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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

LOW-COST AUTOMATION FOR THE FURNITURE AND JOINERY INDUSTRY

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna

LOW-COST AUTOMATION FOR THE FURNITURE AND JOINERY INDUSTRY

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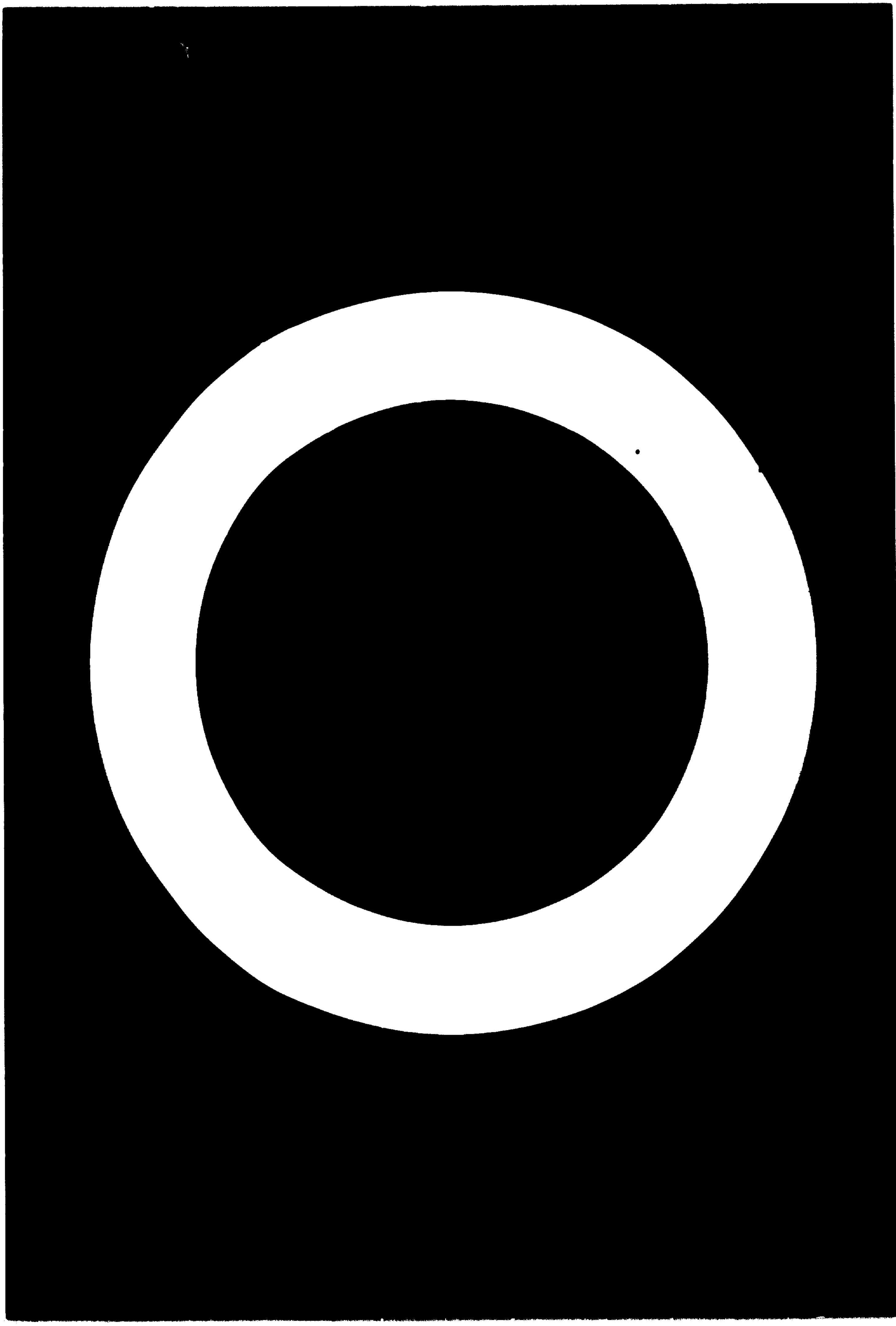
Preface

One of the most pressing needs of the furniture and joinery industry in developing countries is to be able to modernize their equipment and methods to meet demand and competition effectively. These must be met by better product quality, lower production cost, higher output (e.g., for the export market) and higher skilled-labour productivity. To compete, new techniques must be adapted, but, at the same time, capital expenditures must be limited in most of these countries.

Low-cost automation (LCA) can help solve those problems. Ordinarily, the term "automation" connotes highly sophisticated gadgetry, electronic controls, computerized programming and, to the discouragement of small and medium-sized furniture and joinery firms, huge costs. It is hoped that this manual will correct those misconceptions. It is also the aim of this manual to show furniture and joinery companies that they can gain the benefits of automation in their present factories at a relatively low cost and that that automation can be installed by their own personnel, usually on their present woodworking machines.

The arrangement of the material is such that chapters I, II, III and perhaps IV will probably be of greater interest to managers, and chapters IV, V and VI will be most useful to technicians and engineers. Chapter VII will be of interest to all three categories, although from different points of view. The annexes provide an explanation of the symbols used in the many diagrams found in the text and a list of approximate prices of pneumatic components. A bibliography of the literature consulted in the preparation of the manual is provided for readers who want more detailed information.

The views and opinions expressed in this manual are those of the two Philippine authors who were entrusted by UNIDO with the task of preparing this manual: W. J. Santiano, a low-cost automation consultant, and H. P. Brion, a furniture and joinery industry consultant. They do not necessarily reflect the views of the secretariat of the United Nations Industrial Development Organization (UNIDO).



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I. What low-cost automation (LCA) means

Originally conceived in Europe in 1957, low-cost automation (LCA) was one of the factors that transformed Europe to a community of highly industrialized nations from an economy that was characterized by lack of skill, lack of capital and splintered markets. At that time, C. Linsky and R. de Groot, working through the Organization for European Economic Co-operation (now the Organisation for Economic Co-operation and Development (OECD)), developed a programme by which small and medium-sized industries could avail themselves of the advantages of automation enjoyed by large industries through the use of low-cost, standardized, simple and flexible equipment that they could afford to buy and could easily install.

The first national programme to disseminate LCA was set up in 1960 in the Netherlands to supplement that country's industrialization programme. The results showed that LCA could provide a large return for a small investment.

A. An extended definition of LCA

In the present age of industrialization, many entrepreneurs tend to think of automation in terms of the sophisticated machines they admire in the market but do not understand very well. They tend to downgrade their own machines, which may have already served them for years and which, if rejuvenated, could still serve them well for many more years.

Thousands of entrepreneurs either jump from a simple type of operation to a sophisticated, fully automatic operation, or take no step towards greater productivity through automation because acquisition of the machinery available in the market is not financially justifiable. LCA is a state of mind, a concept and a discipline wherein one proceeds to arrive at a higher degree of technological level of operation. That is, one looks at the area "in-between" the area of "compromise", or the "gray area" of a possible improvement. LCA fills precisely that area (fig. 1).

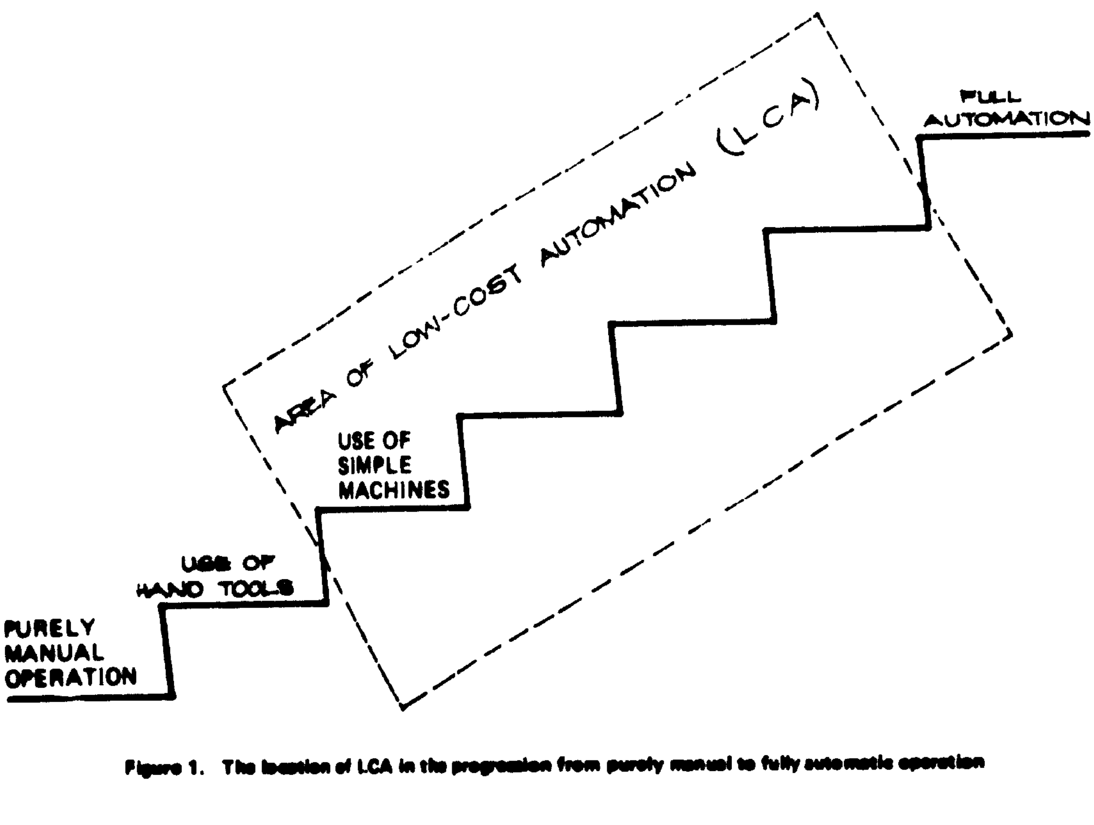


Figure 1. The location of LCA in the progression from purely manual to fully automatic operation

B. Why LCA is low-cost

LCA is low-cost (as distinguished from cheap) because in using the concept, one takes into account the financial and other capabilities of the firm and which aspect of its operation really needs automation so that the firm can achieve, not "perfection", but a significant partial advantage. In other words, in applying LCA, one does not strive to mechanize as many human tasks as possible, but only those whose mechanization is needed at the time.

Since LCA is a relative concept, it is pertinent to compare the costs of complete automation with those of "in-between" automation. The comparison, shown in figure 2, reveals the essence of LCA. In the lower degrees of automation, up to about 65 per cent, one gets more automation per unit of cost. As a general rule, therefore, a firm must try to limit the progress towards full automation to that which it really needs and can economically justify.

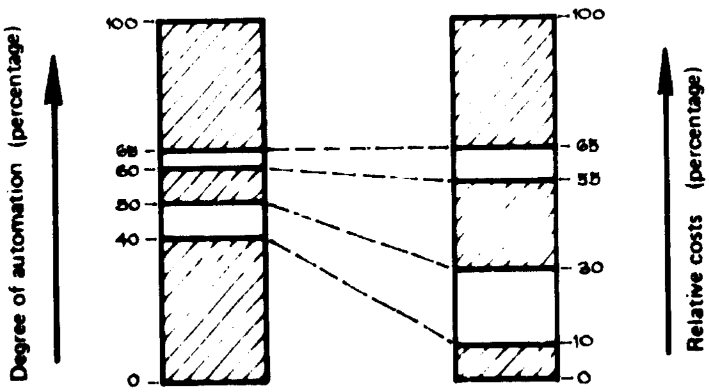


Figure 2. Relative cost of partial automation

A small or medium-sized furniture manufacturer, for example, starting with hand tools, could graduate to the use of jigs, next to the purchase of simple power tools and then, depending on need, to putting attachments on the power tools to make them more self-acting. The manufacturing process thus becomes gradually more sophisticated without at any time surpassing the cash limitations of planned investments.

Another factor that greatly influences costs is the choice of equipment. Some equipment is so expensive because it is developed for a specific purpose; the buyer therefore pays much more for the indirect than for the direct cost of its manufacture. Also, most automatic machinery is built for a limited market; the development cost of that machinery is shared by only a few buyers, and the cost per buyer must be higher. Moreover, when there are only a few buyers, such machines are more likely to be produced on a custom-built, rather than on a mass-production, basis. The cost of equipment is directly proportional to its "custom-builtness". Therefore, one should choose the standard items offered in the market whenever possible.

The question is, what is a standard item? A standard item is a component or a combination of components that can be bought off the shelf, usually by ordering it from the manufacturer's catalogue. Such items are so widely used for many unrelated purposes that the manufacturer just keeps on producing them, and most distributors carry them in stock. A standard item is never made to fit a purchaser's specific needs, nor does the purchaser have to specify his exact requirement before the supplier is able to provide the item. For example, it is not necessary for the purchaser to specify a nut and bolt according to a drawing. As long as he is satisfied with the normal specifications for bolts (standard pitches and diameters), he can get them at low prices almost everywhere. But a purchaser who wants, say, a bolt with left-hand threads must be prepared to pay more for it, since a standard bolt has right-hand threads.

The designer of an LCA project should try to choose the most readily available standardized components that will serve the purpose. If a given standard item does not suit, he should look for one with greater specificity, but then stop his search when the desired specificity has been found. The designer should also realize that there are many ways of combining standard items to make equipment that is quite specific in function. Finding ways to use standard items is not so difficult as it sounds; since LCA is mainly a kind of compromise automation and since standard equipment is designed as a compromise, that is, to be almost all-encompassing in its range of application, there is an ideal marriage between the two.

Some of the standard components often used in LCA are listed below.

Pneumatic and hydraulic equipment

Energy converters: pumps, compressors, motors, cylinders, pressure intensifiers

Controllers: directional control valves, check valves, pressure control valves, shut-off valves

Auxiliary equipment: flow lines and connexions, reservoirs, filters, lubricators, heat exchangers, mufflers

Electrical equipment

Energy converters: motors, pull (or push) electromagnets, rotary solenoids

Controllers: limit switches; various types of relays, such as latch relays, time-delay relays, over-load relays etc.; timers (synchronous motor, bi-metal, clock, fluid etc.); programming units or logic blocks; pressure switches

The above-mentioned components are widely available in the market. They can be combined with each other or with other systems to achieve what is desired.

Another factor that makes most automatic systems so expensive is their sophistication. The LCA designer tries to keep things as technically simple as possible by designing for only the most necessary improvements and adapting simple, available tools to make them. Instead of striving for perfection in the sense of minute precision, he is content to approach the precision required and leave the rest to the human operators of the equipment. That does not mean that precision is out of the question as far as LCA is concerned; the tools or techniques commonly used in LCA can be as effective as the special equipment of normal high-cost automation in certain cases.

It is true that automation means a reduction in flexibility. Loss of flexibility can be very costly in certain cases. But LCA, because it is a compromise, can minimize this loss of flexibility. Not everything need be programmed into a machine in LCA; the flexibility inherent in a human being can be used in consonance with mechanization.

Another advantage of LCA associated with flexibility is compatibility. For example, suppose that in an LCA project components are bought and installed on a cross-cut power saw to increase its production. Once the need for the cross-cut saw has diminished, the same standard components may be detached from it and installed to power a feeding mechanism on a planer.

Basically, LCA is low-cost in most cases because it is unsophisticated in a sophisticated age. Because he builds from what is initially present, the engineer applying LCA is not distracted by the market's new offers. He strives to design an automated system that uses standard, reusable components in a simple, flexible way.

II. What low-cost automation can improve

Low-cost automation can bring about improvement in the following:

- Product quality
- Labour utilization
- Utilization of materials
- Utilization of equipment already in use
- Safety

The improvements lead directly to increases in production capacity and competitiveness, and to reductions in manufacturing costs.

A. Product quality

Normally, the human factor leads to quality problems that are extremely difficult to solve. Workers, even though skilled, tend to get tired, careless, or distracted and thereby adversely affect the output quality. LCA, by reducing human interference in an operation to that level which is just necessary and sufficient, can therefore be a great step towards quality improvement. LCA can be usefully applied even in materials handling operations, where much quality damage occurs.

The point can be illustrated by two examples of how one furniture manufacture solved quality problems through LCA.

The newly sprayed surfaces of chairs were being frequently damaged by handling during transportation from the spray booths to the finishing area, 8 metres (26 feet) away. To solve the problem, the manufacturer built a simple conveyor from wood, bicycle parts, old sandpaper belts and pneumatic components. Figure 3 is a pictorial representation of the device.[1] After placing a chair on the conveyor, the spray-booth operator actuated the foot-operated valve, which made an air cylinder move the conveyor far enough to make room for the next chair. The chairs were thus gradually moved to the finishing department, arriving there dry and without having been touched by anyone.

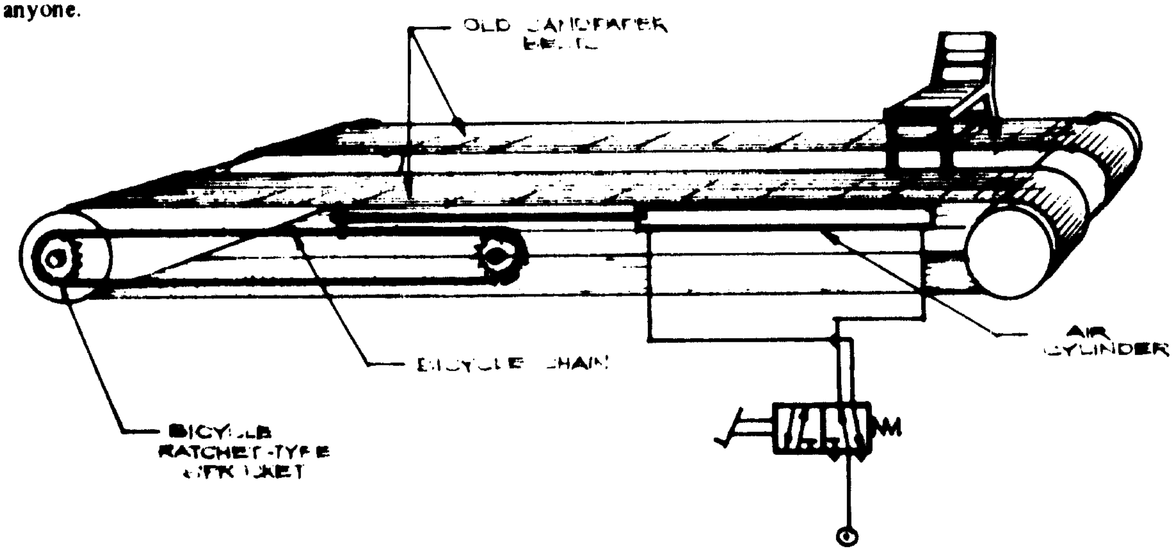


Figure 3. Chair conveyor system

[1] The pneumatic circuit, however, is shown schematically. Explanations of the symbols used in this and subsequent figures are in chapter VI and annex I.

The cost of the project was about $50.[2]

In the same furniture shop, chairs had to be manipulated by hand by the upholsterers as they worked on them. The activity was time-consuming and tiring and the quality of the upholstering gradually deteriorated during the working day because of the workers' fatigue.

The problem was solved by making a C-shaped manipulator that held the chair while it was being upholstered. Figure 4 shows how the manipulator worked. Cylinder A, actuated by a lever-operated valve, clamped or unclamped the chair. While clamped, the chair could still be rotated about the cylinder axis. Cylinder B, actuated by a foot-operated spring-returned valve, held the C-frame in place after it had been rotated on its axle. The operator could now place and hold the chair in any desired position without much effort. Using a pneumatic stapling gun, he could pay full attention to performing a good quality upholstering job.

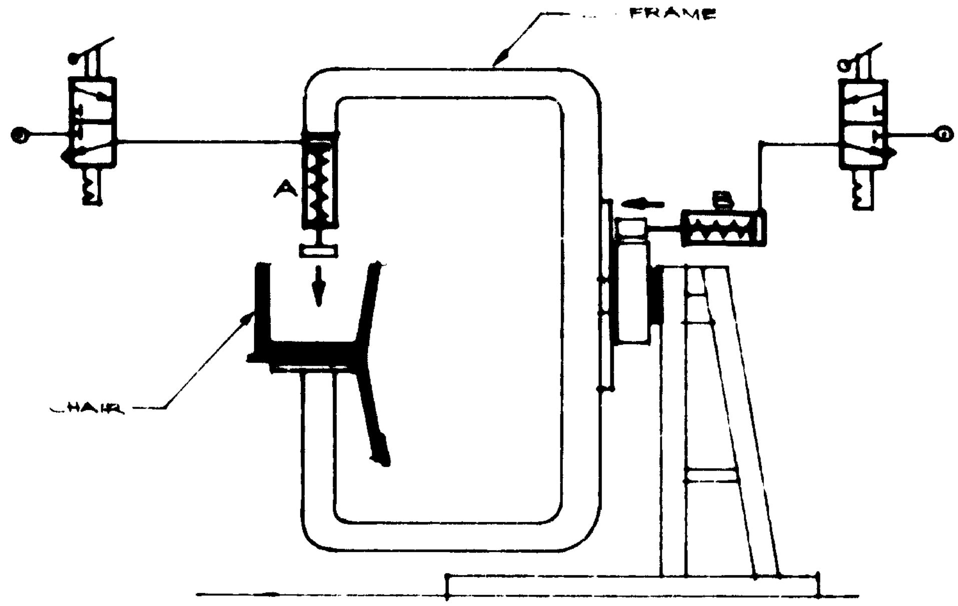


Figure 4. Chair manipulator

The manipulator, which cost approximately $140, besides solving the quality problem, also permitted a three-fold increase in production capacity.

Other examples of quality enhancement through LCA can be found in chapter VII, sections A, H, K, M, N, O, P and Q.

B. Utilization of labour

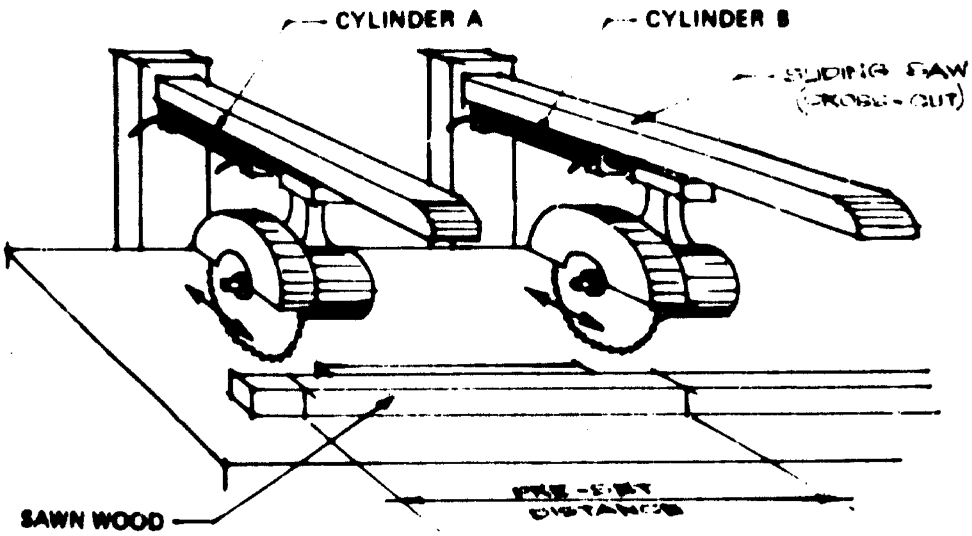
In many furniture shops, skilled workers are underutilized. That is, they spend 40-60 per cent of their time performing activities that do not require their valuable skills. On the other hand, the many unskilled or semi-skilled workers who could do those tasks cannot be employed because the manufacturers cannot fit them into the production process. LCA can be an effective way of correcting this anomaly, as shown by the following example.

