press clutch control operating solenoid valve was changed from single-solenoid operation to dual-solenoid operation. The redundancy thus obtained resulted in a significant decrease in unexpected press clutch actuations. Of course, redundancy is a two-edged sword in that too many orders of redundancy could not only result in diminishing returns of reliabillty, but also could actually reduce reliability.

The use of PLC's in press clutch circuits requires extremely careful design analysis, in order to maximize the operating reliability. First, knowing that PLC's or any other electronic circuit cannot be 100% protected from noise effects, two separate processors are used (i.e., redundancy). Both of these units continually monitor each other during a cycle; if one or the other gets out of step for some reason, an emergency stop is triggered.

Second, the use of ROM's is absolutely necessary in dual processor clutch/brake PLC control. ROM memory is unalterable, and once the program is proven in the dual processors, it cannot be changed (see dicussion of ROM and RAM memories in Section III.B.1.e).

Third, in order to protect against inadvertent shorting of solid state outputs, hardwired relay contacts are placed in series with the valve solenoid coils. Since the clutch control valve is a dual solenoid type, each processor is designed to control one separate solenoid. This further increases reliability. The question might be asked that with the noise immunity superiority of relays over PLC's, why not make the entire clutch control circuit using relays only? The answer is that the diagnostic and computational superiority of PLC's over relays can very rapidly evaluate all of the major failure modes of the clutch control circuit, and spot major problems easier and quicker.

An example of the above approach are the combinations involved in actuating and deenergizing the clutch/brake valve. Just considering the outputs involved in turning power on and off the solenoid coils, there are four such outputs, two involved in each coil. This means that it is possible to energize these outputs in sixteen distinct combinations; only two of these are correct, all of them on or all off. The PLC can very rapidly evaluate the other fourteen and react quickly to a bad combination.

III. A.
13. PLC - Different Scanning Techniques and Their Impact on Control Designs

When PLC's were first developed, it was anticipated that their primary job would be that of relay replacement and in theory that was a logical assumption. It was not long, however, before that assumption was shown to be totally incorrect. First, the diagnostic and computational advantages of the PLC over relay systems were so significant that mere relay replacement rapidly became a secondary goal. Second, the practical implementation of PLC's was such that it was virtually impossible to replace relays directly. It had to be recognized that each type of control device had its own physical idiosyncracies and ground rules of operation.

The basic difference between relay and PLC logic execution is that relays solve their logic program instantaneously, and the PLC solves the same program sequentially (as does any computer program), which introduces a time delay. A simple circuit example will illustrate this basic difference; given the logic circuit shown in Figure 5.

This circuit is a graphical depiction of the Boolean algebra expression:

$$\overline{A}B + A\overline{B} = C$$

and is interpreted "not-A and B or A and not-B = C".

This is the common exclusive-or circuit, and in terms of plain English simply means that either contact A or contact B will energize coil C, but not both (hence the terminology *exclusive-or*).

In a relay circuit, closure of contact A, for example, will instantaneously energize coil C; however, a PLC program will execute the same circuit by solving A, then not-B, jump down to solve B, then not-A, and only then will energize coil C. In other words, it will solve the logic on a rung-by-rung basis, in a sequential manner. The output coil C will not be solved, or energized, until the whole program has been scanned, at which time all of them will be updated. Each contact usually comprises one word of memory, and with a typical scan time for a fast processor of 1 msec/1k of memory, a large program consisting of one hundred or