In a joinery shop, sawn wood was being cut into standard lengths. In the cutting operation, special attention was given to the dimension and quality of cut, since a slight mistake might mean either scrapping the component or an expensive and time-consuming reworking in the assembling area. To ensure a perfect cut, the operator had to double-measure the cutting points and make sure that the guide jig was perfectly clean.

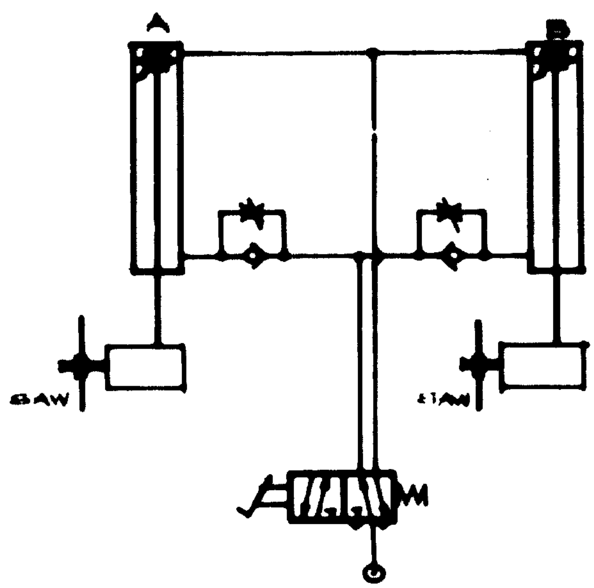
In the LCA solution, use was made of two sliding cross-cut saws located a definite distance apart. The cross-cut saws were already available in the plant. Figure 5*(a)* shows how the two sliding saws were provided with air cylinders, and figure 5*(b)* is a schematic diagram of the pneumatic circuit. When the foot-operated, spring-returned valve was actuated, the cylinders pushed the saws forward to make a cut of definite length. This device could produce cuts of the same quality as those produced by a skilled worker—but a semi-skilled worker (earning 20 per cent less than a skilled worker) could operate it. All he had to do was locate and hold the wood and press the valve with his foot. A further bonus was that a cost savings of $10 per week was realized because there were fewer rejects.

The cost of the components for the project was $100.

[2] Reference to dollars ($) indicates United States dollars.



(a) Pictorial representation of set-up



(b) Schematic diagram of pneumatic circuit

Figure 5. LCA set-up for cutting sawn wood to length

C. Utilization of materials

Usually, more materials than are really necessary are used in a factory because of the need to provide an allowance for waste caused by inaccuracies or mistakes. In a furniture factory, for example, more sawn wood is used at the start, because adjustments may be necessary later. Again, in painting and varnishing, an item is usually over-sprayed to ensure that every part of it is covered. Even so, finishing touches must sometimes be added later. The same is true in gluing operations.

Since LCA can control operations of this sort to a very close tolerance, materials utilization can be optimized, through its use. An example of how savings in varnish were achieved is shown in the experience of a table manufacturer in whose shop table tops were being sprayed with varnish manually with a spray gun. Since the operators were not skilled enough, more varnish than necessary was used; 20-30 per cent was actually being wasted.

Figure 6 shows how LCA was used in this case. A table top was placed on the roller platform in a vertical position and the system started. Cylinder A began oscillating the spray gun connected to it. Meanwhile, valve S opened the air supply to the spray gun to form the spray. As the spray gun oscillated, cylinder B slowly moved the table top along until all of its surface had been sprayed. Then, automatically, everything stopped and all the cylinders returned to their rest positions.

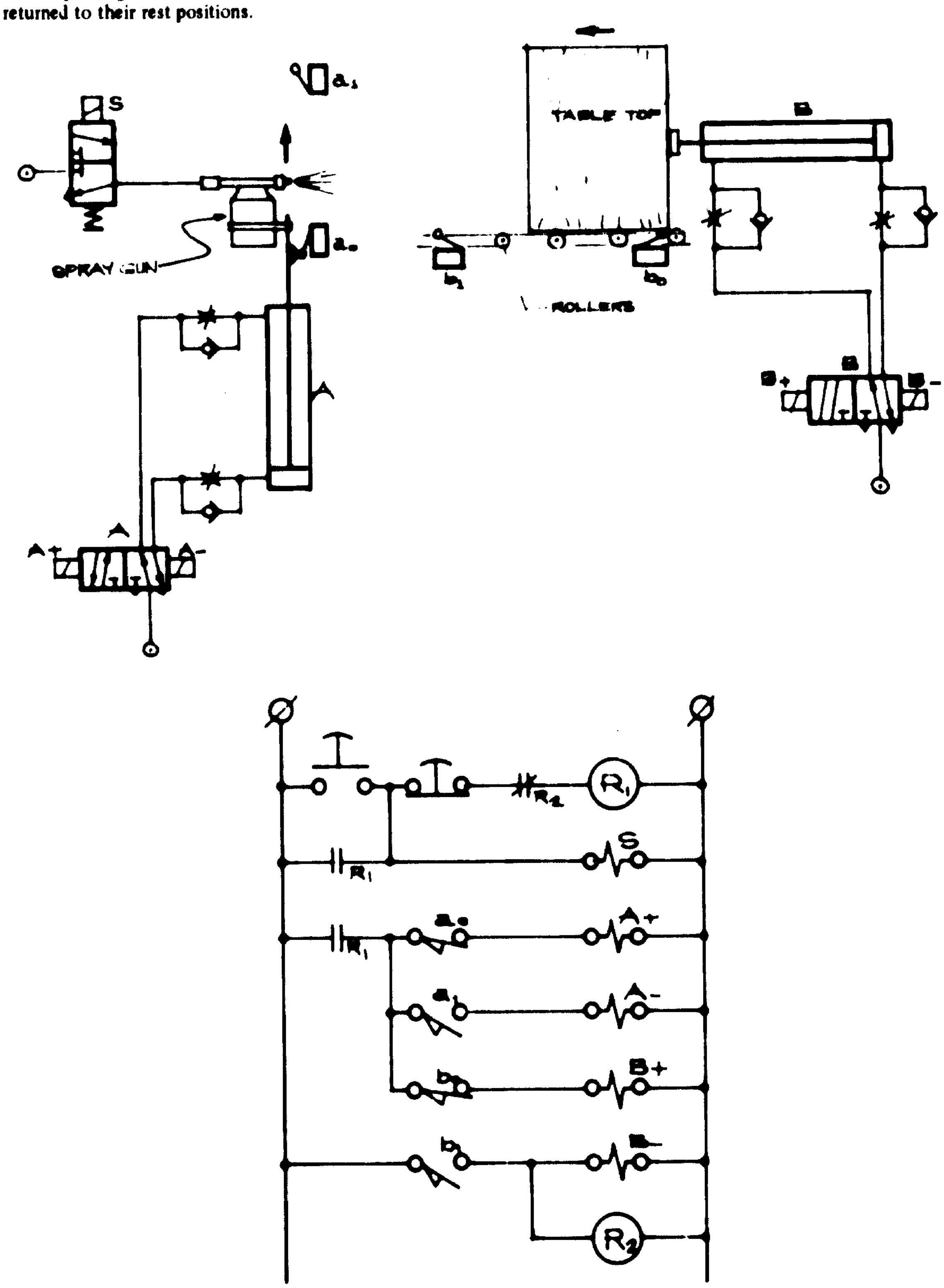


Figure 6. Automatic panel sprayer

The cost of the project was approximately $220, which was recovered through the savings in varnish (15 per cent) in 8 months.

Other examples resulting in materials savings through LCA can be found in chapter VII, sections M and P.

D. Utilization of equipment already in use

Relatively expensive machines, such as tenoners and dovetailers, are frequently underutilized because of the time that has to be spent in operations not consisting directly of machining the wood. For example, a time-study of a tenoning operation might very well show that the tenoner is idle 30 per cent of the time because the operator has to clamp and unclamp the workpiece by hand.

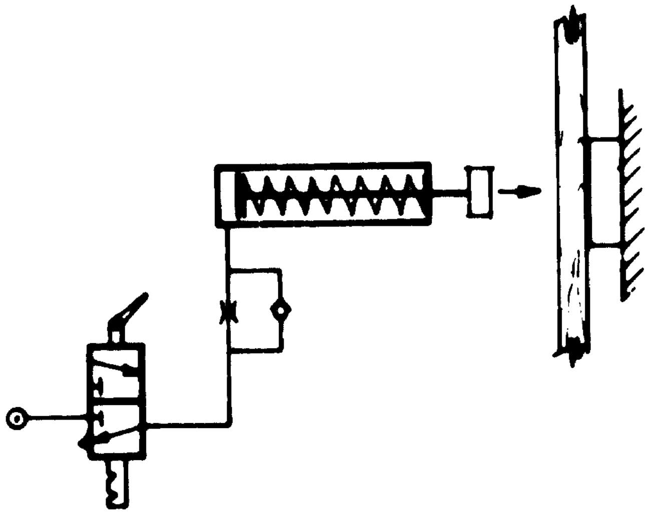


Figure 7. Pneumatic clamp

By simply making use of a pneumatic clamp (fig. 7), at least a 20 per cent increase in equipment utilization can be achieved. The cost of the circuit shown in the figure is approximately $40.

The utilization of a four-side moulder can be increased by using a power feeder (a standard item). An example of a feeding mechanism for a thicknesser is in chapter VII, section F.

E. Safety

In many cases, safety can be improved by means of LCA. Equipment and process can be so designed that it is practically impossible for an operator to feed workpieces into a machine improperly and so risk an accident. In such a design, the operator's role is reduced to ensuring that a feeder is loaded and the equipment is running properly; it is up to the LCA set-up to perform the unsafe functions. For example, in feeding a stationary, electrically driven cross-cut saw, the circuit in figure 8 can be used instead of a stick pusher to feed relatively small materials.

In the circuit, when the manual button is depressed, the cylinder will go forward and retract. When the automatic valve is switched on, the cylinder piston will continuously oscillate and keep feeding the contents of the magazine until the valve lever is switched off. This set-up ensures safety in feeding, because the operator's hands are only involved in depressing switches, moving levers and feeding the magazine.

The cost of the components in figure 8 would come to approximately $80.

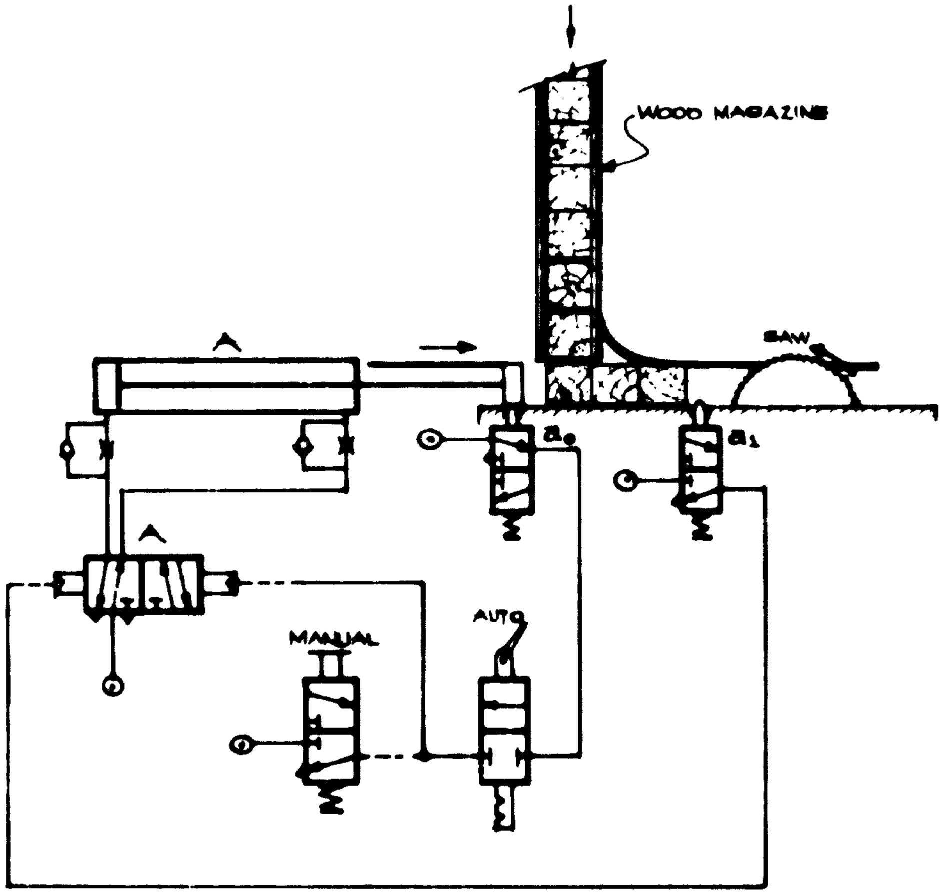


Figure 8. Table-saw feeder

III. Analysing the need for low-cost automation

A. The manager's viewpoint

It is clear from the examples in the preceding chapter that LCA can enhance the competitiveness of a firm by increasing production while at the same time decreasing the cost of production. Managers of furniture and joinery shops may waste no time in getting started on LCA projects. They should, however, first consider these factors:

Economic considerations
Technical prerequisites
Personnel requirements
Capabilities of management

Economic considerations

A basic principle of any change in a production process is that the benefits gained in introducing it should outweigh the cost and this applies also to LCA. Of course, sometimes a project may be more costly compared to the savings a firm might derive from it. The project may be implemented nevertheless because of the improvements in quality or safety that will result, which of course are benefits, too. In any case, whether the reason for automating is safety, quality or economy, knowing the relative cost of proposed projects is still important in deciding which to choose.

Assuming that the decision to automate will be based entirely on cost, the following formula can be used to determine the maximum investment a firm should make in a given project.

$$I = \left[\frac{nN}{1 + \frac{i}{200}(n+1)} \right] \left[\left(\frac{Q_2}{Q_1} - 1 \right) \left(m + w\left(1 + \frac{p}{100}\right) + V_1 \right) + V_1 - V_2 \right]$$

I = maximum allowable investment
i = current interest rate on money (per cent per annum)
n = depreciation period (years)
N = number of operating hours per year
Q_1 = hourly output before LCA
Q_2 = hourly output after LCA
m = fixed hourly machine cost including overhead
w = direct hourly wages
p = proportion of indirect labour cost (percentage of w)
V_1 = variable hourly machine cost at output Q_1
V_2 = variable hourly machine cost at output Q_2

Technical prerequisites

If a firm merely adopts, instead of adapting, automation, production could go down instead of up, especially if personnel are simply not ready for any relatively sophisticated automated process. For example, operators who do not know how to use a machine may damage it. Or, in case of a breakdown, maintenance personnel may not know how to put equipment into proper operation again.

Personnel requirements

The introduction of automation in a plant will cause these changes in the qualitative and quantitative requirements for the technical personnel:

Function	*Number of employees*	*Skill required*
Direct production	fewer	lower
Maintenance	more	higher
Transport	fewer	higher
Engineering	more	higher

Capabilities of management

The management of a plant wishing to introduce automation may have to be improved. If the management of a plant is in a "mess" before automation is introduced, it will have an "automated mess" afterwards. In other words, automation *per se* does not produce any management miracles; on the contrary, it may require some. The increased productivity brought about by automation brings with it a greater demand for materials, more complicated scheduling, more precise technical requirements (e.g. dimensional control) etc. If the management cannot cope with these more complicated interrelationships, it is better to postpone going to any higher degree of automation. A company with weak management must start with the simplest type of automation and progress slowly to more sophisticated types as its management capabilities improve.

B. The engineer's viewpoint

If an engineer were asked to automate a particular process, what would be his first step? Immediately design a system that imitated all of the actions of the present operator of the process? Emphatically, no. The first step would be to analyse the need for automation, i.e., determine the exact degree of automation the company really needed in that process and proceed accordingly.

If the company wants to increase total output, the operation to automate is the one that is the bottle-neck in production. The analysis will disclose whether the operation under consideration is the real bottle-neck. If, for example, the operation shows a backlog of units at its input, it may be the bottle-neck only because of, say, faulty scheduling procedures, in which case it would be foolish to automate it. There are times when an apparent need to automate disappears when the principles of good production planning and control are implemented.

Sometimes, a mere simplification of production techniques through methods (or work) study can serve just as well as, if not better than, automation, as the example below will show.

Wooden legs for beds were being made by turning a rectangular block of wood to a tapered profile and then drilling a hole from one end to the other. It was important that the hole be well centred, but it was proving extremely difficult to achieve. Management wanted to automate the drilling operation. In studying the process, the engineer assigned to the task found that the company used a wood lathe for the drilling operation. Drilling *per se* was easy. What was difficult was keeping the drill-bit centred. After some study and deliberation, the engineer recommended that the operator should drill the hole first and round off the block afterwards. When that was done, the difficulties vanished; there was no need to increase the level of automation. (See fig. 9.)

In the preceding example the need to automate was eliminated by process simplification. It can also be achieved by product simplification through value analysis, usually by simple redesign. For example, there is no need to automate the process of making a certain part if the final product can be redesigned to accommodate a similar part that can be purchased cheaply in the market. Or, if a certain critical design tolerance can be increased without reducing product quality, any automation problem involving that tolerance will at least be easier to solve, if not eliminated. Actually, if the design of the parts or of the whole of the product can be simplified for the sake of automation, the design may be ripe for revision anyway.

Figure 10 illustrates the results of a value analysis that led to product simplification. The cross-members in chair back-rests were being tenoned to fit into routed holes in the upright members. Since accurate tenoning was quite difficult, the manager was thinking of going to a great deal of trouble to automate the process. However, value analysis revealed that the process, and with it the task of automating it, could be simplified if the routed holes in the uprights were enlarged so that tenoning would no longer be required. All that was necessary was to control the depth of routing and the length of the cross-members, something easily done by LCA.

In other words, the engineer, after having decided to automate, tries to simplify his own job without running away from it. And having satisfied himself that there is indeed a need to automate a process, the engineer makes sure that automation is feasible.

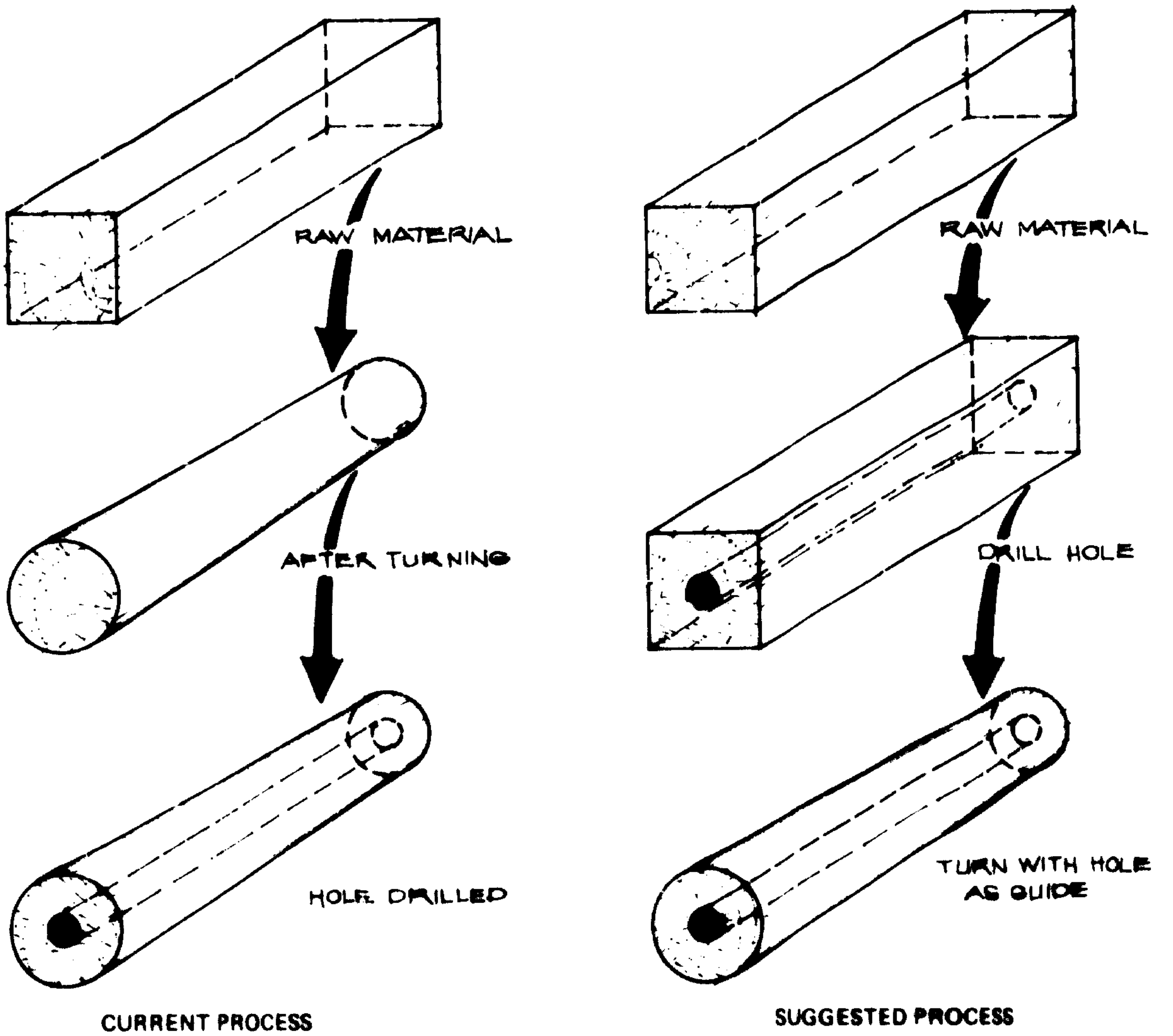


Figure 9. Comparison of process for making wooden legs for a bed. The suggested process produced accurately central holes with far less difficulty than the current process and eliminated any need for automation

Sometimes, a product line will have to be standardized. Automation brings with it a certain loss of flexibility that makes it impractical in the face of great variety. For example, it would be difficult and expensive to build an automatic system that would assemble 20 different types of chairs. There must be a compromise in the sense that only a few types (or sizes) of chairs will be made. On the other hand, there may be some operations that are the same for all of them. Those operations can certainly be automated.

After the need and possibility to automate a process (not necessarily the original one considered) is established, time study of the process should be made. The job is analysed into its elements and the time involved in each is recorded, so that those which take the most time can be determined. On the basis of this time study, the engineer may choose to automate only the most time-consuming element, or to combine some of the elements through automation. Only then does he finally proceed with the design of the LCA system.

In designing, the engineer should consider the safety, cost and other operational aspects of the project. Also, since he is using the current situation as a foundation, he must understand this situation well and how the proposed modification of it will affect the entire company. Any engineer that is able to do all of that will have a knowledge of many disciplines and command a correspondingly high fee for his services.

It is important that a company that has engaged an engineer to design an LCA system should receive from him complete instructions on how to operate the new equipment and copies of all plans necessary for its proper maintenance.

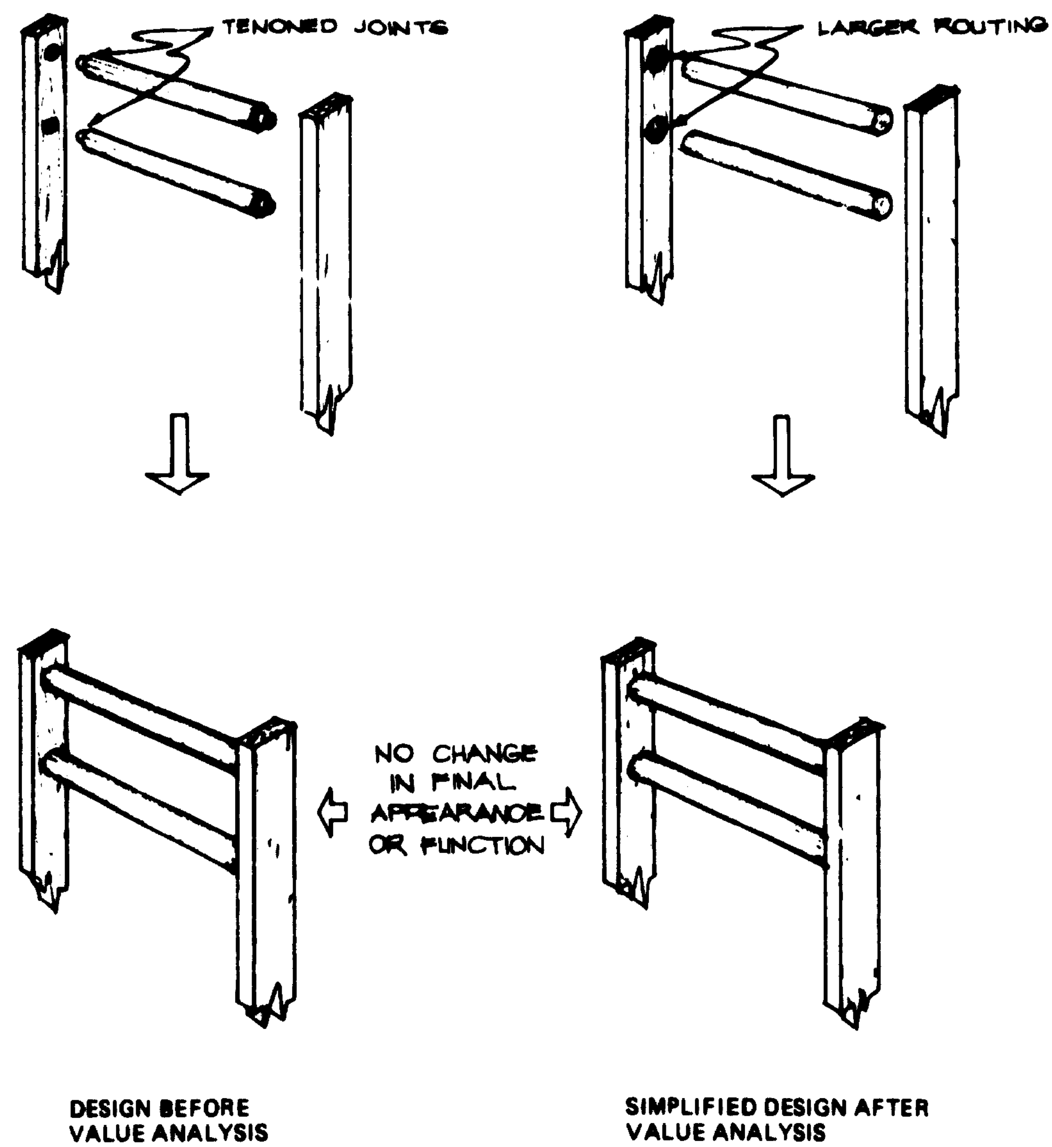


Figure 10. Product simplification by value analysis

C. An actual example of the analytical approach to LCA

Because of a government housing programme, a joinery factory could hardly keep up with the demand for window frames. The management foresaw that the company would soon not be able to keep up at all, even with three shifts per day. Moreover, there was a shortage of skilled workers. The management therefore organized a team of technicians and workers to find out how to avert loss of sales due to lack of output capacity.

In analysing the various processes in the factory, the team compiled the following data on the manual operations that affected output capacity most:

Operation	*Output capacity (frames per day)*	*Unit labour cost (dollars per frame)*
Cutting	22	0.04
Tenoning	5	0.40
Mortising	12	0.10
Assembly	16	0.06

It was at once obvious that the tenoning operation was not only a bottle-neck, it was also the most expensive operation on the list. A concerted effort was launched to improve the tenoning operation.

After more study, the team had three plans for action from which to choose:

1. Design and install jigs and fixtures
   Capacity increase 20 per cent
   Cost $6.00

2. Buy a tenoning machine
   Capacity increase 800 per cent
   Total fixed cost for machine $200 per year
   Total variable cost for labour, maintenance and power $0.09 per frame

3. Subcontract the tenoning operation
   Cost (for up to 200 frames per day) $0.08 per frame

Plan 1 was not attractive; although there would have been some improvement, the operation would still have been a bottle-neck. Plan 2 was definitely tempting; since the company priced the tenoning operation at $0.89 per frame, the break-even volume for the machine was 200/(0.89 0.09) = 250 frames per year, well below the anticipated volume. However, the initial cost of the machine ($1,000) would have adversely affected the cash requirements of the small company. Therefore, plan 3 was chosen; it meant that the bottle-neck could be eliminated with no fixed cash outlay and with lower operating costs.

With the tenoning bottle-neck out of the way, mortising was obviously the next target. This operation consisted of marking the wood for the size and location of the mortise and then chiselling it out by hand. Observing the two mortisers, the team judged that they were adequately skilled for the job. The problem was that even with highly skilled workers the job took too long. As a solution, it was decided to buy a second-hand drill press and equip it with a mortising tool. The drill press cost only $20, but mortising capacity was increased from 12 to 23 frames per day. The duties of the two mortisers were changed; one did the marking, the other the cutting.

The assembly operation became the next bottle-neck, which was relieved somewhat by installing a clamping device made of old fire-hose (see chapter VII, section A). Capacity increased from 16 to 21 frames per day.

The capacities of the cutting, mortising and assembly operations were now approximately equal and sufficient to meet the demand for the following three months. However, den and continued to increase rapidly. Hence, no time was lost in trying to find out l w to increase the capacities of assembly and mortising to 40 frames per day, the capacity that could be obtained in the cutting operation by the purchase of one sliding cross-cut saw. (There was no immediate problem with the tenoning operation, since the subcontractor could still provide 200 frames a day. However, it was planned to negotiate a long-term contract for this job.)

In a time study of the work of the operator of the mortising tool, the following time distribution was recorded:

	Percentage
Clamping and unclamping the work	60
Mortising on the drill press	20
Handling the work	20

It was obvious that the clamping operation was taking relatively too much time. Since the factory already had compressed-air facilities (for spraying), it was decided to use a pneumatic system for clamping. This solution increased capacity by about 40 per cent, to about 32 frames per day. Although that was still below the projected 40 frames per day, the solution gave the company more time to work on further increases.

At a later stage, the plant's technicians designed another LCA attachment for the old drill press that was being used as a mortiser: an air-over-oil system composed of an ordinary air cylinder coupled with an oil-checking cylinder (for feed control) to power the actual mortising operation. This solution finally increased the capacity to 40 frames per day. The increase was due mainly to the increased cutting speed. Details of the solution are given in chapter VII, sections G and H.

In the case of the assembly operation, where clamping was again the bottle-neck because of alignment problems, the scheme shown in chapter VII, section C, increased potential capacity to 104 frames per day.

A year after the start of the capacity improvement programme, it was again apparent that total capacity had to be doubled. Hence, more studies were required.

Starting again with the cutting operation, where introduction of the sliding cross-cut saw had begun the last round of capacity increases, an air cylinder was connected to the saw as in figure 5 (chap. II), to more than achieve the desired capacity.

In the mortising section, it was felt that the wood-handling operation was too time consuming and should also be automated. However, drastic changes on the former attachments had to be made and the old clamp dispensed with. On the other hand, the air cylinder on the clamp could still be used. By adapting the scheme in chapter VII, section I, mortising capacity was more than doubled.

D. General principles of need analysis

The example discussed in the preceding section illustrated the application of the following general precepts:

(a) Know what the costs are;

(b) Determine present conditions accurately;

(c) Study available choices;

(d) Make the choice that is most favourable in terms of operating advantages and cost;

(e) Improve operation step by step according to immediate needs and capability;

(f) Think in terms of improving present equipment instead of replacing it;

(g) Involve factory personnel in designing solutions.

E. Specific LCA needs of furniture and joinery industries

In investigating the need for LCA in small furniture and joinery industries, it is convenient to think in terms of discrete operations: material handling, positioning, clamping, machining and assembly.

Material handling

The mere handling of material does not increase the value of the product made from it; hence, the operations involved should be made as efficient as possible.

Feeding

Except for highly automated equipment, woodworking machines are normally fed manually. Manual feeding is inefficient because of the long time interval between the feeding of individual workpieces, i.e., the machines are underutilized. Also, manual feeding can do damage; e.g., the blade of a table saw can be ruined if feeding is not properly controlled. Feeding can usually be improved by the use of standard attachments, e.g., conveyors, air or oil cylinders, and electric power feeders.

Transporting

Transporting operations within factories are wasteful and should be avoided. If they cannot be avoided, conveyors or bulk carriers, such as pallets and bins, should be used.

Rotating and ejecting

Automatic rotation and ejection of the workpiece and automatic ejection of waste can increase the utilization of tenoners, mortisers, drills, moulders, planers, saws etc. without wasting the valuable time of skilled operators. Pneumatic equipment is particularly useful for this type of automatic operation.

Stacking

Stacking of machined products can be improved by LCA. The circuit for cylinder A of the example in chapter VII, section F, can be used for the purpose, if limit switch S is replaced by a normally closed switch.

Positioning

Since positioning the workpiece for machining must be done carefully, it is relatively time consuming. LCA can perform positioning functions, for example, in dowel-hole drilling, mortising, tenoning, routing and other operations where the woodworking tool is fed to the work. Positioning heavy pieces, as in upholstering operations, is also an area of application.

Clamping

Clamping by LCA can replace clamping by vices, even when the vices are used to hold the work for hand operations (e.g. carving). The result is faster and easier clamping. The time saved can be used for productive activities.

Machining

Equipment in which some components are operated manually can be supplemented by LCA. That not only reduces operator fatigue and increases capacity but also can lengthen the tool life and improve product quality by maintaining the correct rate of tool feed. LCA has found useful applications in sliding cross-cut saws, mortisers, routers (work-bed lifting) and borers.

It may be possible to design simpler and cheaper LCA versions of certain expensive machines. The upsetting machine in chapter VII, section G, is an example.

Assembling

Assembling operations can also be facilitated by LCA. Figure 4 (chap. II) shows an example.

IV. Basic devices for low-cost automation systems

The first means of increasing automaticity in furniture plants was the use of mechanical devices. Although the possibilities of using fluid pressure and electricity were realized, the lack of the required connecting technologies prevented the practical application of these means. The term "mechanization" is still used to describe the lower levels of automation.

With the development of technology, pneumatic, hydraulic, electrical and electronic devices for making processes more self-acting (more automatic) have become more widely available (fig. 11). By combining them, engineers are now able to design sophisticated systems that even include controls.

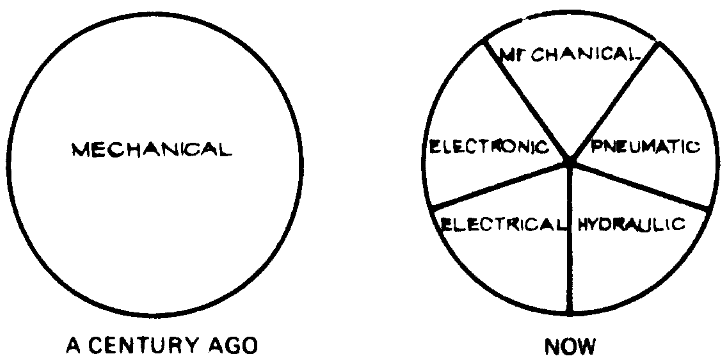


Figure 11. Types of devices available for automation

With the introduction of the new devices, new words were naturally coined. For example, the introduction of pneumatic systems gave rise to the word "pneumation", a combination of "pneumatic" and "automation".

In what follows, the operation of the following types of devices will be discussed in terms of their application to LCA:

Mechanical
Pneumatic
Hydraulic
Electrical
Electronic

The last named is used almost exclusively for control; the other types are used not only for control but also to provide work-performing motions. In following the discussion, the reader should bear in mind that such motions are combinations of these two basic motions: linear and rotary.

A. Mechanical devices

The basic mechanical device used in automation is the cam. It is used to control various motions of a machine. All the manual operations the moving of levers and turning of wheels according to a pattern are replaced by a unit consisting of a shaft with cams having different shapes or curves (fig. 12). The cams lift levers that move the different parts of the machine. In general, one revolution of the camshaft represents one complete cycle. By adjusting the speed of the camshaft, one obtains a certain number of cycles per unit of time. The shape of a cam determines at what speed and at what moment the particular action it controls takes place.

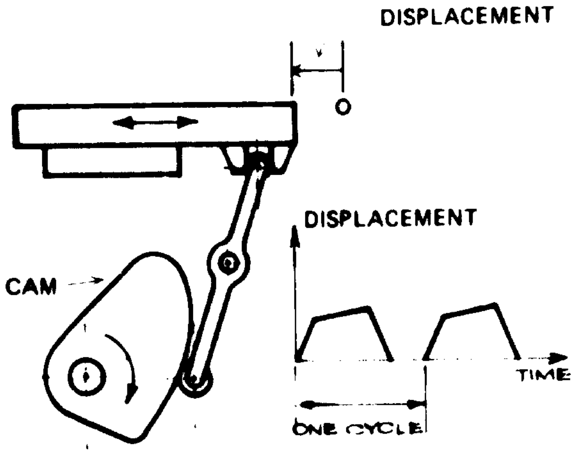


Figure 12. Mechanical cam steering

A construction like the one just described takes over the thinking and the work which human operators previously had to do. This type of purely mechanical machinery can still be found in some old tenoners and mortisers and in some new, low-cost machines. However, the basic method, called "control timing", does not have the possibilities now required for modern automatic units.

Figure 13 shows another mechanical device, the screw-and-nut mechanism frequently used in LCA systems to convert rotary to linear motion.

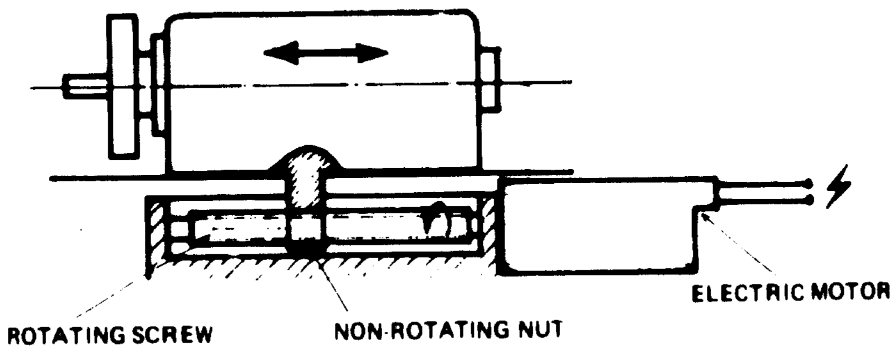


Figure 13. Conversion of rotary to linear movement

Mechanical systems have the following advantages:

(a) A high degree of reliability can be achieved;

(b) Excellent synchronization is possible;

(c) Maintenance of the equipment is fairly simple and can be done by the plant maintenance crew.

On the other hand, mechanical systems do have these disadvantages:

(a) Usually, the individual parts must be custom-designed. That requires a high degree of engineering skill;

(b) Generally, a mechanical set-up is not flexible; the program is often fixed and difficult to change;

(c) Replacing the "program" of a system is very costly, as parts are non-standard and may have to be custom-made;

(d) When devices that are far apart have to be interconnected, a mechanical system becomes too expensive. An example is the transmission of power by means of a long shaft;

(e) It is difficult to build into a mechanical system a way of checking whether any step in a program is done properly (as when a tool breaks).

Generally speaking, unless it is a case of improving existing mechanical equipment, any project involving mechanical systems for low-cost automation is frowned upon as being too difficult or too expensive. That does not mean, however, that it should not be adopted, if the expense can be justified.

B. Pneumatic devices

A back-and-forth movement can be easily arranged with a pneumatic cylinder (fig. 14), which is normally the cheapest solution, if applicable.

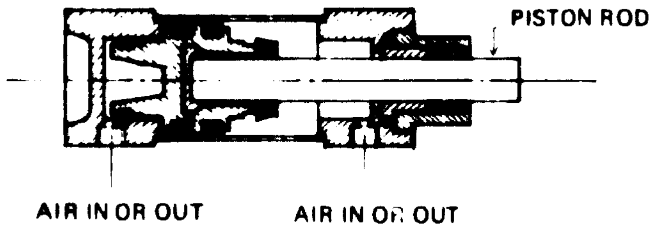


Figure 14. Double-acting air cylinder

Since a pneumatic cylinder is powered by air, which is compressible, piston speeds are difficult to control when they are low. For example, when the piston speed goes below approximately 75 mm/min (3 in./min), an uneven (pulsating) movement results. However, uneven piston movement can be counteracted by hydraulic damping, with which one can achieve a minimum constant speed of around 40 mm/min (1.6 in./min). The arrangement is shown in figure 15.

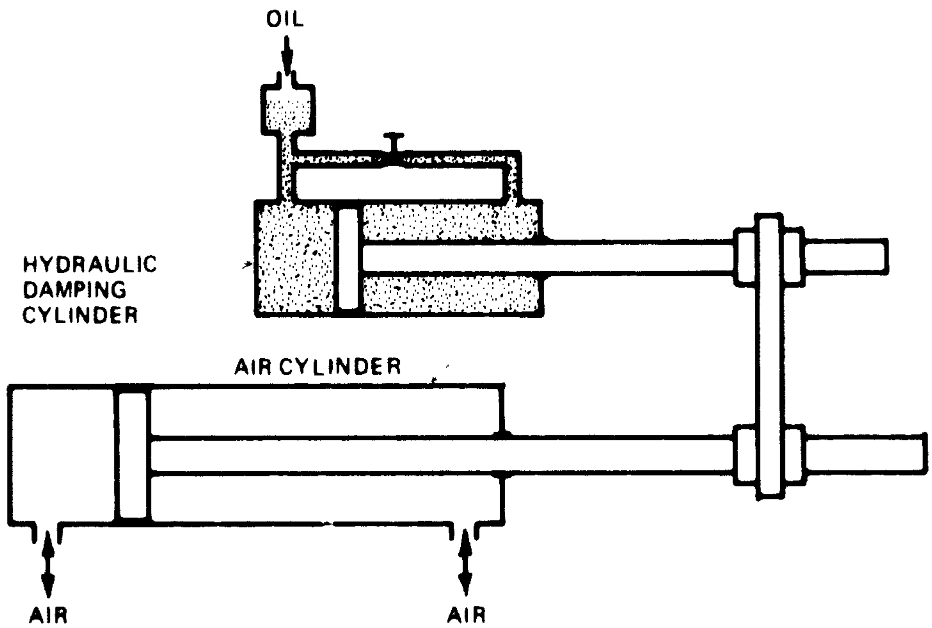


Figure 15. Double-acting air cylinder with parallel hydraulic damping cylinder

To control the back-and-forth movement of the piston, directional control valves supply compressed air to one side of the piston and then to the other, at the same time allowing the air to exhaust from the opposite side of the piston. The valve in figure 16 has either two or three distinct positions. The valve is placed in one or another position by manual, mechanical, electrical or pneumatic actuation, whichever is the most appropriate in a given situation.

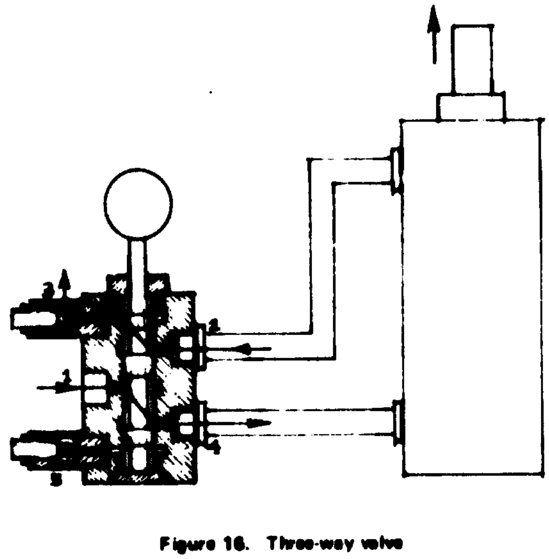


Figure 16. Three-way valve

An advantage offered by pneumatic equipment is the possibility of adjusting the speed simply by reducing the air flow through the exhaust port or air supply line. The first method yields more constant speeds. Sometimes, however, as with single-acting cylinders, it is impossible to use the exhaust line because there is none. Then the restriction has to be in the supply line. Another advantage is the possibility of setting and maintaining the pressure to the level required by a simple adjustment of the pressure regulator. For example, to obtain a force of a certain magnitude for clamping, a regulator set for that force is placed ahead of the cylinder, as in figure 17.

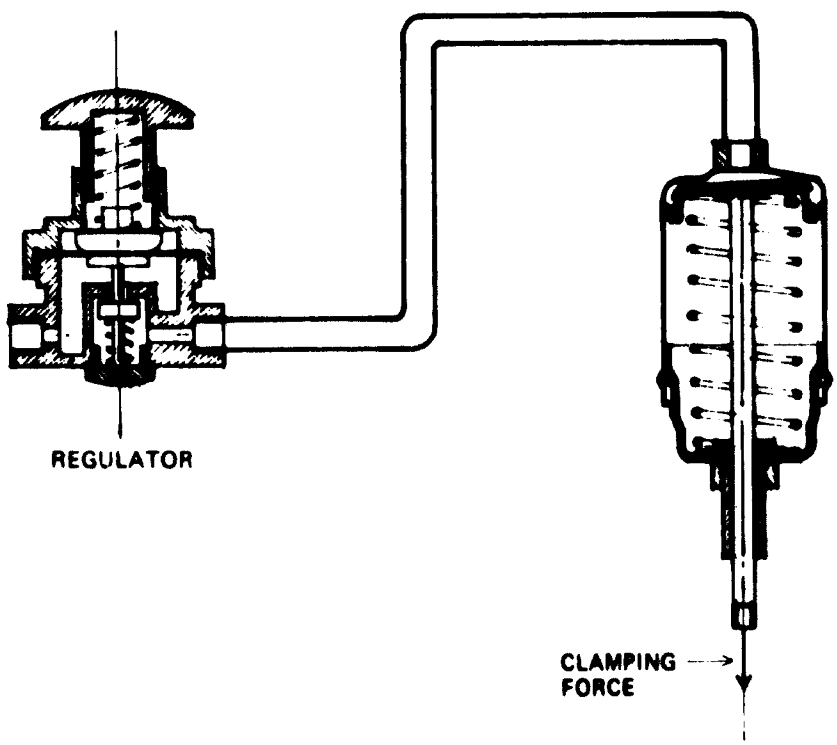


Figure 17. Single-acting thrust cylinder with pressure regulator for control of clamping force

So far, only pneumatic devices that produce linear motion have been described. For rotary motion, air motors, controlled by the same type of valves as described above, can be used. These are usually of the vane type or the piston type. In vane-type air motors, rotation of the shaft is achieved by the "turbine effect" of air on the vanes coupled to the shaft. Piston-type air motors are similar to combustion piston engines, but the source of power is compressed air instead of steam or internally combusted fuel.