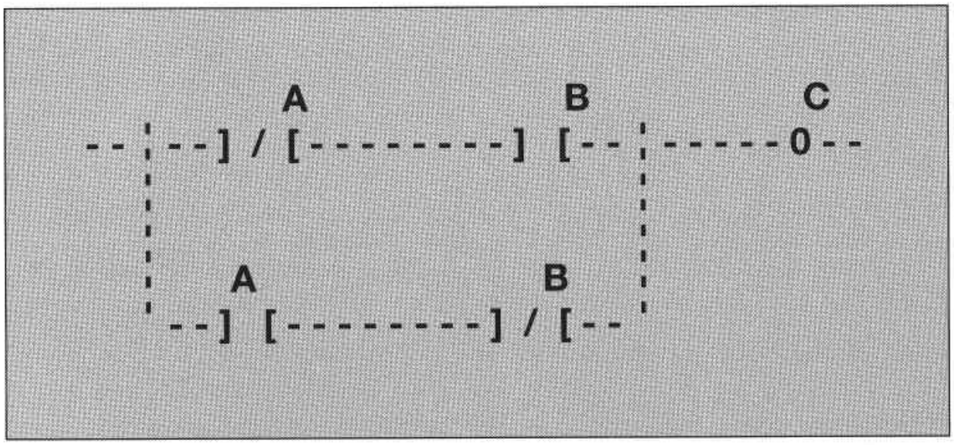

Figure 5. Exclusive - OR Logic Circuit

more K of memory can add significant time delays to the actual response time of the control system. This inherent characteristic of the PLC system must obviously be considered in the design, and in fact there are a number of ways to accommodate to this problem.

Finally, although every PLC must solve its program instructions in a sequential manner, virtually every PLC manufacturer has the solving sequence formatted in a different way. For example, one manufacturer solves its logic by breaking the program into *networks* of several rungs of ladder logic at a time, and solves each network in its entirety before proceeding to the next network. It does this by solving the logic one column of the network at a time, progressing column by column to the end of the network.

Another manufacturer has its PLC solve a program by sequencing it one rung at a time, solving that rung, and proceeding in that manner through the entire program. It is apparent that the key to writing a good program requires a familiarity with the *ground rules* imposed by a specific type of PLC.

III. A.

14. Hard/Mounted Warning Signs

In tri-axis transfer presses, and particularly the embodiment used as an example in this paper, there are a number of local point-of-operation areas associated with the ancillary equipment. In addition, the point of operation of the transfer press itself is really governed by the dynamic perimeters of the transfer feed as opposed to the press slides themselves. As previously discussed, it is the manufacturer's responsibility to guard the transfer press production system, especially while it is operating in the automatic mode. This usually takes the form of so-called *safety gates* which enclose the entire system, and which must be closed completely before the system can be started in automatic.

As a supplement to the guarding provided by the safety gates, the liberal use of warning signs is required. These should be posted on the press columns of the transfer press, as well as by each piece of ancillary equipment. Of course, the entire diagnostic and fault system will have danger and warning signs that will appear on the CRT monitors as the occasion demands. These signs should warn of the danger involved in entering into the point-of-operation areas while the machine is running.

The maximum value of warning signs occurs when they warn of hidden dangers, as opposed to obvious hazards. Thus, in addition to the warning signs described above, there should be additional signs warning of high-electrical voltage, high-pressure alr and hydraulics, springs and weights, and accumulators that are not blown down upon the stopping of the system.

Another danger that is very real is that the safety gate may be closed with a person on the inside, trapping him, and subjecting him to dangers of the moving machinery should someone start it up inadvertently. Therefore, a series of emergency stop buttons must be placed at various positions where a trapped individual can conveniently reach them. In some cases, a stop bar or light beam may be called for.

As a corollary to the above, there must also be signs warning of the possibility of parts of the machinery suddenly starting up, either inadvertently, or unexpectedly in an automatic fashion. The extreme example of this is the transfer feed mechanism, which in many cases has heavy drive cams associated with it, as well as counterbalance air cylinders, and brake and overload holding mechanisms. If a failure occurs during a stopped period, the feed bars could cycle unexpectedly for a number of cycles, posing a serious threat to both personnel and machinery.

There is also potential danger to die setters, maintenance personnel, and other non-operating personnel, in that each component of the transfer press line, including all the ancillary equipment, must be capable of being run separately and manually without the rest of the line in operation. This is for maintenance purposes, die checking and repair, and other general inspection procedures. Extreme care must therefore be taken to prevent other equipment from feeding into the component under repair, as well as following the exact safety procedures for protection of personnel who must enter local points of operation for those purposes. Warning signs are always a good supplement to guarding and interlocking procedures.