A special group of pneumatic devices is represented by such pneumatic hand tools as drills, wrenches, nut-runners, screwdrivers and grinders. Compared with electrical hand tools, they have some distinct advantages:

(a) Pneumatic hand tools are more compact and lighter than electrical hand tools of the same power rating;

(b) Infinitely variable speed control is possible by varying the air supply. Torque, of course, will also vary;

(c) The hand tools can be overloaded and stalled without any risk of damage;

(d) Construction is simple and parts can be changed easily. Therefore, the equipment can be easily maintained.

Although nominal air consumption while running can be high, pneumatic hand tools usually consume little air when run intermittently. At an assembling station, for example, a pneumatic nut-runner may be run for only 2 sec in a 30-sec work cycle.

In summary, some of the advantages of pneumatic automation systems are:

(a) The set-up can be highly flexible;

(b) Forces can easily be controlled (by a pressure regulator);

(c) Compared to hydraulic systems, pneumatic piping is simpler (no return piping);

(d) The power source (compressed air) is relatively safe since line pressure is normally only 7-10 atm. However, the air reservoir may be subject to certain safety regulations;

(e) Compressed-air devices can be stalled without damaging them;

(f) Compressed air is easily piped to any point in the factory.

The disadvantages are:

(a) The compressibility of air can be a disadvantage when used in a system where the load is fluctuating and the speed desired should be fairly constant. As mentioned above, hydraulic damping must be used to alleviate this problem;

(b) As a source of energy, air is relatively expensive compared with hydraulic or electrical energy.

Because of the nature of its advantages, the pneumatic system is the one most commonly used in LCA projects.

C. Hydraulic devices

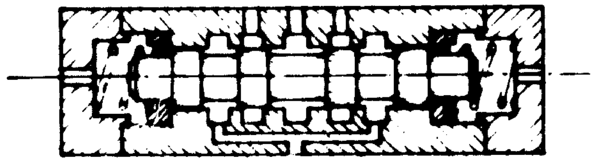
Hydraulic and pneumatic devices both utilize the pressure of a fluid: a liquid (oil) in hydraulic, a gas (air) in pneumatic, devices. However, oil and air are quite different, and so are the operating characteristics of the two kinds of device. Hydraulic cylinders are relatively smaller than pneumatic cylinders. Also, since oil is practically incompressible, hydraulic cylinders can be accurately controlled even at very low speeds.

Hydraulic systems require a special pump for supplying each unit with oil in adequate quantity and pressure. That can be a disadvantage of hydraulic systems compared with pneumatic ones, since the latter need only one compressor, no matter how many components there are in the system.

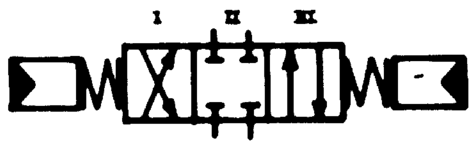
The devices used to get back-and-forth movement are also cylinders, as in the pneumatic case. The hydraulic cylinder is controlled by means of a directional control valve that allows oil to flow to either one side of the piston or the other. The directional control valve can be actuated in the same way as pneumatic valves. However, there are several essential differences. A hydraulic valve, for example, usually has more than two positions so that it can have several different flow-paths in the same valve. A three-position valve is shown in figure 18.

Another characteristic of hydraulic systems is that the oil that has been used to power a component is returned to a reservoir, whereas in pneumatics, the used air is allowed to escape into the atmosphere. Also, since the pressure is greater, hydraulic piping must fit more tightly and precisely. The same requirements are imposed on the working components themselves. Hydraulic piping and components are thus more complicated and expensive.

Speed regulation in a hydraulic system is accomplished, as in a pneumatic system, by inserting a device that reduces the flow through the ports to some constant value independent of variations in pressure (fig. 19). This method of regulation has the disadvantage that there is a relatively high energy loss because the pumping unit was designed for the high flow needed for high speeds. The bypassed fluid in these systems has to be carried back into the reservoir by means of a bypass valve. The heat generated in the valve has to be conducted away from the fluid reservoir.



CROSS-SECTIONAL DRAWING



SCHEMATIC SYMBOL

Figure 18. Three-position hydraulic valve

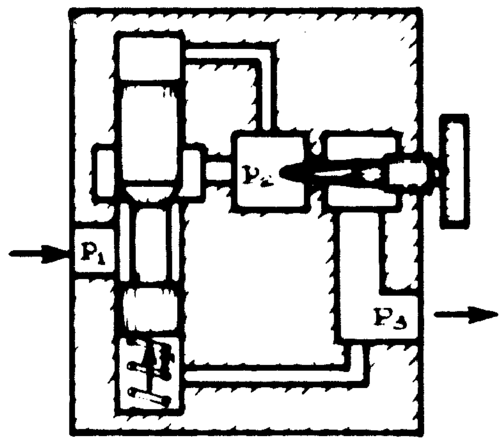


Figure 19. Hydraulic "constant flow" control valve

Another, but more expensive, possibility for speed regulation is to use a pump with variable displacement (fig. 20). This has the advantage that energy losses are much lower but the disadvantage that it is difficult to use one pump for more than one cylinder at a time, since the variation in oil consumption can be great.

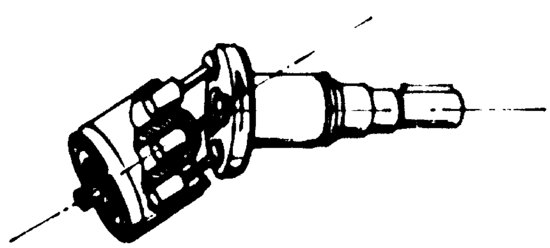


Figure 20. Hydraulic pump with variable displacement

In general, maintenance of hydraulic units is much more complicated than of pneumatics and can only be handled by special engineers.

To summarize, the advantages of a hydraulic system are:

(a) It is compact, yet can deliver large forces;

(b) Energy can be transmitted over long distances by means of piping;

(c) Since oil is the medium, a hydraulic system is self-lubricating;

(d) A high degree of flexibility is possible;

(e) It has the ability to absorb shock loads without loss of longevity;

(f) It can easily be provided with overload prevention devices;

(g) Infinitely variable speed control is possible;

(h) Speed can be controlled and loads positioned with high precision;

(i) Like a pneumatic system, it can easily be linked to electrical and electronic control systems;

(j) Operating cost is lower than with pneumatics.

The disadvantages are:

(a) It is more expensive to set up than a pneumatic system.

(b) It is more complicated to maintain and install.

D. Electrical devices

When the energy required by work-performing devices must be transmitted over considerable distances, an electrical system is, generally speaking, the cheapest choice. The best known work-performing electrical device, the electric motor, need only be connected to adequate mains.

The rotary motion of an electric motor has to be converted in some way if linear motion is desired. A common way is to use a screw-and-nut mechanism, as illustrated in figure 13. For short linear movements, a magnetic coil that moves an iron part, like the one in figure 21, can be used.

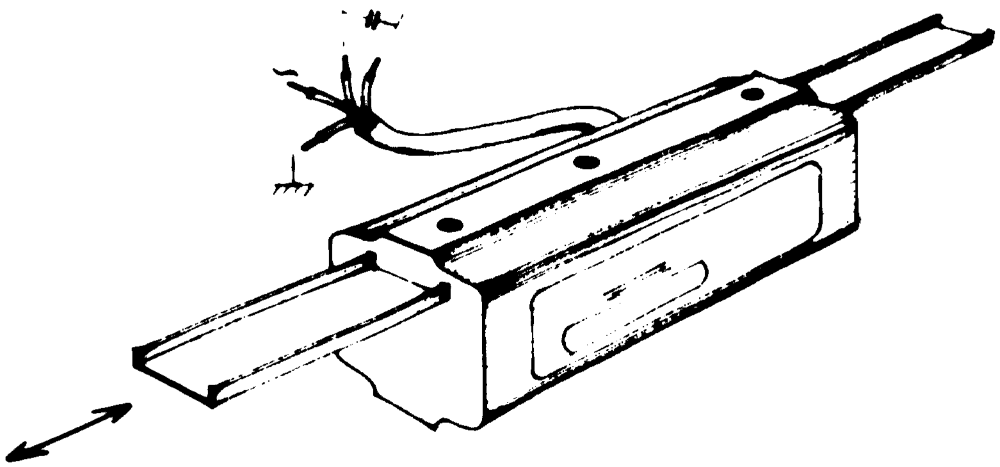


Figure 21. Magnetic coil for short linear movements

Regulating the speed of an electric motor is much more difficult than regulating the speed of a pneumatic or hydraulic system. The speed of an AC motor can be changed by varying the frequency of the alternating current, which needs a special and complicated set-up. Another method of changing the speed of an AC motor is by changing the number of its poles, which results in a stepped, rather than a continuous, variation.

The speed of a DC motor can be varied more easily, by means of varying the resistance. The method can provide continuous variation, but it is not necessarily a cheap solution. Nevertheless, DC motors have come into more use during the last decade for indirectly performing linear movements in special production equipment.

One disadvantage of motors is that they cannot be stalled for a prolonged period without damage.

An electric "cylinder" is available for small forces. It is a new development that permits delivery of a "non-moving" force without damaging the unit. But even here a pneumatic or hydraulic solution is cheaper.

The current to electrical devices is frequently controlled by a relay, an electro-mechanical device consisting of electrical contacts that are closed or opened by an electromagnet (fig. 22). There are many types available for different power loads and different contact arrangements. There are also special types, such as time-delay relays, pulse relays and step relays.

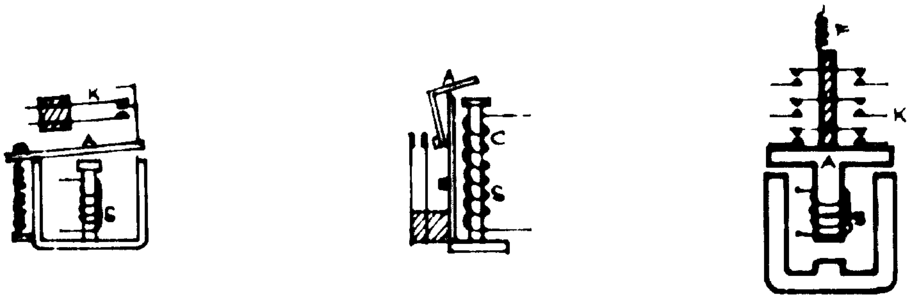


Figure 22. Electric relays

In electrical systems, resistors and capacitors can be made to serve the same functions as pneumatic restrictors and reservoirs, respectively.

Several types of electric switches and punch card readers are available for programming control systems. The switches, for example, can give signals at fixed time intervals (time control).

E. Electronic devices

Electronic devices and systems are mainly limited to controlling the actual work-performing devices, which are usually electric, pneumatic or hydraulic.

The best known electronic devices are radio transistors. However, another type, the switching transistor, is the chief type used in control systems. Like an ordinary switch, it has two states, open and closed, but it has no moving parts and therefore an essentially infinite life.

By combining transistors with other electronic components, it is possible to build modular devices with specific functions, which can be surprisingly small, considering the large number of components they sometimes contain.

V. Choosing components for a low-cost automation system

It is difficult to give simple rules for choosing components for an LCA system; there are many factors to consider, although sometimes the demands are such that a certain type of component will emerge clearly as the best solution. When the problem of choice does need to be faced, a start can be made by answering these general questions:

(a) What accuracies and speeds are required? It is a waste of money to buy a component with high accuracy or precision in movement (and a correspondingly high price) if an ordinary one will do. In the same way, switching lag time may or may not be a factor, depending on the requirements of the job;

(b) What is the environment in which the system will operate? For example, pneumatic controls are preferred to electrical controls if there is much dust in the air (as in a furniture shop);

(c) What forms of energy are available? If compressed air is already available, as when a furniture shop is using it for paint spraying, a pneumatic system should be seriously considered;

(d) What are the capabilities of the shop maintenance personnel? The system should be one that they can easily repair themselves. Normally, pneumatic equipment is the simplest to understand;

(e) What forces must be applied? Hydraulic devices can apply more force than pneumatic devices;

(f) What is the economical justification for the project? The cheapest solution is not necessarily the best. One should ask, rather, if the expected advantage of a given choice is worth its cost.

Normally, an LCA system based on only one of the basic types of devices described in the preceding chapter is quite satisfactory, but often better results are obtained when different types are combined. For example, when it is essential to avoid lags in signal transmission, electrical components should be used to control a basically pneumatic or hydraulic system of work-performing components.

The information about devices given in chapter IV and the answers to the questions above should provide a sufficient basis for deciding which types of components to use in a proposed LCA system. Once that has been done, the technical specifications for each component have to be decided upon. This chapter provides the information and data necessary for this decision in a form that can be easily understood by an engineer who has been assigned the task of building an LCA system in his shop.

A. Pneumatic components

Terminology

It is necessary to explain some of the terms that are used in specifying compressed-air components.

An *isothermal* compression or expansion of a gas is one in which the temperature of the gas is unchanged. *Boyle's law*, which is fundamental in compressed-air work, states that the product of the pressure P and volume V of a given weight of an ideal gas remains constant in an isothermal compression or expansion: PV = const.

Sample problem. A cylinder of volume 283 cm^3, initially open to the air, is closed, and a piston is used to compress isothermally the air within it to a volume of 41 cm^3. What is the final pressure? Using i and f as subscript labels for "initial" and "final", respectively,

$$
\begin{aligned}
P_i V_i &= P_f V_f \\
P_f &= P_i V_i / V_f = (V_i / V_f) P_i \\
&= (283/41) P_i = 6.9 P_i \\
&= 6.9 \text{ atm, or } 103 \text{ lb/in.}^2 \text{ (psi)}
\end{aligned}
$$

(P_i = 1 atm = 14.7 psi).

The *compression ratio* r is the number of unit volumes that have been compressed into a unit volume. In the sample problem above, the compression ratio is therefore $r = V_i/V_f = 6.9$. It is, of course, also equal to P_f/P_i. A convenient formula for r in compressed-air work, where P_i is usually equal to P_a, the atmospheric, or free-air, pressure, is $r = (P + P_a)/P_a$, where P is the working pressure as read on an ordinary pressure gauge (which reads 0 in free air). If P is read in pounds per square inch gauge (psig), the formula becomes $r = (P + 14.7)/14.7$; if P is read in atmospheres gauge (atmg), $r = P + 1$.

A given volume of compressed air will have a *free-air equivalent volume*, which, as can be seen from the discussion above, is equal to the compression ratio times the compressed-air volume ($V_i = rV_f$).

Components of the compressed-air supply system

Compressors

Compressed air is produced by compressors, which are nothing more than pumps that take in air at atmospheric pressure and deliver it at a higher pressure.

There are several ways of classifying compressors. For the purposes of this manual, compressors will be classified according to:

(a) The frequency of the compression cycle (mainly applicable to reciprocating types):
- (i) Single-acting, compression taking place every other stroke;
- (ii) Double-acting, compression taking place every stroke;

(b) The nature of the cycle:
- (i) Single-stage, compression taking place in a single cylinder,
- (ii) Double-stage, compression beginning in one cylinder and completed in a second cylinder, thus dividing the temperature rise between the two cylinders and permitting cooling of the compressed air between the stages;

(c) The moving parts:
- (i) Reciprocating, compression being achieved by the back-and-forth movement of a piston;
- (ii) Centrifugal, being designed to deliver large quantities of air at low pressure, moved by centrifugal force generated by a fast-revolving rotor;
- (iii) Rotary, having a vane rotor or equivalent mounted eccentrically in a stationary casing, thus forcing incoming air into a smaller volume.

The type of compressor most commonly used in furniture plants is the reciprocating type, which can produce pressures up to 10 atm. Pressures lower than 5 atm may not be sufficient for some requirements, while pressures higher than 15 atm may result in ice formation on the LCA units due to too much expansion cooling.

Compressor capacity is normally given as the number of cubic feet per minute (cfm) or cubic metres per minute (m^3/min) of free air delivery (FAD). Occasionally, compressor capacity may be rated in terms of the volume of free air displaced, in which case this displacement figure must be multiplied by the efficiency of the compressor to obtain the FAD volume.

Sample problem. A compressor is rated at 500 cfm (14 m^3/min) free air displaced. The efficiency of the compressor is 88 per cent. Find its FAD rating.

$$\begin{aligned} \text{FAD} &= (\text{free air displaced}) \times (\text{efficiency of compressor}) \\ &= 500 \times 88/100 \\ &= 440 \text{ cfm } (12.46 \text{ m}^3/\text{min}) \end{aligned}$$

Figure 23 gives the theoretical value of the energy required by single-stage and double-stage compressors to deliver a unit volume of air at a given compression ratio. This figure does not take the efficiency of the compressor system into account, which is normally only about 35-50 per cent because of various mechanical and electrical inefficiencies.

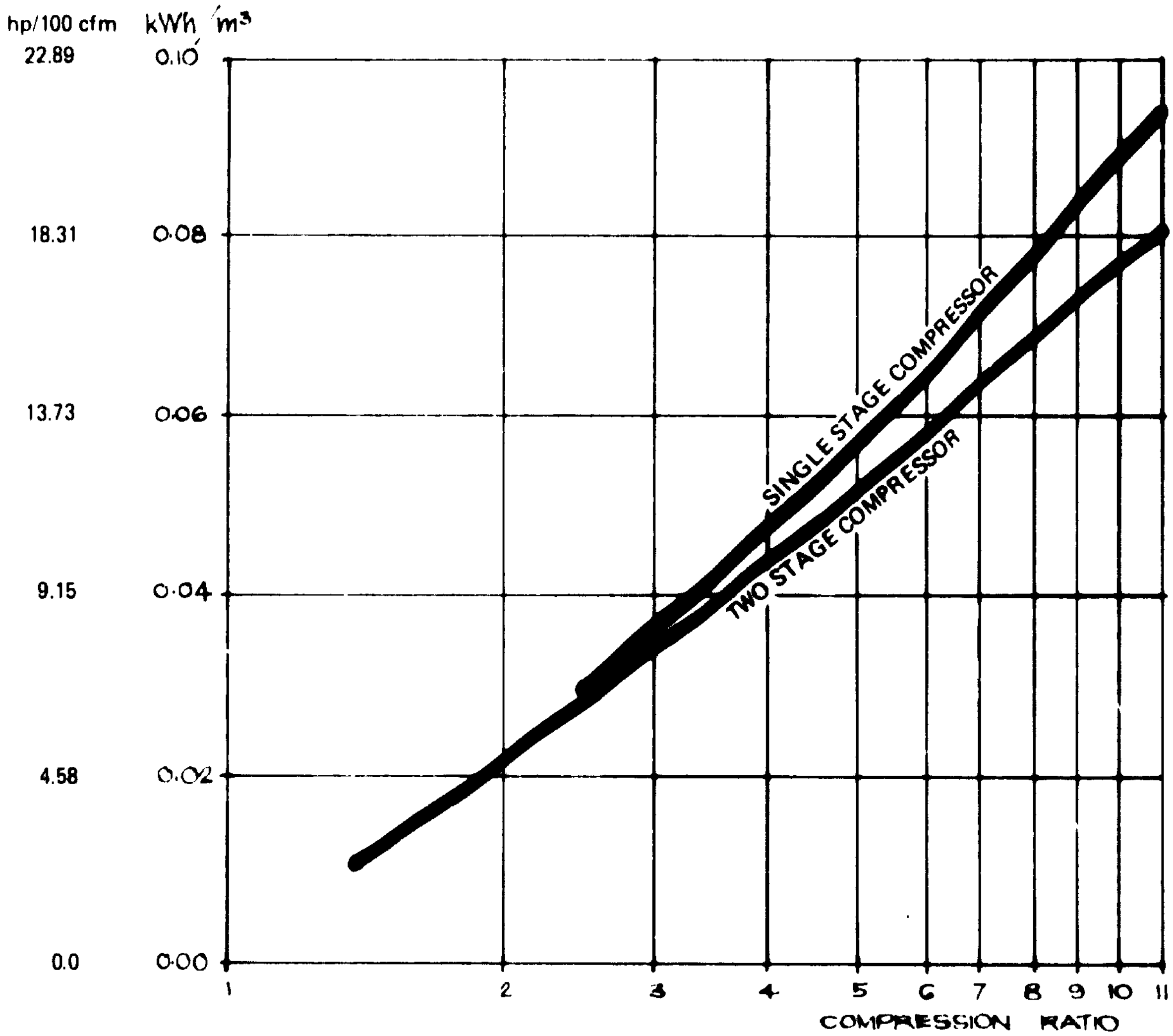


Figure 23. Theoretical specific energy requirement for air compression

Air receiver

The volume of the air receiver (storage reservoir) must be at least equal to the actual compressed air volume delivered by the compressor in one unit of time:

$$V_m = Q/r$$

where V_m is the minimum volume, Q is the compressor output in one unit of time (FAD), and r is the compression ratio. This minimum size is suitable, theoretically, for a constant demand system. In practice, it is better to employ a larger receiver to meet variable demand.

$$V_p = AQ/r$$

where V_p is the practical volume, and A is a factor ranging from 1.5 for constant demand to 3.0 for a variable demand system.

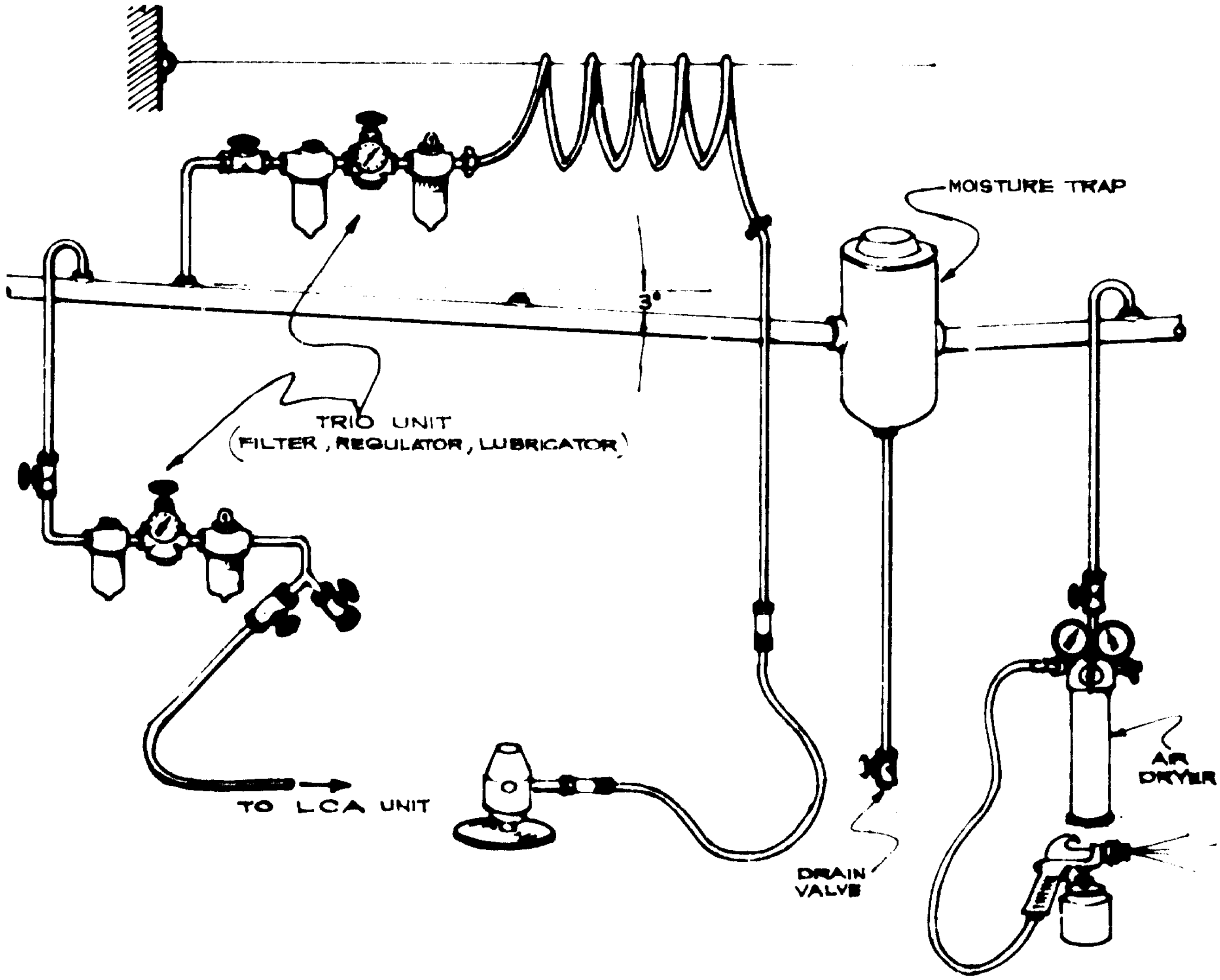


Figure 24. Air-line system

Piping

In an air compressor system (equipped with air receiver for storage), the main pipes (headers) to the various distribution points should be inclined at an angle of about 3° from the horizontal. Also, drain pipes with valves that can be easily opened for draining entrapped water should be connected to the low point of the header ahead of the actual distribution point. That will ensure that only clean, dry air gets into the LCA units.

Another rule to follow is that the lines to the LCA units should be connected to the top of the header pipe to prevent dirt from being fed to the machines.

Figure 24 shows an air-line system that illustrates the rules just given.

For compressed air up to a pressure of 12 atm, medium-thickness pipes can be used. If possible, the pipes should be cleaned before being installed.

Since pipes run from a compressor air-receiver to a system that may be remote, the pipe should be large enough to minimize friction losses. Table 1 is a guide to finding the correct size. To use this table, first determine the air flow to be carried. Find its value in the first column and read across to the column showing the approximate length of run to find the suggested pipe size for minimum loss. For example, 25 cu ft/min (0.7 m^3/min) of air can be carried up to 150 ft (45.7 m) using a pipe with an inside diameter of 0.824 in. (20.9 mm). If the total run is over 150 ft (45.7 m), a 1.049-in. (26.6-mm) pipe should be used all the way.

If the air flow is not known, use the compressor horsepower (second column) to enter the table. For flows not included in the table, assume that about 3.5 cu ft/min (0.1 m^3/min) is produced by each unit of compressor horsepower. The calculation is only approximate since the flow/horsepower ratio depends on the efficiency of the compressor. When in doubt, it is best to oversize the air headers, as they become part of the air reservoir.

TABLE 1. SUGGESTED PIPE SIZES FOR A COMPRESSED-AIR DISTRIBUTION SYSTEM

Air flow			*Run*							
			(feet)							
			25	*50*	*75*	*100*	*150*	*200*	*250*	*300*
			(metres)							
(cu ft/min)	*(m^3/min)*	*Compressor horsepower*	*7.6*	*15.2*	*22.8*	*30.5*	*45.7*	*61*	*76.2*	*91.5*
5 or less	0.14 or less	1.4	0.622 (15.8)							
10	0.28	2.8	0.622 (15.8)			0.824 (20.9)				
15	0.43	4.3	0.622 (15.8)	0.824 (20.9)						
20	0.56	5.6	0.824 (20.9)							
25	0.70	7.0	0.824 (20.9)					1.049 (26.6)		
30	0.85	8.5	0.824 (20.9)				1.049 (26.6)			
35	1.0	10.0	0.824 (20.9)		1.049 (26.6)					
40	1.12	11.2	0.824 (20.9)	1.049 (26.6)						
50	1.40	14.0	1.049 (26.6)							
70	2.0	20.0	1.049 (26.6)				1.380 (35.0)			

Source: Air Compression Research Council.

Note: The figures in the main body of the table are the inner diameters in inches (millimetres in parentheses) of standard black pipe that will keep the pressure loss to a reasonable minimum over the runs indicated.

The pressure drop nomogram in figure 25 is also useful in piping design. The arrows illustrate how the nomogram is used to solve the following problem:

Suppose that an air flow of 10 m^3/min (353.1 cu ft/min) is desired in a 70-mm (2.76-in.) pipe, 200 m (660 ft) long. If the initial pressure at the head of the pipe is 7 bar (101.5 psi), what will the final pressure at the delivery end be? The intersection of the lines representing 10 m^3/min and 7 bar is found in the right-hand part of the nomogram and projected diagonally upwards towards the left to the vertical border line between the two parts of the nomogram. Then the horizontal line is followed to its intersection with the vertical line representing the pipe length of 200 m. From this intersection the path is diagonally downwards to the horizontal line representing the pipe diameter, 70 mm, then vertically downwards to the scale, where the pressure drop, 0.1 bar (1.45 psi), is read. The delivery pressure is therefore 7.0 − 0.1 = 6.9 bar (100 psi). Any other problem involving the five quantities represented in the nomogram can be solved in analogous fashion.

As a rule of thumb, when interconnecting valves and cylinders for a pneumatic circuit, use the port-size of the cylinder as a guide. In any case, assuming that the factory already has a source of compressed air, the magnitudes of the pressure fluctuations and of the lowest pressure need to be known when calculating the cylinder size to decide whether there is enough air to drive the equipment. If not, the capacity of the compressed-air plant must be increased.

Air "conditioners"

Compressed air can be regarded as fully saturated with water vapour. Since the amount of water that can be retained in vapour form in a given volume of air is an increasing function of temperature, any fall in the temperature of saturated compressed air will result in excess moisture condensing out in the system. The quantity of water so deposited can be great enough to cause improper operation of a pneumatic system. Besides moisture, raw compressed air may contain abrasive compounds and sludges that can cause great damage to pneumatic components.

To prevent these bad effects an "air-conditioning" system is needed: suitable air-processing equipment placed in the circuit ahead of cylinders, valves and other tools to dry, filter and add lubricant to the compressed air and to regulate the pressure. The air-conditioning assembly pictured in figure 26 is referred to as a "trio" unit because it comprises three components:

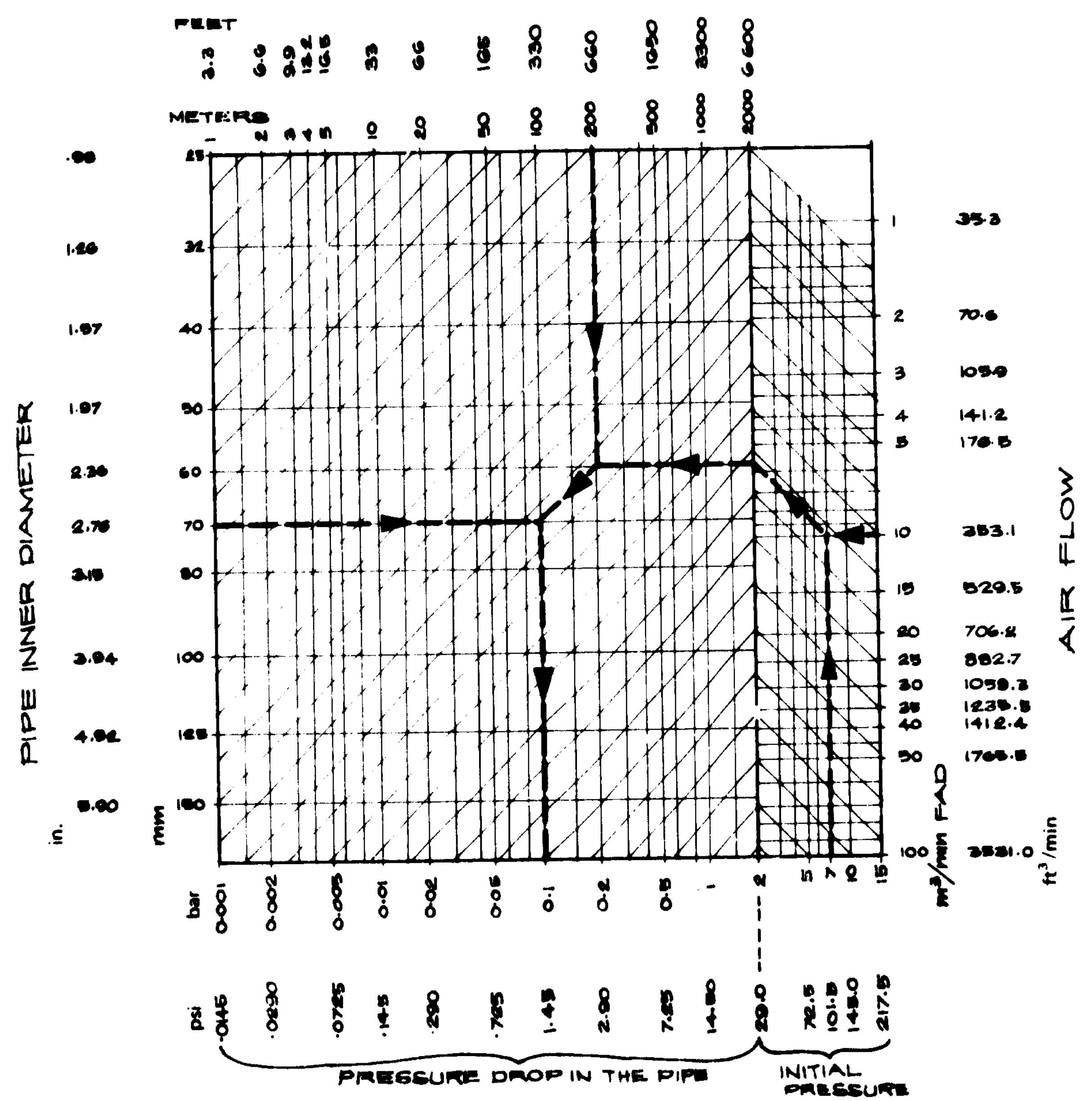


Figure 25. Pressure drop nomogram

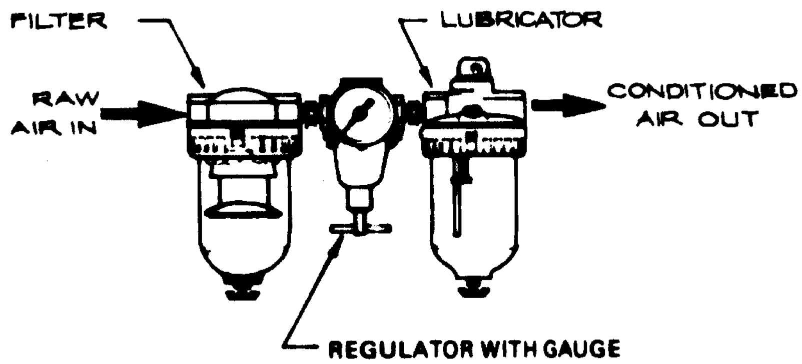


Figure 26. Trio unit: filter, regulator and lubricator

(1) *Air filter and drier.* This component traps residual moisture and dirt in the compressed air by swirling the "raw air" around the bowl. Because of centrifugal action, the heavier elements stick to the side of the bowl and are no longer in the air stream. The accumulated water and dirt are periodically taken out of the filter by opening the valve below the bowl. This "flushing-out" should be performed before the bowl is completely filled with water; otherwise the dirt particles might get back into the system.

(2) *Pressure regulator.* By setting the knob on the pressure regulator, a definite, constant air pressure can be maintained in the line. It is not advisable to have too high an air pressure; the extra pressure only means wasted energy. Note that a pressure regulator can only maintain pressures that are less than the header pressure. It cannot provide a pressure higher than the pressure at its inlet.

(3) *Air lubricator.* Air lubricators are important since air by itself is not a lubricant. Without lubrication, the various components in the system will deteriorate and their life will be considerably shortened.

Air lubricators are normally filled with a light oil, which, converted to a fine mist, travels with the compressed air into the equipment. The amount of oil going into the system should be adjusted with care: too little, and wear will occur; too much, and clogging will result. A good rule-of-thumb in adjusting the lubricator is "one drop of oil (as seen in the sight glass of the lubricator) should fall for every 20 cu ft (500 dm^3) of free air consumed by the equipment".

To determine the size of the trio unit needed, a good rule-of-thumb is that it should be one size larger than the largest component in the system.

Cylinders

In choosing a pneumatic cylinder, the following items should be considered:

- Required feeding force
- Required feeding speed
- Required feeding length
- Mounting requirements
- Adverse forces on piston and cylinder
- Need for end-cushioning
- Working environment
- Air consumption

Required feeding force

The thrust exerted by the piston rod of a pneumatic cylinder depends on the pressure of the air supplied to it and the effective area of the piston face against which the pressure acts:

$$\text{Thrust} = (\text{pressure}) \times (\text{effective area})$$

If the pressure acts against the front face of the piston, the effective area is $A = \pi D^2 4$, where D is the diameter of the piston, which is essentially the same as the diameter of the cylinder bore (fig. 27). The thrust is a compressive force; it tends to push the rod out of the cylinder. But if the compressed air is admitted behind the piston, so that it acts against the back face, the area covered by the rod is ineffective in producing thrust (fig. 28). The effective area in this case is A minus the cross-sectional area of the rod. The thrust is a tractive force; it tends to pull the rod into the cylinder. It is important to remember that a cylinder having a rod in one end only has more push than pull, whereas a cylinder having a "through-going" rod pushes as hard at one end as it pulls at the other.

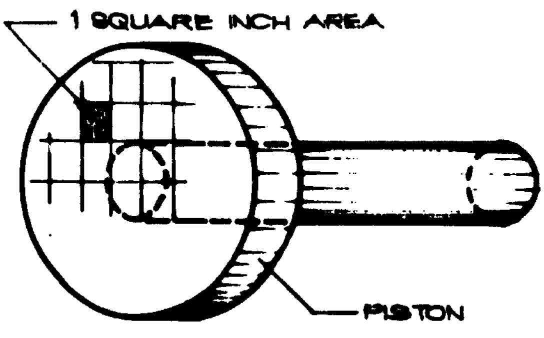


Figure 27. Effective area of piston face

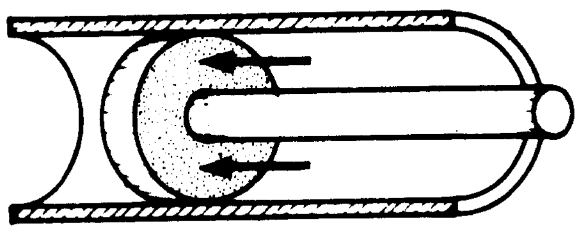


Figure 28. Effective area of rod-end of piston

The compressive and tractive forces of air cylinders with selected bores of 25-200 mm (0.98-7.87 in.) as a function of pressure can be taken from the chart in figure 29. The chart may also be used for low-pressure hydraulic cylinders, such as in an air-over-oil system. In any case, however, the chart should be used only as a guide; it does not take into account friction losses in the part to be driven or in the cylinder itself. The latter can be 5-15 per cent of the theoretical value given by the chart. For a more exact determination of available thrust, the information furnished by the cylinder manufacturer should always be carefully studied.

Figure 30 shows an air cylinder supporting a load weight of 1,000 lb (454 kg). The cylinder bore is 4 in. (102 mm), and the line pressure is 80 psi. According to the chart in figure 29, the cylinder is developing a thrust almost exactly equal to the weight of its load: the cylinder will not move. To move the load, the air cylinder must be sized to have more thrust. The amount of oversizing needed depends on the speed of movement desired; the greater the oversizing, the faster the load will travel.

There are many factors to be considered in estimating the amount of oversizing required. For the purposes of this manual, this rule-of-thumb will suffice:

> If speed is not important, select a cylinder with about 25 per cent more thrust than needed to just balance the load. To get high speed, oversize the cylinder by 100 per cent.

Required feeding speed

An air cylinder can be used for driving at speeds in the range of 0.07-150 mm/min (0.003-6 in./min). Speeds below 50 mm/min (2 in./min) require attachment of a hydraulic damping cylinder. The speed is a factor in choosing a suitable type of cylinder. At high speeds for example, end-position damping might be required to reduce mechanical strains. The speed is also of interest when deciding which type of directional control valve to use, whether to use fixed or adjustable throttling, and how these should be placed. To calculate the maximum flow speed of the air and thereby the instantaneous air consumption, the piston speed and the working frequency of the cylinder must be known. The air consumption for various strokes and cylinder diameters is information normally supplied by cylinder manufacturers. However, the engineer himself can do some calculations regarding air consumption; the amount of air required per minute is equal to the area of the piston times the number of strokes per minute times the length of stroke. This figure is the consumption based on the volume of compressed (not free) air. In making the calculation for double-acting cylinders, the effective area of each side of the piston and both strokes should be taken into account.

Required feeding length

What stroke length to choose for a cylinder depends on whether the stroke must be exactly the same as the feeding length required by the driven device. If it must, then it is important to specify that stroke and have the cylinder made to order. Sometimes, however, it does not matter whether the stroke is too long, since an external stopper can be incorporated in the set-up. In this case, standard-stroke cylinders can be ordered from suppliers' catalogues.

Mounting requirements

A cylinder can be mounted in many different ways by means of the so-called standard attachments that are available. There are different attachments for both cylinder and piston rod. Incorrect mounting can cause damage to the cylinder as well as to the equipment driven by it.

Adverse forces on piston and cylinder

Besides forces due to incorrect mounting, adverse forces can act on the piston and cylinder for two other reasons.

First, when a cylinder rod is subjected to radial forces (fig. 31), forces may be exerted on the cylinder seal or the inside walls of the cylinder. These portions of the cylinder are not designed to sustain such forces and hence may fail prematurely.

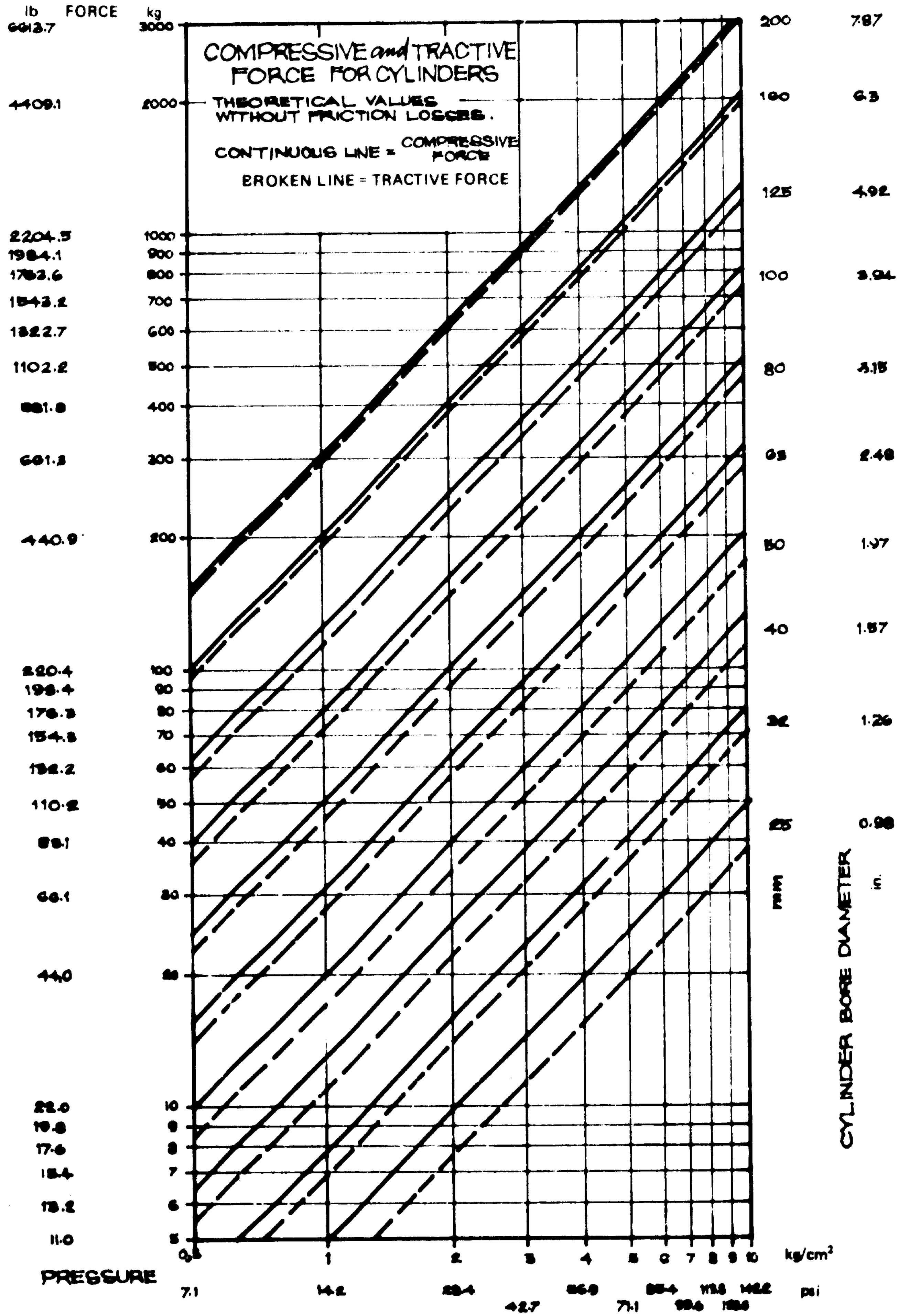


Figure 20. Compressive and tractive forces for cylinders

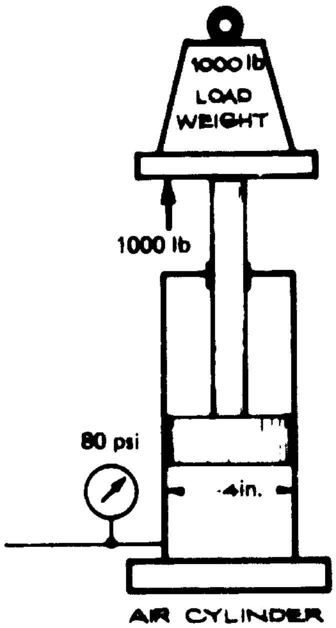


Figure 30. Load-thrust equilibrium of an air cylinder

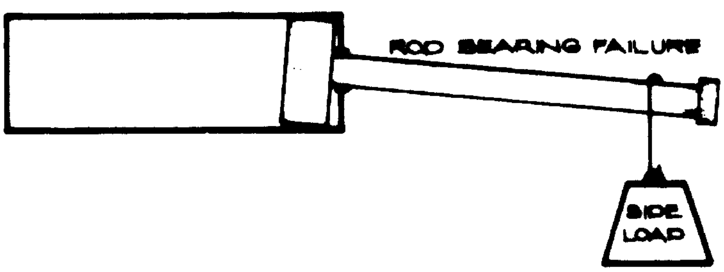


Figure 31. Result of side forces on a piston rod

To prevent heavy side loading of cylinders, they must be carefully mounted so that the rod does not bind in any part of the stroke. Use a guide or a load-relieving mechanism if necessary, to assure that no side load is transmitted to the cylinder rod.