In summary, the number of signs, the type, and the placement of them, warrant as serious consideration by the design team as the engineering design itself. The four legs of the design *stool*, as previously described in this article must constantly be kept in mind:

PRODUCT DESIGN =

ENGINEERING
+
SAFETY ASPECTS
+
ECONOMIC CONSTRAINTS
+
ERGONOMIC CONSIDERATIONS

III. A.

15. Production Data Collection

This aspect of the tri-axis transfer press line, while not in the direct flow of material through the system, is absolutely vital to efficient line operation. With the proper memory size, and the inherent speed of the computer, vast amounts of all types of information may be collected, displayed, and stored for future reference. Since it is not critical to the specific running of the system, the equipment required to accomplish this task should be designed to be bypassed in the case of problems with it, so that production could continue uninterrupted. The information thus collected can be categorized into two basic types:

1. Production and scheduling data
2. Downtime and preventive maintenance data

As examples of production and scheduling data, there could be:

a. Total part count per shift, and accumulated count
b. Downtime of equipment
c. Uptime of equipment
d. Average Line speed
e. Scrap pieces, and at what point
f. How many pieces left to go on current job
g. Next job description-is it loaded on the bolsters, ready to go
h. Estimated date and time the next job will be started.

There are, of course, many other aspects that could be and are collected for analysis. Some downtime and preventive maintenance data examples are:

a. Total downtime
b. Downtime, broken out into time of occurrence and length of each segment
c. Primary cause of downtime: planned or unplanned
d. If unplanned, what was the primary fault shutting the system down?
e. Complete computer analysis of faults that occurred, including the time of occurrence, the length of the shutdown due to that fault, and a comparison of types of faults that might indicate a trend to more serious problems
f. A complete printout of early warning messages, and second, priority diagnostic messages (i.e., those not resulting in immediate and emergency shutdowns).

Again, there are many other categories and subsets of these categories that could be listed. This list, however, illustrates the power of the computer to furnish copious amounts of information to serve management as a valuable tool for production decisions.

The final parts of this paper will appear in Volume 9, No.1 of the Triodyne Safety Brief.

Editor: Beth A. Hamilton
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What is a Defect?

The definition of a defective product in a state may be found in the case law of that state. In our Safety Briefs, we explore leading product liability case law for one or more states. Triodyne Inc. relies on the trial bar for selection of the cases cited.

MINNESOTA

Defect has been generally defined by the Minnesota Supreme Court as:

> any condition not contemplated by the user which makes a product unreasonably dangerous to him; a product is not in a dangerous condition when it is safe for normal handling and consumption.

Farr v. Armstrong Rubber Co., 288 Minn. 83, 179 N.W.2d 64 (Minn.I970). An "unreasonably dangerous condition" is one where:

> (the product) is dangerous when used by an ordinary user who uses it with the knowledge common to the community as to the product's characteristics and common usage. A product may be unreasonably dangerous because the manufacturer has failed to give adequate warnings of the known or knowable dangers involved.

Karjala v. Johns-Manville Products Corporation, 523 F.2d 155 (8th Cir. 1975). An unreasonably dangerous condition in a product may arise in a number of different ways, including a defect in the manufacture of the product, but arguably the most common cause of action in products liability is for defective design.

A manufacturer of a product has a duty to exercise reasonable care in its choice of design. In order to determine whether manufacturers have exercised reasonable care, the Minnesota Supreme Court adopted a "balancing test" in *Bilotta v. Kelley*, 346 N.W.2d 616 (Minn.1984). This case involved an action brought in negligence and strict liability against the manufacturer of a dock board, for injuries sustained by plaintiff when a forklift tipped off of the dock board and fell on him. Plaintiff claimed that the dock was defectively designed, based upon evidence of an optional safety device. At trial, the District Court applied the Consumer expectation standard of the Restatement (2nd) of Torts, §402A, and the plaintiff prevailed.