Secondly, column failure (buckling) of the piston may occur if the stroke is too long compared to the rod diameter (see fig. 32). The chart in figure 33 can be used as a guide for choosing the proper rod diameter, given the stroke length of the cylinder.

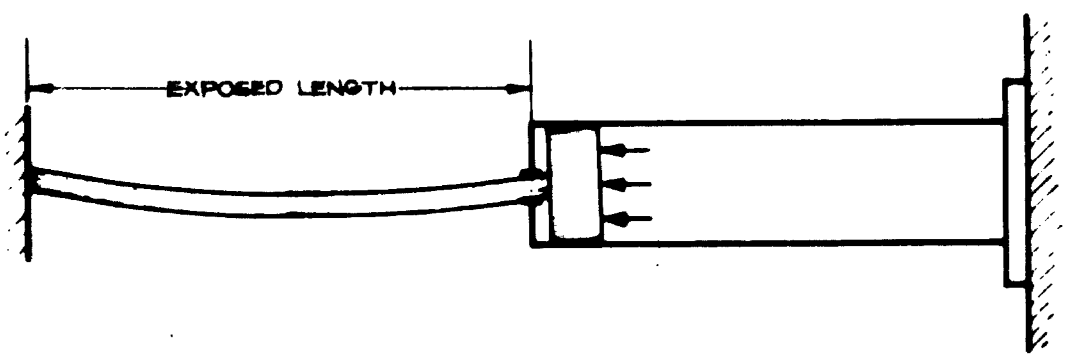


Figure 32. Column failure of piston rod

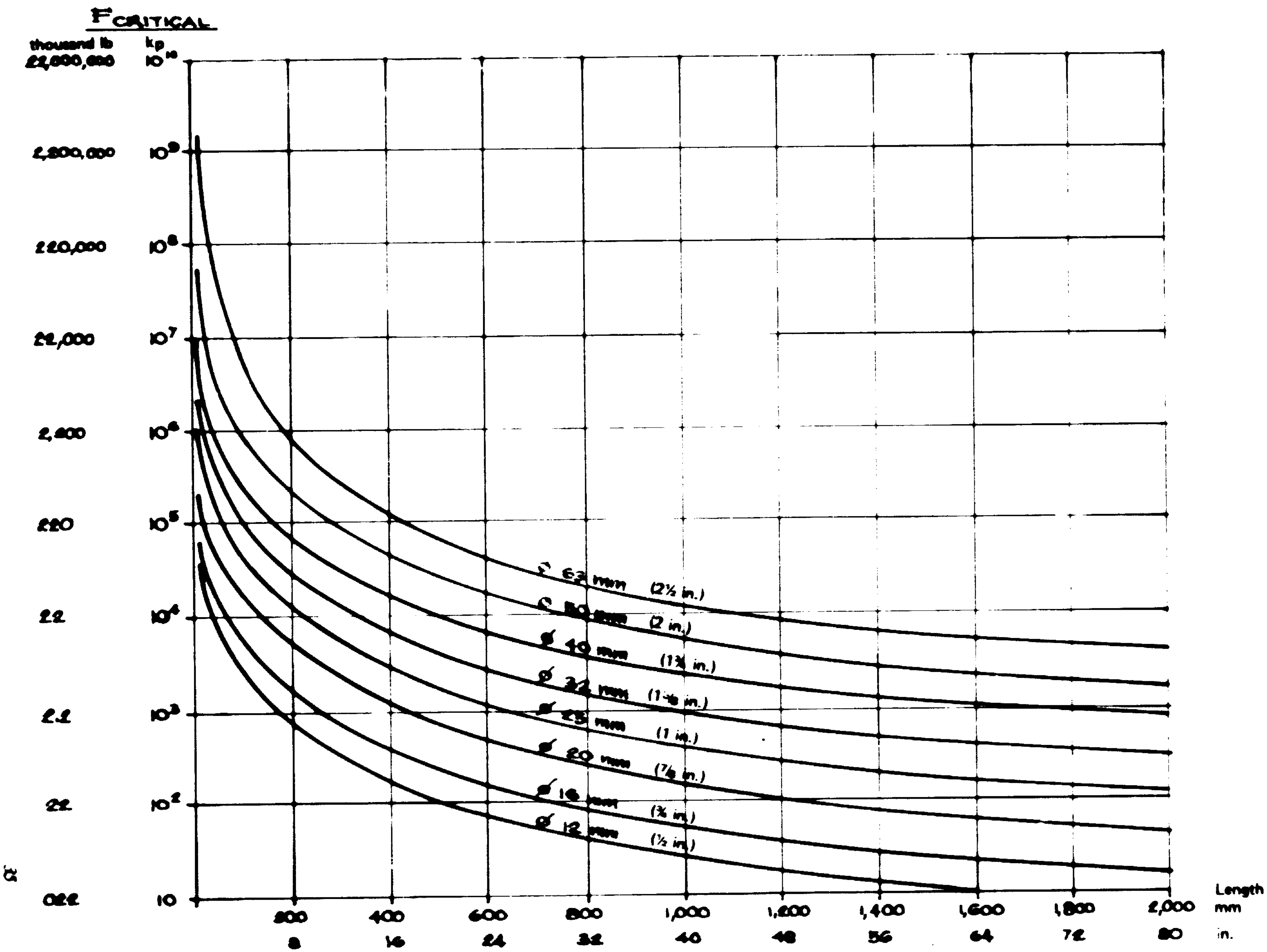


Figure 33. Minimum piston-rod diameter to prevent buckling of rod

To use the chart, find the exposed length of rod at maximum stroke along the bottom line of the chart and the work load on the vertical line on the left. The intersection of the corresponding lines gives the minimum rod diameter.

Need for end-cushioning

Cylinders that work at a high piston speed or drive a relatively large mass should be equipped with so-called end-position brakes, which reduce the speed during the last part of the stroke so that the mechanical forces on the cylinder and the driven device are reduced. The retardation produced by these brakes can be adjusted.

Working environment

Different cylinder series have been developed to match the various types of environmental conditions in which they must work. Fortunately, the conditions in furniture and joinery factories are not so aggressive as those found in chemical industries. Thus, special resistant cylinders (which are of course more expensive) are not necessary.

Air consumption

The air consumption of a cylinder is directly related to its displacement, i.e., the volume of compressed air consumed per stroke. To obtain the consumption in terms of free air the cylinder displacement must be multiplied by the compression ratio. (See the first subsection of this section, headed "Terminology".)

Sample problem. The displacement of a cylinder is 44 cu in. (721 cm^3). Find the consumption in terms of free air for a working pressure P = 60 psig (4.08 atmg).

Compression ratio r	$= P + 1 = 5.08$
Free-air displacement	= rx (compressed-air displacement)
	= 5.08 x 44
	= 224 cu in.
	= 0.13 cu ft (3663 cm^3)

Valves

In choosing valves, information is needed about their function, capacity, actuation and mounting.

Function

Valves are designed to control or regulate direction of flow, amount of flow or pressure. Directional-control valves are available with two, three or five ports and two or more positions. A flow-regulating valve can be variable or fixed, with or without return. Pressure-regulating valves come with or without a secondary outlet.

Capacity

The valve size must correspond to rate of flow of air through the valve. For a given rate of flow, pressure losses are greater in a small valve than in a large one. In fact, the capacity of a valve can be stated in terms of the pressure drop as a function of flow at various inlet pressures. It is usually shown in diagrams available from the supplier.

Capacity is sometimes given only as a flow; this refers to the quantity of air at normal conditions and at a pressure drop of 3 psi (0.2 kg/cm^2) across the valve, unless otherwise specified.

Actuation

Valves can be equipped with various types of devices for direct or remote actuation. Direct actuation means that the valve is operated manually (by a botton, knob or bar, for example) or mechanically (by a lever, for example). Remote actuation means that the valve is operated by a pneumatic or electric signal originating some distance away from the valve. Direct actuation is the simpler and also the more reliable of the two types. Its disadvantage is that the valve must be close to the operator. The removal of that disadvantage is, of course, the principal reason for having remote actuation, in spite of its lower reliability, greater complication and higher cost. However, a system for remote actuation should be designed so that direct actuation is still possible in case of failure of the system.

Remote actuation by electrical signals has the advantage of being faster than by pneumatic signals. However, since solenoids are needed, electrical actuation is also more expensive.

Mounting

Pneumatic valves are usually designed for mounting in different ways. For example, connexion of fittings can be made direct to the valve housing or by using a special mounting plate to which the air lines are connected. The latter is a method that is becoming more and more common; the valve can easily be changed if it fails. Another way of mounting is the so-called panel mounting for manual operation, where one wishes to have the valve inside a cabinet with the actuating device outside.

B. Hydraulic components

The basis for the choice of hydraulic components has a strong similarity with that for pneumatics, and many of the principles discussed above for pneumatics will also hold for hydraulics.

Supply system components

Pumps

The pumping capacity required for a hydraulic system is easily computed by summing all the requirements of the system and adding a certain amount for inefficiency.

The input power, i.e., the power required to drive the pump, depends mainly on two factors, the flow rate and the pressure level. Increasing the pump speed increases the flow rate and therefore indirectly affects the input power. As a rule-of-thumb, the input-power requirement is directly proportional to the flow-rating of the pump. A pump with twice the rating needs twice the input power to maintain the same pressure level. The input-power requirement is also directly proportional to the pressure level. If the pressure level increases five times, it will take five times as much power to produce a given flow rate. The power formula is:

Power = (volume flow rate) X (pressure)

The required power for the pump is obtained by dividing the power as determined from the formula by the efficiency, which is normally about 85 per cent.

Shock absorbers (accumulators)

In hydraulic systems shock is absorbed by "accumulators", which are storage devices for high-pressure hydraulic oil (fig. 34). The pump delivers oil to the accumulator during periods when it is not delivering oil to other units. The stored oil is available at a later time either to supplement pump oil or to maintain pressure when the pump is shut down. Also, in case the thrust movement of a cylinder (for example) is suddenly stopped, some of the on-rushing oil will go to the accumulator and thus relieve the system of sudden shock forces, which can be quite destructive.

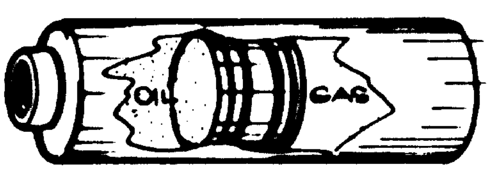


Figure 34. Piston-type accumulator

In installing accumulators, the following safety measures should be taken:

(a) Before disconnecting any section of piping containing accumulators, open the bleed-down valve to relieve the system of pressure (fig. 35);

(b) Securely enclose accumulators;

(c) In changing the gas inside a gas-containing accumulator, always use an inert gas; otherwise, explosions due to the diesel effect may occur if the accumulator develops internal leaks.

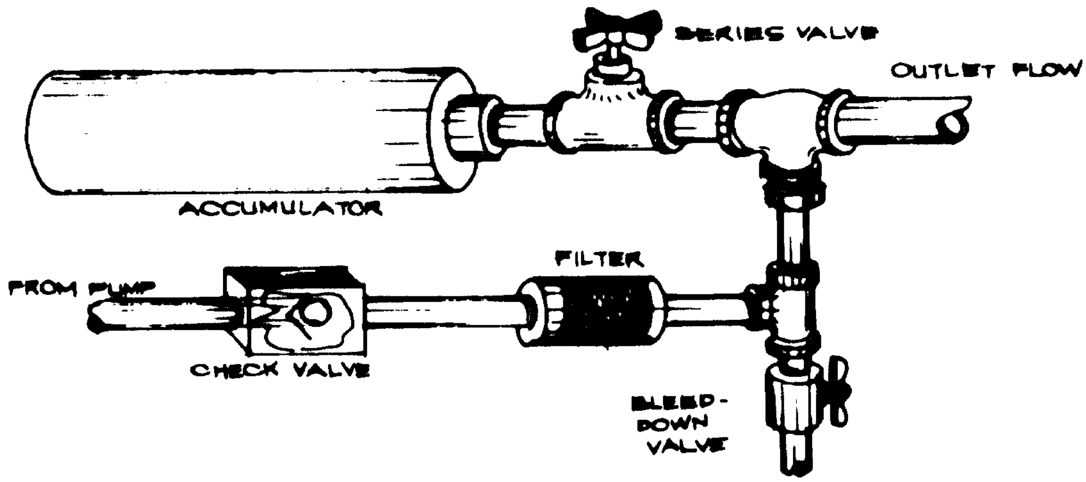


Figure 35. Suggested method of connecting an accumulator

Cylinders

Feeding force

The thrust of a hydraulic cylinder can be computed from the same formula as that used for pneumatics: the piston area times gauge pressure. However, to allow for mechanical and fluid losses, hydraulic cylinders need be oversized by only about 10 per cent. Note also that oversizing a hydraulic cylinder decreases its speed, assuming the same pump volume.

Feeding speed

For hydraulic cylinders, speed is calculated by determining the volume flow rate of oil going to the cylinder (normally the rate from a positive displacement pump) and dividing it by the area of the piston.

Sample problem. An oil flow of 10 gallons per minute (gpm) goes to a cylinder. The area of the piston is 9.62 sq in. Determine the piston speed. (See fig. 36.)

$$10 \text{ gpm} \times 231 \text{ cu in./gal} = 2310 \text{ cu in./min}$$

$$\text{Piston speed} = \frac{2310 \text{ cu in./min}}{9.62 \text{ sq in.}} = 240 \text{ in./min}$$

Note that in calculating the speed of return of the piston, the area occupied by the rod should be subtracted from the piston-face area.

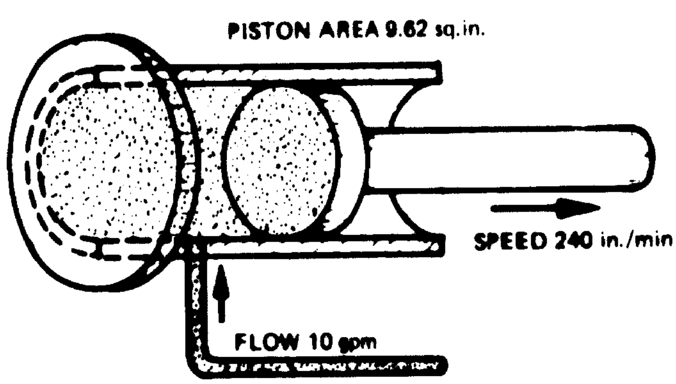


Figure 36. Hydraulic cylinder speed

Valves and piping

To replace an existing valve, all that is required is to use a replacement valve similar to the old one (assuming the old one was correct). However, on new installations, the problem is somewhat more difficult. In choosing the right valve, considerations of adequacy and economics play a role. The easiest approach to the problem is first to determine the linear flow rates in the system (see the table in the next paragraph), then the correct size of piping (from the formula below) and finally the valve size (selected according to the pipe size).

These are suggested flow velocities inside pipes:

Pump suction lines	2- 4 ft/sec (0.61-1.22 m/sec)
Pressure lines up to 34 atm	10-15 ft/sec (3.05-4.57 m/sec)
Pressure lines from 34 to 204 atm	15-20 ft/sec (4.57-6.10 m/sec)
Pressure lines over 204 atm	25 ft/sec (7.62 m/sec)
Oil lines in air-over-oil systems	4 ft/sec (1.22 m/sec)

The formula for pipe size is:

$$d^2 = \frac{1.27 \times (\text{volume flow rate})}{(\text{linear flow rate})}$$

where d is the inside diameter of the pipe.

C. Electrical components

Aside from electric motors for rotary and limited linear movements, electrical components are used in LCA mainly for controlling or programming the work sequence of pneumatic and hydraulic components. Such control is basically achieved through signals from switches. There are hundreds of types of switches and new ones are being designed every day. In fact, any mechanic can make his own type of switch.

The simplest switch has a pair of contacts which can be "made" (connected) or "broken" (disconnected) by the actuator. More complex switches can be classified according to the number of independent contact pairs (poles) that can be made or broken by a single operation of the actuator: single-pole, double-pole, triple-pole, and multiple-pole (four or more poles). The number of poles is really only the number of single-pole switches that can be thrown (actuated) at once. If, instead of contact pairs, the switch has contact triples P, A, B, such that P is alternately connected to A and B by consecutive operations of the actuator, it is called a double-throw switch. The extension of that idea is the multiple throw, or multi-position, switch, in which P can be consecutively connected to A, B, C etc. Multiple poles can be combined with multiple positions, contributing to the large number of distinct types of switch available.

Contacts of switches are usually made of silver, tungsten or other alloy that has high wear and oxidation resistance but low electrical resistance. However, whatever they are made of, there is the tendency for arcing (sparking) to occur at the switch contacts whenever a current is switched on or off. Arcing causes the contact points to burn. To avoid it, it is desirable to have a rapid making or breaking of contacts, especially if the current they are carrying is relatively large, when the arcing problem is relatively more severe. Ordinary light switches "click" because they have a spring-cam combination that produces such a rapid making and breaking action. Most industrial switches also have this clicking action.

Some switches do not have handles or other form of actuator but are electrically or magnetically operated by other switches (e.g., the relay discussed below). In others, the switch body itself is the handle. That is, the position of the body determines whether the switch is open or closed. An example is the mercury switch.

Of the many types of switches now available, only the push-button switch, the limit switch and relays will be discussed below.

Push-button switches

Push-button switches are often used to signal manually the start or stop of an operation that is electrically controlled. When pushed, the "button", usually of plastic, actuates a spring-loaded contact that bridges two terminals. Push-button switches are momentary contact switches. The switch is closed only as long as the button is held down. Ordinarily, push-button switches can handle only small electrical loads, because their construction is such that they make or break their contacts slowly. Their use in high-current circuits will produce arcing that shortens the life of the switch.

The contacts of push-button switches can be single-break or single-make contacts, or they can be obtained as multimake or multibreak contacts. By rearranging the contacts, push-button switches can also be made to have make-and-break contacts: one set makes and the other breaks simultaneously when the buttom is pushed.

A flush-mounted button will help prevent operations of a switch by accident. That is, since the button is flush the only way it can be operated is by deliberately pushing the button. Sometimes, it is desired to have a push-button switch that will stop a system in case of an emergency. In this case, the switch should have a prominent button, e.g., one in the shape of a mushroom head. This particular switch is so made that it can be operated by a quick blow of the hand that does not need to be well-aimed. The important thing is to have a switch that can be easily operated with a minimum loss of time. There are also push-button switches that are used to light a small lamp if the power line is live or if some circuit is activated. The cover of the light bulb may be the button itself.

Push-buttons are intended to be operated by a person's finger; mechanical devices like cams can damage them or cause premature failure. The proper type of switch to use with mechanical actuators is the limit switch, which will be discussed next.

Limit switches

Incorporated in an electrical or electronic circuit, the limit switch can make or break electrical connexions as the result of a mechanical force from outside. The actuating force usually comes from a moving element, such as a machine part, a cam, a door, or even the product itself, working on the actuator.

Parts of a limit switch

The basic configuration of the limit switch is shown in figure 67 in chapter VI. Four major elements can be distinguished: enclosure, contacts, actuator and terminals.

Enclosure. This is to house the electrical contacts. Depending on the application requirements and the number and type of contacts inside, it may vary in size and design. For example, it may be oil-tight, dust-tight (in furniture plants) or explosion-proof. Usually non-metallic (e.g., bakelite), the enclosure is often placed in a more rugged metal casing to protect the limit switch from adverse environmental conditions (e.g., in wood shops).

Contacts. Apart from the variation in number of contacts, we can distinguish contact arrangements, such as:

Single-pole, single-throw (SPST)
Single-pole, double-throw (SPDT)
Double-pole, double-throw (DPDT)

The switch in figure 67 is an SPDT switch. The pair of contacts c,a is normally closed (NC), and the pair c,b is normally open (NO).

Contacts can also be divided into the categories of slow-action contacts and snap-action contacts. In a slow-action contact, the contact arm that actually makes or breaks the contact moves as far as the actuator moves and at a speed equal or proportional to the speed of the actuator. In a snap-action contact, the contact arm does not move until the actuator has reached a certain point. Then a spring mechanism snaps the contact arm from the non-actuated position into the actuated position. In this case, the speed of the action is not determined by the speed of the actuator but by the design of the spring mechanism.

Actuator. Of the many different designs possible, some examples are shown in annex I. A special type is the so-called "collapsible" actuator. It is used when a moving part should actuate the limit switch only in the forward stroke and not in the return stroke.

Terminals. Located on the outside of the limit switch, the terminals are connected with the contacts inside. They make the link with the wiring of the circuit in which the limit switch is incorporated. Depending on the type of terminal, the wires from that circuit can be connected to the terminal by soldering, screwing or plugging.

As each of these four major elements of the limit switch can vary in shape, size or number, it will be clear that there is a tremendous number of possible combinations of them.

Some rules for the proper use of limit switches

The quality of limit switches manufactured today is such that a switch can perform many millions of working cycles without causing any trouble. Most cases in which limit switches do malfunction arise from improper use of the switch or a wrong choice of switch for the given application. The most common mistakes can be avoided if the following rules are observed.

Do not connect the NC and NO terminals of a limit switch to device terminals of opposite instantaneous polarities. If this admonition is ignored, there may be a short circuit that will damage the switch or even ruin it if it is one of those small, oil-tight, snap-action types used on machine tools. Always follow this rule: If the NC and NO terminals of a limit switch are to be connected to different devices, make sure that they are connected to terminals on those devices that are on the same side with respect to the line.

Do not overload limit switches. This common-sense rule is often forgotton. For example, a limit switch rated at 10 A should never be used in the power line to operate a 10-A motor, which might have a starting current of 60-100 A. Limit switches, unlike most relays, are rated for pilot duty, and that certainly rules out motors as loads.