On appeal, the Supreme Court found the "consumer expectation" standard inapplicable to design cases where the condition of the product was exactly as intended, and instead, adopted the "reasonable care balancing approach." Under this test, when determining whether the manufacturer has exercised reasonable care in its choice of design, it must be determined whether that choice of design strikes an acceptable balance among several competing factors, including:

a. the usefulness and desirability of the product;
b. the availability of other and safer products to meet the same need;
c. the likelihood of injury and its probable seriousness;

d. the obviousness of the danger;
e. common knowledge and normal public expectation of danger;
f. the avoidability of injury by care in the use of the product, including the effect of instructions or warnings; and,
g. the ability to eliminate the danger without seriously impairing the usefulness of the product, or making it unduly expensive.

After applying its test to the facts of the *Bilotta* case, the Supreme Court reversed the trial court's decision, and remanded the matter back to the trial court on the issue of liability.

In the aftermath of the *Bilotta* decision, the drafters of the Minnesota Jury Instruction Guides issued a third edition which contained a specific instruction, in which this reasonable care "balancing test" is set forth as listed above, with one additional factor for the jury to consider. The instruction indicates that the manufacturer is obliged to keep informed of scientific knowledge and discoveries in its field.

The parties in *Bilotta* settled the matter before the balancing test could be applied to the facts; however, the balancing test was applied by the Court of Appeals in *Westbrook v. Marshalltown Mfg. Co.*, 473 N.W.2d 352 (Ct.App.Minn.1991). In this case, plaintiff was injured in an accident involving a mechanical power press, manufactured by Marshalltown. Plaintiff maintained that the power press was defective and that Marshalltown should have installed point-of-operation safety guards on the press. Marshalltown made a motion for summary judgment, arguing that the multipurpose nature of the machine precluded installation of a single safety device which would not impair the machine's multifunction nature. The Court of Appeals agreed with Marshalltown's analysis, and upheld the District Court's grant of summary judgment on the design defect issue, but reversed on whether Marshalltown had a duty to warn of the potential hazards of the press.

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NEVADA

The seminal case for a definitional statement of "defect" in the State of Nevada is *Ginnis v. Mapes Hotel Corp. and Dor-O-Matic*, 86 Nev. 408,470 P.2d 1935(1970), in which the Court adopted the following:

> "After examining a multitude of cases and legal writers, we think the most accurate test for a 'defect' within strict tort liability is set forth in *Dunham v. Vaughn & Bushness Mfg. Co.*, 247 N.E.2d 401,403 (Ill. 1969), where it was held: Although the definitions of the term 'defect' in the context of products liability law use varying language, all of them rest upon the common premise that those products are defective which are dangerous because they fail to perform in the manner reasonably to be expected in the light of their nature and intended function."

In the *Ginnis v. Mapes Hotel Corp. and Dor-O-Matic* case, Mrs. Ginnis, along with her husband and a friend, were business invitees to the casino area of the Mapes Hotel in Reno. Both Mr. Ginnis and the friend exited the hotel by going through two sets of automatic doors. When Mrs. Ginnis stepped across the theshold of the inner door, it closed on her, knocking her over the rail alongside the door and pinning her to it. Mr. Ginnis tried to extricate her from the predicament, but had to seek help when he could not force the door open alone.

What happened immediately following this event is in dispute. The Ginnises both testified that a maintenance man carrying a tool box removed the threshold plate and worked on the door's mechanism. The maintenance man denied he had a tool box or worked on the mechanism, but, with a security officer, simply walked through the door several times and it functioned properly.
Ginnis sued Mapes Hotel and Dor-o-Matic, the door manufacturer, upon four theories: negligence, implied warranty, res ipsa loquitur, and strict tort liability, for injuries she sustained. Her expert testified that the cause of the door closing on Mrs. Ginnis was a malfunction of the safety relay in the door mechanism and that it was a condition dangerous to human safety. He described two safety features which could have prevented closing as it did: (1) the door could have been equipped with a duplicate control network or "redundant system," or the door could have been equipped with a trip or pressure switch such as is commonly found on elevator doors to prevent them from closing on passengers. The defendant's expert agreed that the safety relay must have been responsible for the door's malfunction, but claimed that the company had received no compliants concerning the operation of this or any other doors they supplied.

The district court rendered judgment for the defendants; the plaintiff appealed, on the basis that the trial court had refused three instructions which would have permitted the jury to consider the doctrine of strict liability against Dor-O-Matic. The Supreme Court of Nevada held that where action was brought under strict liability in tort, evidence of subsequent, similar orders involving the same door and prior and subsequent repair orders were relevant to causation and defective and dangerous condition. The trail court's decision was affirmed as to Mapes Hotel Corporation and reversed and remanded for new trial as to Dor-O-Matic.

The scope of strict liability has expanded in Nevada to a point far beyond that which was originally contemplated. In *General Electric v. Bush*, 88 Nev. 360, 498 P.2d. 366(1972), the "failure to warn" theory was adopted as part of the tri-parted analysis of theories encompassed in the strict liability doctrine (the other two theories being manufacturing defect and design defect).

Dee Ann Bush, as wife of a rigger and guardian of their three minor children, brought action against the manufacturer of a large vehicle used in open pit mining and General Electric, the manufacturer of the electrical control cabinet used on the vehicle. Dee Ann's husband, a rigger, was rendered a permanent invalid when the 1,130 pound control cabinet fell on him when an eyebolt broke while riggers were placing the cabinet in the vehicle.

The cabinet had been shipped to Ely, Nevada, where it was to be reassembled by a professional rigging company crew, of which Bush was a member. The eyebolts met ASTM standards and were in the cabinet at the time it arrived in Ely. No rigging diagram or warning was given by any of the manufacturers. The rigging crew was experienced and professional and a test lift was performed safely. The evidence showed that the rigging was in accordance with usage and custom in the trade. During the trial, it was shown that the eyebolt had been defective, possibly from previous use. The jury awarded the rigger three milllion dollars, his wife $500,000 for loss of consortium and $50,000 for each of the children for their loss of companionship.

On appeal, the appellants contended that the jury predicated liability on the companies' failure to warn and instruct the reassembly crew. Their position was that such notice and warning is not required when the reassembly crew consists of professionals who not only know how to rig, but also know the dangers attendant therewith. They claimed that if failure to warn was accepted by the jury, it sounded in negligence and they were therefore entitled to defense instructions on contributory negligence and assumption of risk. The appeals court disagreed that the trial court had erred when it refused to give the jury such instructions.

The appellants' assignment of error was also directed at the trial court's failure to sustain objections to respondents' line of questioning in order to establish a duty to give warning. The evidence had shown that the rigging was in accordance with custom and, had the companies required different rigging, suitable instructions or warnings to that effect would have been appropriate. Without them, the riggers were free to use the accepted method they felt proper.

The appellants challenged the three million award to the injured rigger, who had a life expectancy of thirty-nine years from the time of the trial. This did not shock the judicial conscience of the court, which affirmed this and all the trial court's decisions, except that of the award to the children, which was set aside.

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NEW YORK

In New York, the manufacturer of an allegedly defective product may be subject to causes of action asserting breach of warranty (express or implied), negligence and/or strict liability. A plaintiff may assert that the product is defective because of (a) a manufacturing flaw; (b) improper design; or (c) inadeguate warnings. In 1973, the New York Court of Appeals adopted strict liability and held that:

> "the manufacturer of a defective product is liable to any person injured or damaged if the defect was a substantial factor in bringing about his injury or damages; provided:
>
> 1. that at the time of the occurrence the product is being used (whether by the person injured or damaged or by a third person) for the purpose and in the manner normally intended,
> 2. that if the person injured or damaged is himself the user of the product he would not by the exercise of reasonable care have both discovered the defect and perceived its danger, and
> 3. that by the exercise of reasonable care, the person injured or damaged would not otherwise have averted his injury or damages."

Codling v. Paglia, 32 N.Y. 2d 330, 342-343, 345 C N.Y.S.2d 461; 469-470, 298 N.E.2d 622, 628-629 (1973). In August 1967, Paglia was driving his Chrysler Newport sedan south of Albany when suddenly his vehicle crossed the highway centerline into the oppposite lane and collided head-on with a automobile driven by Codling. Paglia had then owned the Chrysler about four months and had driven it about 4,000 miles. At no time before the accident had he experienced any difficulty with the steering mechanism, but at the time of the accident, his vehicle drifted uncontrollably into the opposite lane.