When actuation is slow, use a snap-action limit switch. In a slow-action switch, the actuator is directly linked to the contacts. There is danger that the actuator may move so slowly that the normally closed contacts open, thus stopping the device that has been driving the actuator before the actuator has done the second half of its job, namely, closing the normally open contacts.

There are cases in which a slow-action switch is the better choice. For instance, a safety limit switch may be tripped only once or twice in many years, but if it is tripped, it must work. If the contact mechanism has become corroded or otherwise stuck from inactivity, a snap-action switch may not operate at all, and the emergency provision may be lost. But if a slow-action switch is used, the actuator will either force the contacts open or tear the whole switch off its mounting.

In all other cases, and especially where the actuating motion is slow, the snap-action switch usually is the best choice because its contact action is very fast and independent of the actuating speed.

Install limit switches so that actuators are not struck or released suddenly. One of the most common causes of mechanical wear in limit switches is the stress at the first instant of mechanical contact. The mass of the actuator must be kept low. Some designers believe that the old-style limit switches are more rugged and last longer because they are larger. That is definitely not true. The new, smaller switches, if properly used, have a much longer mechanical life than their larger ancestors.

The rate at which the operating force is applied is also important; carefully inclined cams should be used. If a limit switch is suddenly released after being actuated, it may be re-actuated when it "flies back" past its operating point. The chance of fly-back is increased if the actuator has no contact with the smaller diameter of the cam at the moment of release. The cam should still depress the actuator a little even in its released position. Some limit switches have nylon rollers to minimize fly-back.

Be sure the limit switch is actuated long enough. It usually takes about 0.2 sec for a limit switch to actuate relays, solenoid valves and other devices in the electrical circuit. Sometimes, after a machine has been equipped with limit switches and is running well, an attempt is made to increase production by speeding up the cycle. The machine may then work badly if the limit switches are operated so fast that their associated devices do not have time to operate. Remember also that the operating point and the reset point of a limit switch are not the same. Enough return motion of the operating member must be allowed to ensure resetting of the limit switch after it has operated.

Do not use a limit switch as a mechanical stop. A limit switch should never be driven past its safe overtravel point and certainly not to its mechanical limit. For that reason, a limit switch should not be operated directly by the workpiece being processed since the motions of the latter may be difficult to control. A well designed and properly mounted triggering mechanism will operate the switch in a controlled way regardless of how "wildly" and from what direction the mechanism is hit by the workpiece.

Do not add heavy or extra long actuators to limit switches. The actuator on a limit switch should be used as it is delivered from the factory and not be extended unless the limit switch is specifically designed for an extension. Otherwise, the sheer weight of the extension might damage the switch, or the switch might fail to reset. If the distance between the limit switch and the operating mechanism is too great to be bridged by the standard actuator, either mount the limit switch nearer to the operating mechanism or redesign the latter. The effort will pay off in more reliable performance and longer life of the limit switch.

Select the proper type of actuator according to the operating force. Each application should be given at least an elementary kinematic study to ensure that operating forces are in a useful direction.

Relays

Another type of switch that is very useful for automatic control is the relay, which consists of an electromagnet or similar device that controls the position of one or more contacts. The moving contacts in a relay usually have two positions. The so-called "normal" position is assumed by the contacts when the operating mechanism is de-energized, the "operated" position, when it is energized. Relay contacts can be arranged in as many ways as the contacts of ordinary switches. The only real difference between a relay and a switch is the way contacts are actuated.

A typical relay is shown in figure 68 in chapter VI.

Functions

Relays are valuable in automation because they can be made to amplify signals, multiply signals, provide memory, and invert signals.

Amplification. Normally, limit switches and push-button switches are capable of handling only small electrical loads. Of course, a switch that can handle larger loads could always be built, but it would have contacts so large that an enormous physical force would be needed to operate them. By making use of a relay, a large load can be controlled by a small switch. The switch is used only to energize the coil of the relay, which takes only a relatively small amount of current. The resulting electromagnetic force in the core pulls the larger contacts of the relay together. These in turn switch on the higher current in the load (e.g., a motor). The net effect is an amplification of the small current into a larger one that can do far more work.

Multiplication. By simply adding contacts to be operated by the electromagnet of one relay, several different loads or signals can be controlled by only one small, SPST switch. In effect, the number of circuits that can be controlled at one time has been multiplied.

Memory. Normally, return springs ensure that the contacts of a relay will always re-assume their original position when the coil is de-energized. However, one of the sets of contacts in a multiple relay can be used to carry current to the coil of the relay even after the original signal provided by the push-button switch has been removed. All the other contacts, therefore, will remain in the "make" position. In effect, the relay "remembers" that a signal has been received long after it has disappeared and keeps the contacts made until a different signal is received.

Another kind of memory relay is the "latch" relay, so called because a spring latch falls and holds the contacts in the state they assume when one of the two coils in the relay is momentarily energized. The contacts can assume another state only if the other coil in the relay is subsequently energized. This type of relay remembers a signal pulse "mechanically". It should be realized, however, that in case of power failure, this type of relay will remain in its "last" position, which will make it unsafe in some set-ups.

For more discussion on the memory capability of relays, refer to Chapter VI.

Inversion. Sometimes, it is desired that the signal sent by a switch should mean that the current through a load should be cut off rather than switched on. That is done simply by making the contacts of the relay break instead of make when the coil is energized. This type of relay is called a normally closed (NC) relay. The signal is said to be inverted.

Selection

In selecting a relay, the contact load, duty cycle and voltage rating should be considered.

Contact load. Usually, the object in using a relay is to control a load. When a set of relay contact closes, current flows to the load through it. While it remains closed, it must carry the full load current. And when it opens, it must break the full load current.

The three functions of a contact, namely, making, carrying and breaking should be considered separately for proper determination of the type of contact needed. The initial load in making may be different from the steady load in carrying. For example, when a relay is used to switch on a motor, the initial current load may be 5 to 10 times the current rating of the motor, which is its current draw while running. In such cases, it is advisable to use relays with a continuous current rating of not less than 50 per cent of the peak value of the starting current. In most LCA projects, however, which require relays mainly for switching purposes, it is customary to rate relays at not more than 67 per cent higher than the continuous current capacity desired.

Duty cycle. Relay applications vary greatly as to frequency of operation. Some relays, for instance, are called upon to operate several times a second over extended periods of time. Other applications call for very infrequent operation. A minimum of 1 million operations (on-off) is regarded (arbitrarily) as the standard life of an industrial relay. Individual units may exceed this minimum life by a large margin.

Voltage rating. The voltage rating of the coil of a relay should be specified according to the power source available. If the power source has fluctuating voltage, the fact should be taken into account in determining the voltage range over which the relay should operate.

Because of the possibility of breakage of relays and associated wiring in a furniture factory, there is a definite electrical shock hazard to personnel. It is therefore advisable to install step-down transformers and utilize relays rated at no more than 24 V.

The following list of important points to be considered can be used as a guide in selecting the proper relay for a given application.

Contact system

- Contact arrangement
- Load on each contact
- Open-circuit voltage
- AC or DC
- Type of load
- Maximum surge current
- Duty cycle
- Life requirement
- Circuit

Actuation system

- Type of power source
- Amount of energy available
- Nominal voltage or current
- AC or DC
- Maximum voltage or current
- Fast operation
- Time delay
- Rectified AC
- Forms
- Shock
- Coil resistance
- Circuitry

Environmental conditions	*Physical requirements*
Normal ambient temperature	Space available
Maximum temperature	Size
Minimum temperature	Shape
Military specifications	Mounting
Standards laboratory specifications	Termination
Moisture	Plug-in
Humidity	Enclosure
Dust	Dust cover
Shock	Hermetically sealed
Vibration	Sealed
Linear acceleration	

D. Electronic components

Since many engineers in furniture and joinery factories may find the application of electronics too sophisticated, only a brief discussion of it will be made.

Electronic components are used mainly for control purposes; in fact, they are used more often than electrical components for those purposes. The most common electronic device used for control is the switching transistor, which serves the same function as a relay. But there are important differences:

(a) Relays are voltage-operated–transistors are current-operated;

(b) Relay switching is done by moving contacts–transistors do not have any moving parts;

(c) Most relays have several contacts–most transistors have only one current path;

(d) Relays can be operated on either AC or DC, depending on the coil design–transistors can be operated only on DC;

(e) Relays do not have a definite polarity–transistors do;

(f) Relays can be built to have "snap action", a term that is meaningless in transistor theory–but transistor switching is faster even than that of a snap-action relay.

VI. Understanding low-cost automation language

The symbols used by LCA engineers on their design papers arrows, squares, lines and half circles may look like hieroglyphics to one who has not seen them before. However, as the explanations in this chapter will show, these standard symbols and their combinations are much easier to understand than words and sentences of any written language.

A. Symbols for components

Pneumatic and hydraulic components

Cylinders

In general, a cylinder is composed of a cylindrical tube, a piston with a rod, and two end-covers. The end-covers are provided with threaded holes for connexion to the air or hydraulic line. Figure 37 shows these parts of and the standard symbol for a double-acting cylinder without cushioning.

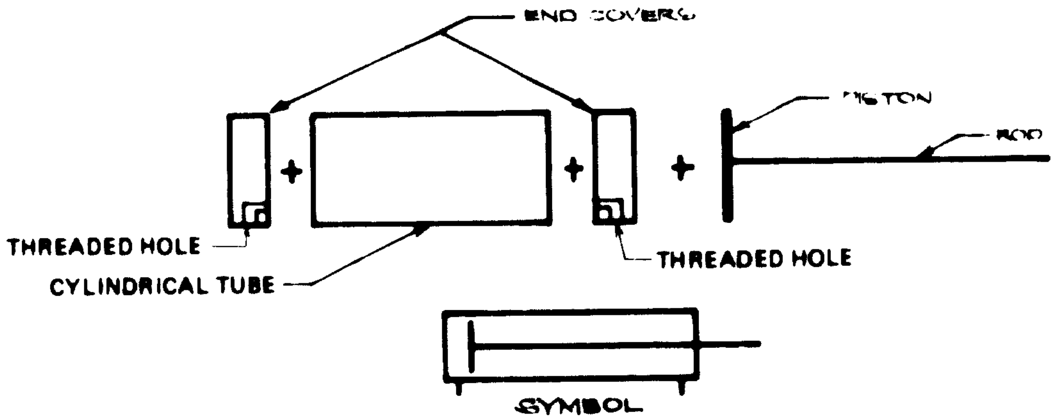


Figure 37. Double-acting cylinder, parts and symbol

A single-acting cylinder (fig. 38) is the same, except that it lacks one of the threaded holes; the return movement of the piston is accomplished by a mechanical spring.

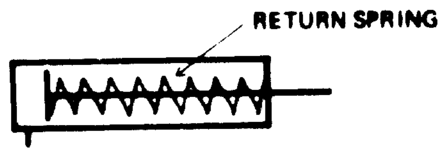


Figure 38. Symbol for a single-acting cylinder

A cylinder can also be equipped with cushioning devices to prevent jarring at the end of the stroke (fig. 39).

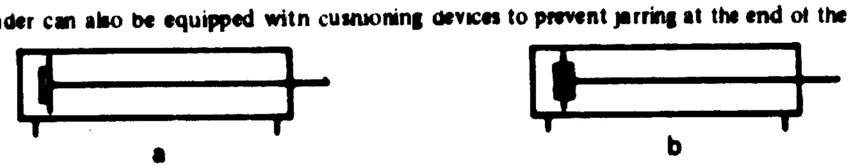


Figure 39. Double-acting cylinders with cushioning at (a) one end and (b) both ends

When the cushioning devices are adjustable, the corresponding symbols are as in figure 40.

Figure 40. Double-acting cylinders with adjustable cushioning in *(a)* one end and *(b)* both ends

Figures 41-44 are symbols for special types of cylinders. More symbols for cylinders are given in annex I.

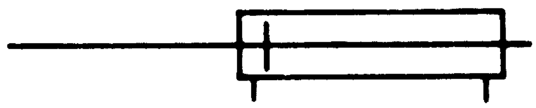


Figure 41. Cylinder with "through-going" piston rod without cushioning

Figure 42. Tandem-cylinder with adjustable cushioning in both ends

Figure 43. Three-position cylinders (strokes equal)

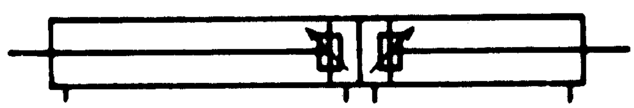


Figure 44. Four-position cylinder (strokes unequal)

Valves

Directional control valves. To understand the standard symbols for valves easily, it helps to look at the valve itself. Figure 45 shows a conventional, manually operated valve with two positions and two connecting ports. In the position shown, no fluid can pass through the valve because the passage between the ports is blocked by the spool (poppet). The spool will remain in this position unless actuated from the outside because of the spring holding it there from the inside. If the spool is pushed by a force larger than that exerted by the spring, so that the part of the spool with reduced cross-section is inside the passage, oil or air can pass through the valve.

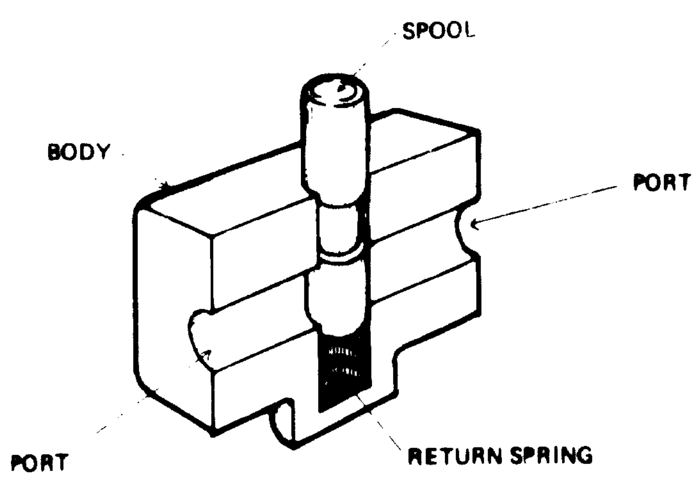


Figure 45. Manually operated valve with two positions and two ports

The basic symbol for the valve in figure 45 is shown in figure 46. The two squares in the symbol represent the two discrete positions of the valve spool. The upper square represents the position that allows flow and the lower square represents the blocking position.

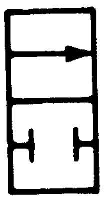


Figure 46. Basic symbol for the two-position, two-port valve in figure 45

The basic symbol is developed further by adding lines representing the tubing connected to the ports (fig. 47). The symbol is easier to understand if it is imagined that the two squares together represent the spool and move up and down together, with the tubing fixed, just as the real spool moves up and down in the fixed valve body. In figure 47*(a)* the spool is up, as in figure 45. No external force has been applied; the valve is said to be "not actuated". (In fact the spring is actuating the valve.) There is no flow-through; the valve is closed. In figure 47*(b)*, a force has been applied to push the upper square between the ports; the valve is said to be "actuated". Flow-through can occur; the valve is open.

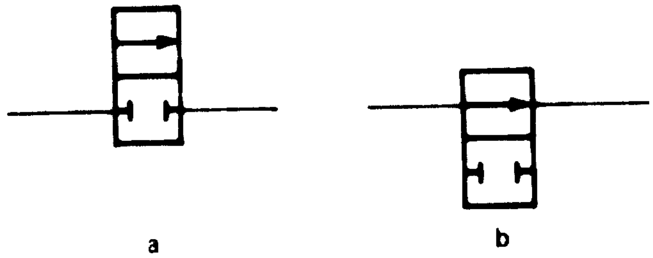


Figure 47. Symbols for two-position, two-port valve in *(a)* closed and *(b)* open states

To complete the symbol symbols that show the types of actuation used are added. A valve can of course be actuated in many ways. Some are shown in figures 48 and 49, and more are in annex I.

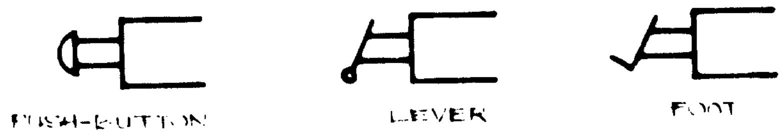


Figure 48. Manual actuators

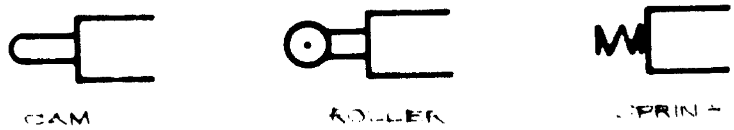


Figure 49. Mechanical actuators

The valve being described has an internal spring actuator (fig. 49) and can have a push-button (fig. 48) fitted to the other end of the spool. Symbols for these are added to the squares as in figure 50.

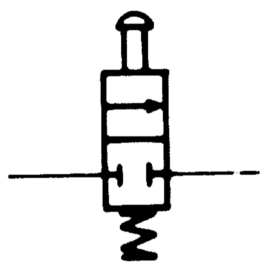


Figure 50. Complete symbol for two-position, two-port valve, showing actuators

Figure 51 shows the basic symbols for actuators controlled remotely by air (pilot valve) and electricity (solenoid), and figure 52 is the symbol for a composite air-electric actuator.

Figure 51. Remotely controlled actuators

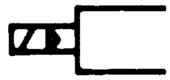


Figure 52. Electrically operated with pilot valve

There are also differential pressure valves, with priority on one side. In figure 53, air signal *b* has a higher pressure than air signal *a* and will operate the valve even if signal *a* is present.

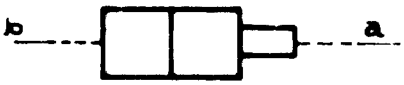


Figure 53. Signal *b* has priority over signal *a*

The most widely used type of valve in pneumatics is not, however, the one described above, but a combination of two of that type, one normally open and the other normally closed (fig. 54). If only the normally closed valve were actuated, the air would pass through and move the piston and piston rod out (to the right in the figure). Then if the actuator were released, the valve would return to its original position as drawn. The piston rod would stay out because the air in the cylinder could not escape. By coupling a normally open valve to the first, a path is provided for escape of the air when the actuator is released.

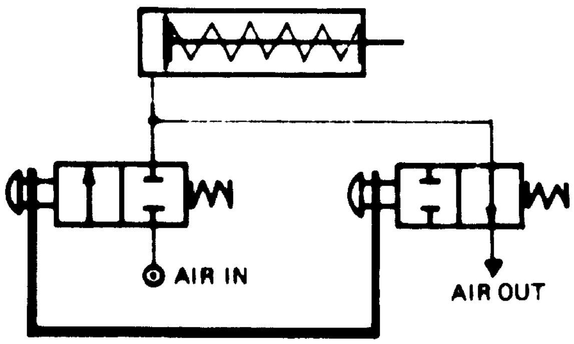


Figure 54. Two two-port valves connected mechanically, one normally open and one normally closed

Figure 54 also shows two new symbols. The circle with centred dot indicates connexion to the source of compressed air, and the inverted triangle connected to the valve with a line indicates evacuation through a threaded port. If the port is not threaded, the line is omitted and the triangle is placed directly on the valve symbol.

A cheaper solution than that of figure 54 is that of figure 55, which shows a valve called a two-position, three-port valve connected to the working cylinder. The situation drawn is the "rest" (not-actuated) position. (Normally, a system is always drawn in the rest position.) The air supply is seen to be blocked and the single-acting cylinder has been allowed to exhaust its air. When the knob is pushed, air is admitted through the valve to the cylinder. When the knob is released, the spring returns the spool to its former position, blocking the air supply again and allowing the compressed air in the cylinder to exhaust. The cylinder spring pushes the piston to its former position.

Another well known valve is the so-called five-port valve, which combines the function of two mechanically coupled three-port valves. For example, a double-acting cylinder can be operated by two coupled three-port valves (fig. 56) or by one five-port valve (fig. 57).

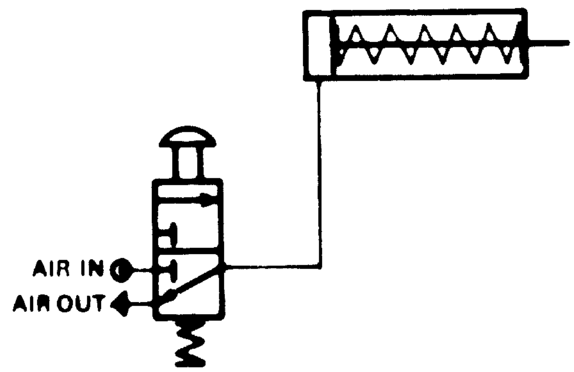


Figure 55. Two-position, three-port valve replacing the two valves of figure 54

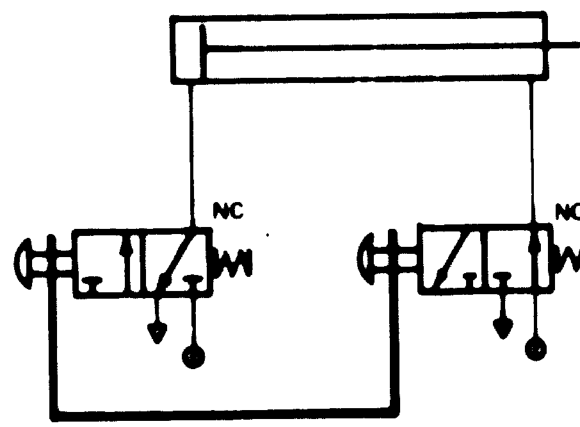


Figure 56. Double-acting cylinder operated by two coupled three-port valves

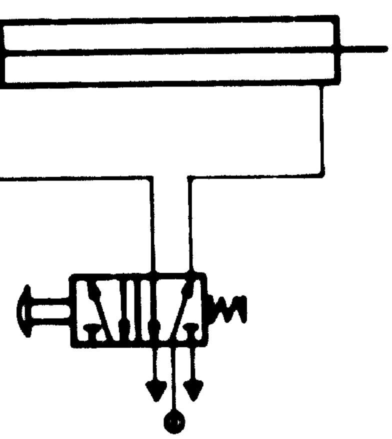


Figure 57. Double-acting cylinder operated by one five-port valve

According to standards set by the European Oil Hydraulic and Pneumatic Committee (CETOP) and the International Organization for Standardization (ISO), one is free to use either of the symbols in figure 58 for the three-port valve.

Only two-position valves have been under discussion so far. Valves with more positions are drawn by adding one square for each additional position (fig. 59).

Directional control valves are given numerical designations in the CETOP standards. Examples are in figure 60. The first figure gives the number of ports, the second the number of discrete positions.

Two special directional control valves are the check valve and the shuttle valve. The first (fig. 61) permits flow in one direction, stops it in the other. The second (fig. 62) permits flow into a common line from one or the other of two different sources, but not from both at the same time. It is sometimes called the "or-function" valve.