In *Codling*, facts of a specific defect were lacking, but the jury found circumstantial proof that an automobile's steering mechanism "was not fit for the purpose for which it was intended." It was not necessary that the *defect* be apparent when the car left the manufacturer's factory. The trial court acknowledged in its charge that the manufacturer could be held liable for a latent defect which later caused damage.

In 1983, the New York Court of Appeals had occasion to outline the elements of a defective product design case. In *Voss v. Black & Decker Mfr. Co.*, 59 N.Y.2d 102, 463 N.Y.S.2d 398, 450 N.E.2d 204 (1983), the plaintiff was using a circular power saw to cut two-by-four boards which had been set upon sawhorses. While making a cut across one of the boards, the saw hit a knot which projected the saw upwards and then down on plaintiff's hand severing part of his thumb. According to the court, there was no dispute that the guard was operating properly, and that it closed as far as it could before the blade came in contact with the plaintiff's hand.

The *Voss* Complaint had alleged that defendant's saw was defectively designed because of excessive exposure of the saw blade. At trial, the plaintiff produced an expert to testify that it would have been easy to design an extended moveable guard which would have brought the saw in conformity with UL safety standards.

At the close of plaintiff's case, the trial court dismissed the strict liability cause of action asserting design defect. The Court of Appeals reversed and remitted the case for trial finding that plaintiff had, at minimum, presented a *prima facie* case in strict liability for design defect:

> "In order to establish a *prima facie* case in strict products liability for design defects, the plaintiff must show that the manufacturer breached its duty to market safe products when it marketed a product designed so that it was not reasonably safe and that the defective design was a substantial factor in causing plaintiff's injury.
>
> The plaintiff, of course, is under an obligation to present evidence that the product as designed was *not reasonably safe*, because there was a substantial likelihood of harm and it was feasible to design the product in a safer manner. The defendant manufacturer, on the other hand, may present evidence in opposition seeking to show that the product is a safe product–that is, one whose utility outweighs its risks when the product has been designed so that the risks are reduced to the greatest extent possible while retaining the product's inherent usefulness at an acceptable cost. . . The guestion for the jury, then, is whether after weighing the evidence and balancing the product's risks against its utility and cost, it can be concluded that the product as designed is *not reasonably safe*.

In balancing the risks inherent in the product, as designed, against its utility and cost, the jury may consider several factors. Those factors may include the following:

1. the utility of the product to the public as a whole and to the individual user;
2. the nature of the product–that is, the likelihood that it will cause injury;
3. the availability of a safer design;
4. the potential for designing and manufacturing the product so that it is safer but remains functional and reasonably priced;
5. the ability of the plaintiff to have avoided injury by careful use of the product;
6. the degree of awareness of the potential danger of the product which reasonably can be attributed to the plaintiff; and
7. the manufacturer's ability to spread any cost related to improving the safety of the design.

Id., 59 N.Y. 2d at 107-109, 463 N.Y. 2d at 402-403, 450 N.E. 2d 204, 208-209 (emphasis added and citations omitted).

Applying these standards to the facts in *Voss v. Black & Decker*, the Court of Appeals found simply that it should be a jury question whether the saw as designed and marketed was "not reasonably safe." The jury could consider plaintiff's testimony as to the extent of the exposed portion of the saw as well as plaintiff's expert's testimony that it did not meet minimum safety standards and his opinion that a safer saw could easily be built at a reasonable cost. Then, if the jury were to determine that the product was defective, the next question would be whether the defective design was a substantial factor causing plaintiff's injury.

Of course, if a subsequent modification were performed on the product by a third party which "work(ed) a substantial change in the condition in which the product was sold by destroying the functional utility of a key safety feature" which, in turn, was the proximate cause of the injury, then the original manufacturer of the product would not be liable. *Robinson v. Reed Prentice Div. of Package Machinery Co.*, 49 N.Y.2d 471, 481, 426 N.Y.S.2d 717, 721, 403 N.E.2d 440, 444 (1980).

Where safety guards are easily removable, however, and the versatility of the product is augmented when operated without the guarding, then it is a jury question whether the product as manufactured is "not reasonably safe". *See, e.g., Lopez v. Precision Paners. Inc.*, 107 A.D.2d 667 (2d Dep't), 484 N.Y.S.2d 585 (1985), *aff'd*, 67 N.Y.2d 871, 501 N.Y.S.2d 798, 492 N.E.2d 1214 (1986). The New York Court of Appeals has held:

> "a manufacturer is obligated to exercise that degree of care in his plan or design so as to avoid any unreasonable risk of harm to anyone who is likely to be exposed to the danger when the product is used in the manner for which the product was intended. . . as well as an unintended yet reasonably foreseeable use. . .
>
> What constitutes 'reasonable care'. . . involve(s) 'a balancing of the likelihood of harm, and the gravity of harm if it happens, against the burden of the precaution which would be effective to avoid the harm'."

Micallef v. Miehle Co., 39 N.Y.2d 376, 385-386, 384 N.Y.S.2d 115, 121, 348 N.E. 2d 571, 577-578 (1976) (citations omitted).

The plaintiff Micallef was employed as a printing-press operator assigned to operate a photo-offset press. While working on the press in January 1969, Micallef discovered that a foreign particle (a "hickie") had appeared on the plate, having the potential of causing a blemish or imperfect ion on the printed pages. He advised his supervisor that he would attempt to "chase the hickie" by using a piece of plastic to remove it from the high-speed cylinder. The plastic was drawn into the nip point between the plate cylinder and an ink-form roller, along with Micallef's hand.

The machine had no safety guards to prevent such a happening. Micallef testified that while his hand was trapped, he reached for a shut-off button but could not contact it because of its location. Micallef was aware of the danger of getting caught in the press by "chasing hickies" on a running press instead of shutting the press down first. It was an industry custom to do so, he testified, because once the press was stopped, it required at least three hours to resume printing. Although it was possible to have removed the hickie from the other side of the machine, such an approach would have increased the chances of scratching the plate.

In one expert's opinion, it would have been a good practice to have placed guards near the rollers where Micallef's hand entered the machine, since the danger of human contact was well known. Moreover, the expert claimed that at least three different types of guards were available which would not have impeded the practice of "chasing hickies," but would have protected employees.

In New York, "a manufacturer does not have the duty to design a product that is impossible to misuse or one whose safety features cannot be circumvented." *Amatulli v. Delhi Construction Corp.*, 156 A.D.2d 500 (2d Dep't), 548 N.Y.S.2d 774, 776 (1989), *aff'd*, 77 N.Y.2d 525, 569 N.Y.S.2d 337, 571 N.E. 2d 645 (1991). Manufacturers are under a duty to provide adequate warnings. Inadequate warnings alone can make a product "not reasonably safe" and, therefore, defective. In New York, "where the theory of liability is failure to warn, negligence and strict liability are equivalent", *Wolfgruber v. Upjohn Co.*, 72 A.D.2d 59, 62 (4th Dep't), 423 N.Y.S.2d 95, 97 (1979), *aff'd*, 52 N.Y.2d 768, 436 N.Y.S.2d 614, 417 N.E.2d 1002 (1980). In a strict liability failure to warn case, however, the plaintiff need not prove scienter on the part of the defendant, *Lancaster Silo & Block Co. v. Northern Profane Gas Co.*, 75 A.D.2d 55, 64 (4th Dep't), 427 N.Y.S.2d 1009, 1015 (1980), and the reasonableness of the warning is usually a jury question. See *Johnson v. Johnson Chemical Co., Inc.*, 183 A.D.2d 64 (4th Dep't), 588 N.Y.S.2d 607 (1992) in which plaintiff's failure to read warning did not preclude jury question on adequacy of warnings.

In *Amatulli*, *supra*, an above-ground swimming pool had been installed partially in the ground by its owners contrary to the manufacturer's instructions. The installation concealed what was otherwise a "common-sense patent observation. . . equivalent to a warning" of the four-foot depth of the pool. *Id.*, 156 A.D.2d, 548 N.Y.S.2d at 776. The court found that the pool was not defective due to any absence of depth markings but that a trial would determine whether the distributors and owners were liable for negligent installation contrary to the manufacturer's instructions.

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