Figure 58. Alternative symbols for the two-position, three-port valve

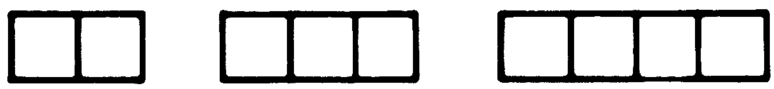


Figure 59. Basic symbols for two-, three-, and four-position valves

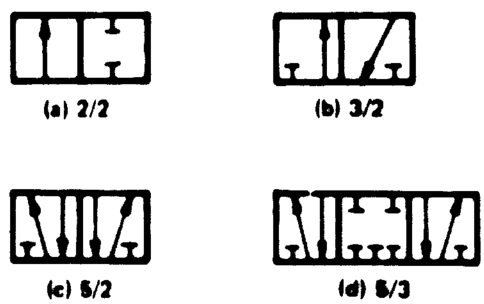


Figure 60. Symbols for and names of various directional control valves

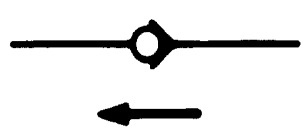


Figure 61. Simplified symbol for a check valve. Flow is possible only in the direction of the arrow

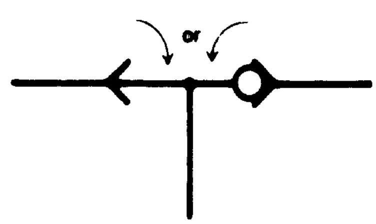


Figure 62. Simplified symbol for a shuttle valve. The arrows show the alternative flow paths

Flow-control valves. In pneumatic circuits, the flow-control valve, or restrictor, is the equivalent of the resistor in electric circuits. The symbol for a fixed restrictor is in figure 63, that for an adjustable restrictor in figure 64.

Figure 63. Fixed flow-control valve, or restrictor

Figure 64. Adjustable flow-control valve, or restrictor

The combination of an adjustable flow-control valve and a check valve is used for speed regulating or timing circuits (see fig. 65).

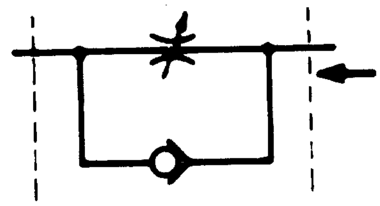


Figure 65. Adjustable flow-control valve with flow in direction of arrow unrestricted; flow in the opposite direction meets the restriction

Pressure-control valves. One well known type of pressure-control valve is the pressure regulator. The symbol is in figure 66

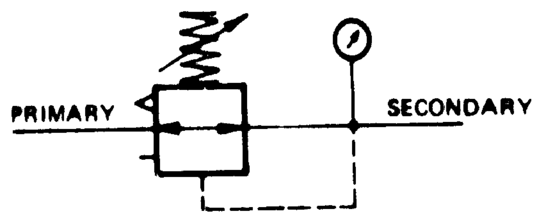


Figure 66. Simplified symbol for a pressure regulator. When the pressure in the secondary line rises above the pressure exerted by the adjustable spring actuator, the valve is actuated and exhausts the excess primary line pressure. When the pressure is too low, the spring actuates the valve to add pressure

Standard symbols. The symbols described above are a few examples of symbols standardized by CETOP, ISO and the United States Air Standards Institute (USASI). Annex I gives many more USASI symbols. Knowing one type will result in understanding the other symbols, since they are quite similar and developed from the same logic.

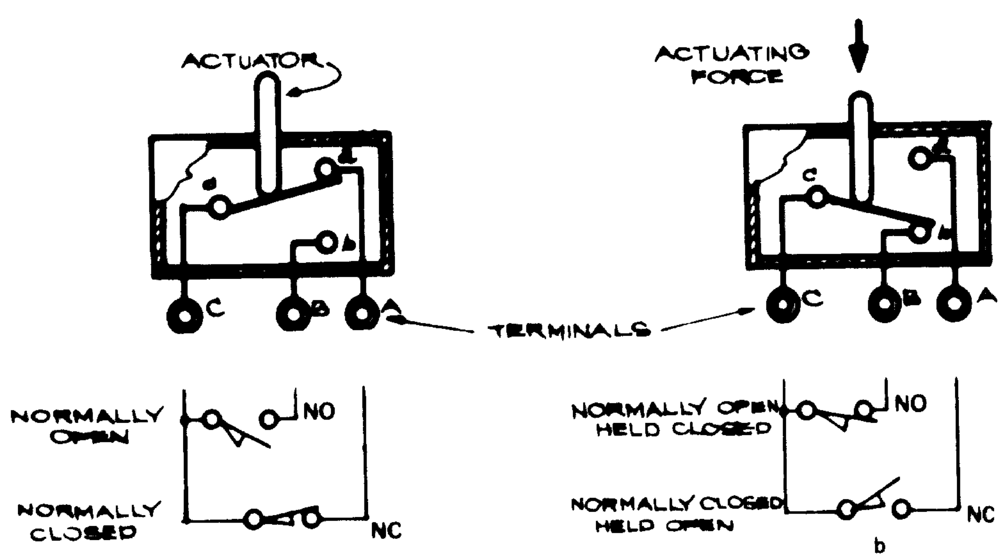


Figure 67. Diagrams and symbols for a typical limit switch in (a) unactuated (normal) and (b) actuated states

Electrical components

As explained in chapter V, section C, the most important electrical components used in LCA are switches: push-button, limit and relay. Symbols for them will be found in annex I. Although the symbol for the push-button switch is self-explanatory, those for the other types require some explanation.

Figure 67 shows pictorial diagrams and standard symbols for a limit switch. In the diagrams, three internal contacts a, b and c are connected to corresponding external terminals A, B and C. In the unactuated (normal) state, contact pair a, c is made and pair b, c is broken. Terminal A is therefore usually identified on the switch by the letters NC (normally closed), terminal B by the letters NO (normally open), and terminal C by the letter C (common).

When the actuator is pushed down, it moves the contact arm from a to b as if it were pivoted on c. In the actuated state, the normally open switch is held closed and the normally closed switch is held open as long as the actuating force remains. Removing the actuating force causes the limit switch to return to its normal condition.

Figure 68 shows a pictorial diagram of a typical SPDT relay together with the standard symbols for the relay and the switches it operates.

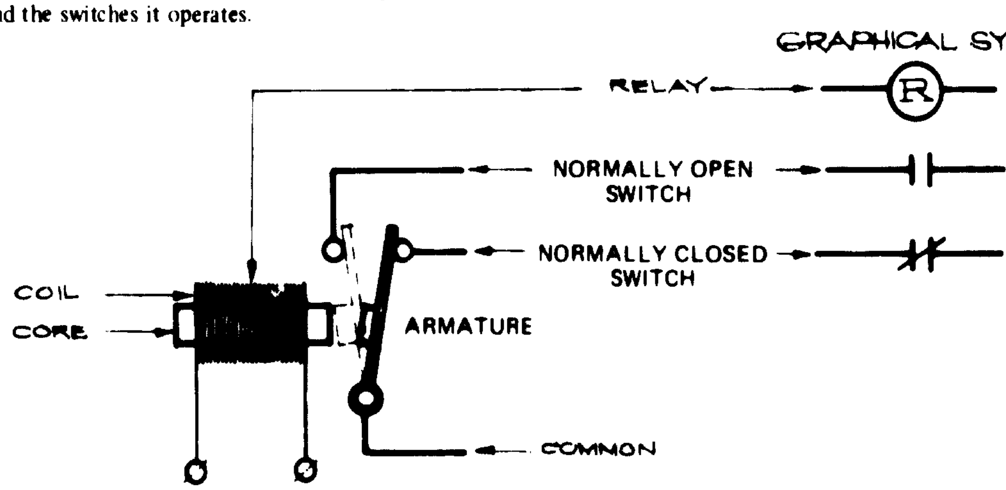


Figure 68. Diagram and symbols for a typical SPDT relay. Position of the relay armature in the actuated state is shown by the broken outline

When the relay coil is energized, the magnetism developed in its core pulls the armature, making one contact and breaking the other, as in the limit switch.

B. Schematic diagrams of control systems

Control system basics

The block diagram of figure 69 is a general representation of a control system. In this diagram, the detectors could be, for example, pneumatic or hydraulic valves, electric switches, photo-electric cells (electric eyes), a person's hands, eyes or ears. The power units could be, for example, motors, cylinders, or a person's hands or feet.

Every automatic machine works according to the basic principles involved in the general system of figure 69. The simple control system of figure 70 is merely a special case of figure 69, one without detectors and feedbacks. However, one could argue that the operator who sets the control box into action performs the function of those missing parts.

Building pneumatic and hydraulic control systems

In pneumatic and hydraulic control systems, or circuits, valves serve for detection and control, and cylinders are the power units. For example, in figure 71, cylinder A is controlled by a 5/2 valve in response to signals A_+ and A_-. The two 3/2 valves on the right detect the changes in position of the cylinder piston rod and yield the feedback signals a_0 and a_1. Note these conventions:

(a) Pneumatic or hydraulic cylinders are labelled with capital letters;

(b) The state of a cylinder with its piston rod retracted is called state 0 (zero); with it in the forward position, state 1. Stages between the fully retracted or fully forward positions are called 2, 3 etc., depending on the number of them;

(c) The signal to the cylinder control valve is given a symbol consisting of the cylinder label and subscript + (plus) if it makes the rod go forward or – (minus) if it makes the rod retract;

(d) Valves that detect the state of the cylinder (position of the piston rod) and the feedback signals from them are labelled with the same letter as the cylinder, but lower case, and a numerical subscript corresponding to the state.

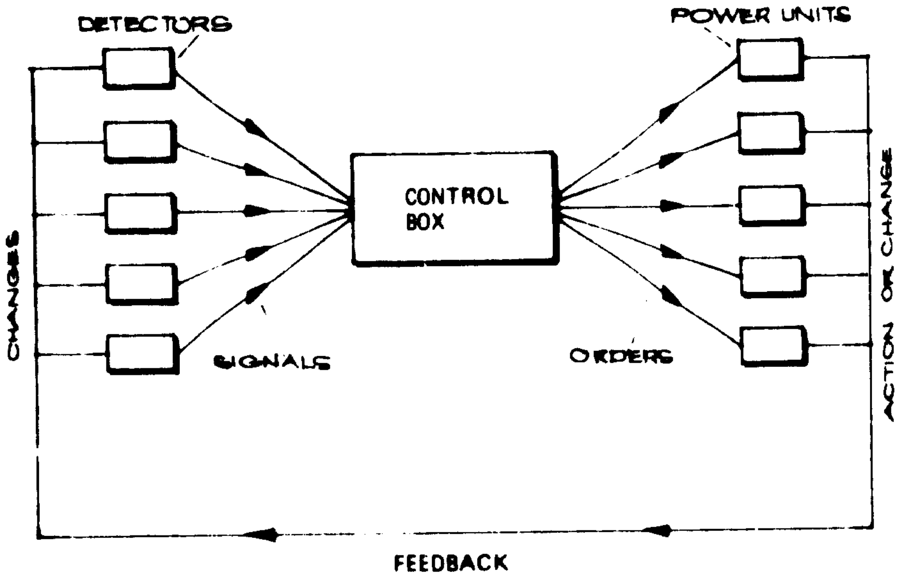


Figure 69. Block diagram of a generalized control system

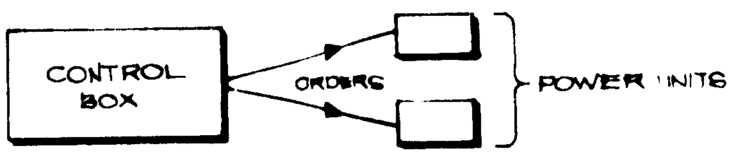


Figure 70. Block diagram of a simple control system without ostensible feedback

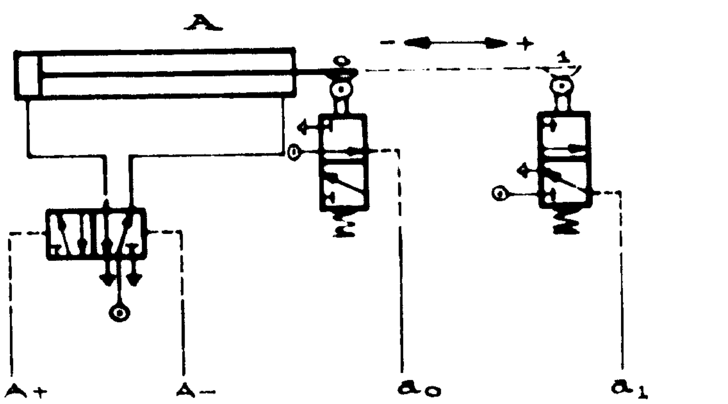


Figure 71. Uncompleted pneumatic (or hydraulic) circuit diagram. See text for explanation

If the feedback loop in figure 71 is completed by connecting the line from a_0 to A_+ and the one from a_1 to A_- (fig. 72), the result is a continuously oscillating cylinder: When the cylinder arrives in state 1, valve a_1 is actuated and directs a signal A_- to the control valve, which "orders" the cylinder back to state 0; here, valve a_0 takes over and sends the cylinder to state 1 again, to repeat the cycle as long as pressure is maintained in the supply lines.

In figure 73, two cylinders are actuated in the sequence $A_+ B_+ A_- B_-$ each time the "on-off" valve at the lower left is actuated. This circuit could be used, for example, as follows: Cylinder A positions the work under a stapling gun, and cylinder B triggers the gun.

It is clear that as components are added the circuit diagram rapidly becomes complicated and quite difficult to interpret. A help in interpretation and design is the time-motion diagram.

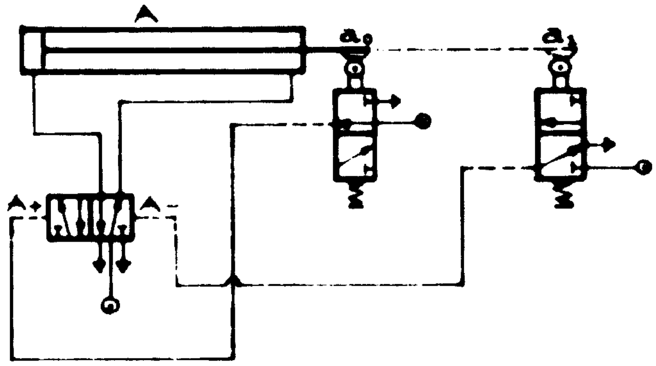


Figure 72. Continuously oscillating cylinder (completion of circuit in figure 71). See text for explanation

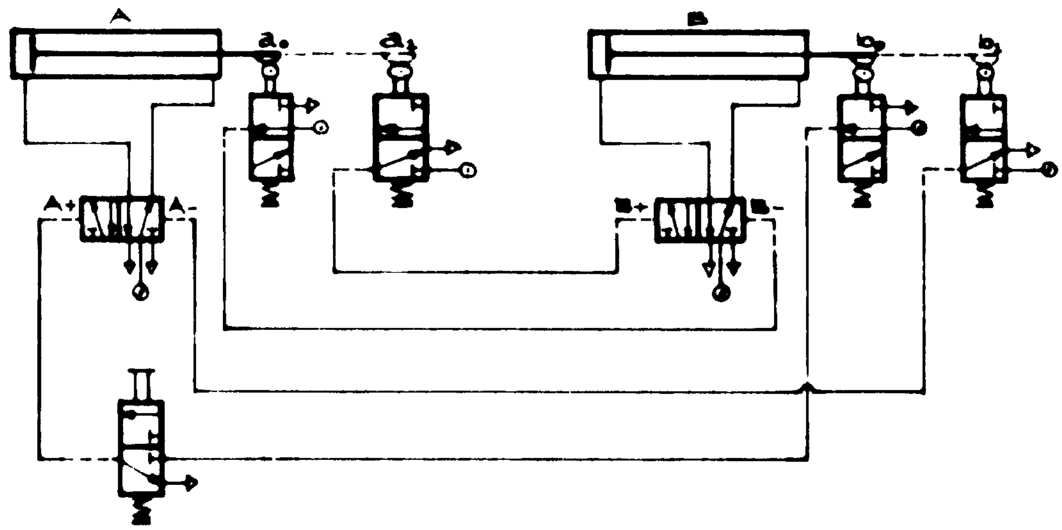


Figure 73. Two-cylinder circuit. When the valve at lower left is actuated, the signal sequence is $b_0A_+a_1B_+b_1A_-a_0B_-$

Figure 74 is the time-motion diagram for the cylinders of the circuit in figure 73. For each power unit (in this case cylinders), there are horizontal lines in the diagram representing its discrete positions (in this case 0 and 1). The vertical lines divide the complete cycle into time intervals, each representing a step made by the equipment during the performance of the cycle. These lines are labelled with Roman numerals from left to right. In this case line IV represents the end of the cycle (and equally well the beginning if it is automatically repeated).

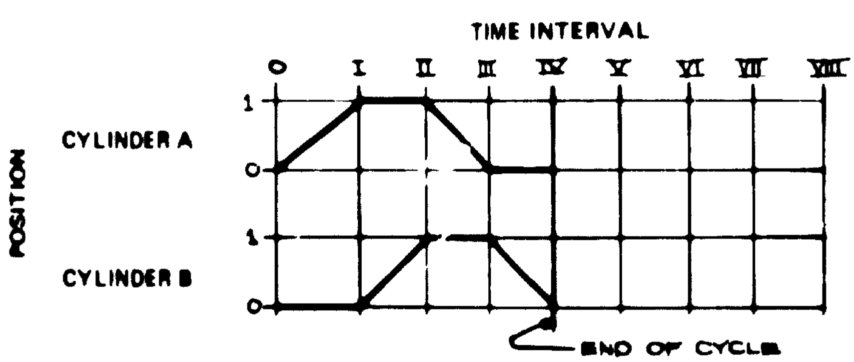


Figure 74. Time-motion diagram for the circuit of figure 73

Using the time-motion diagram, it is easier to interpret how the cylinders will react and, more important, to convey to an LCA engineer the motion the designer wants.

Building electrical control circuits

Figure 75 is a schematic diagram of an air-cylinder system connected to a solenoid-operated, spring-returned 4/2 valve. Figure 76 is the associated electrical circuit diagram. When push-button switch 1 is actuated, current passes through the coil of the solenoid $A_{(+)}$, causing the valve to shift. To return the cylinder to its former position, the push-button is released.

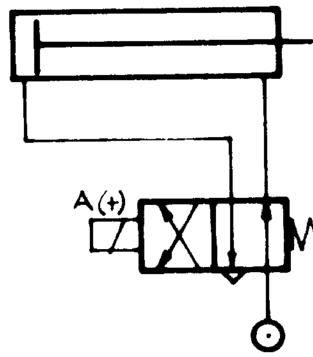


Figure 75. Air cylinder controlled by a solenoid-actuated valve

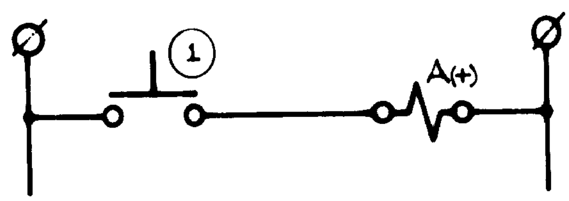


Figure 76. Electrical circuit for controlling the air cylinder of figure 75

Another possibility is the circuit in figure 77, which makes use of relays to carry the solenoid coil current.

If the cylinder is to remain actuated even if the push-button is released, the circuit of figure 78 can be used. Relay S has two sets of contacts, S_A and S_M. When push-button 1 is depressed, relay S closes both sets. Set S_A energizes the solenoid $A_{(+)}$, while S_M provides "memory" by keeping the relay actuated even after push-button 1 is released. To return the cylinder, the normally closed push-button switch 2 must be operated.

The cylinder rod can be made to return automatically to its former position after it has reached some point of its stroke by replacing push-button 2 by a (normally closed) limit switch located at that point (fig. 79).

The circuit of figure 80 yields an oscillating motion of the cylinder. The oscillation is started by depressing push-button 1, which initiates this sequence: Relay W operates and latches; relay S operates and latches; coil A is energized; piston goes to 1; a_0 and a_1 open; S_A opens; piston returns to 0; a_0 and a_1 close; S operates and latches again, repeating the sequence from the point until the oscillation is halted by depressing push-button 2, which destroys the memory of W.

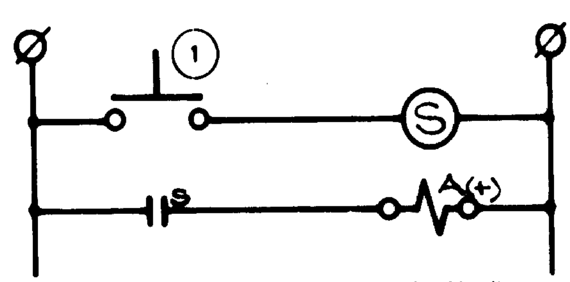


Figure 77. Inclusion of a relay to control solenoid coil current

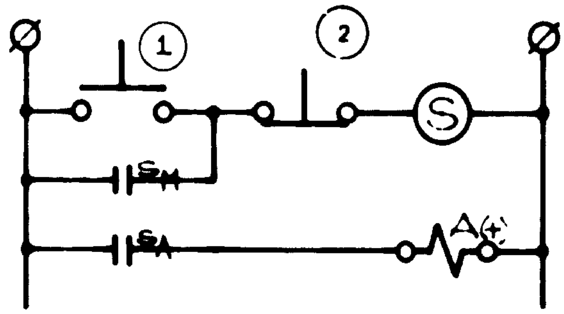


Figure 78. Use of solenoid with "memory" to keep cylinder actuated after push-button is released

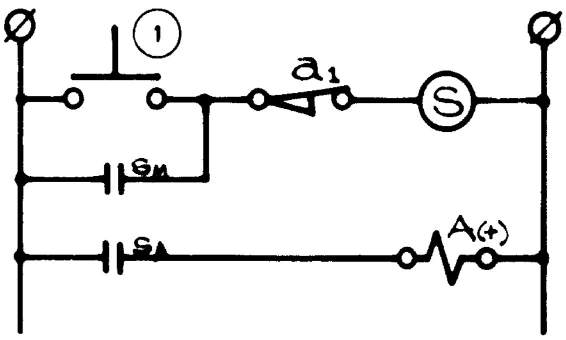


Figure 79. Use of limit switch to destroy memory of relay at a predetermined time

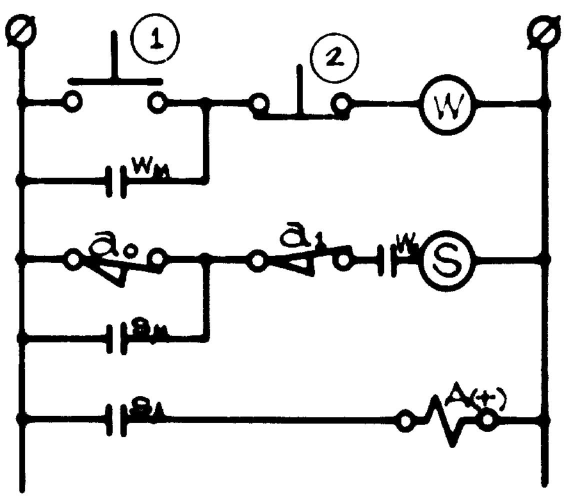


Figure 80. Control circuit for an oscillating cylinder

Suppose that the cylinder of figure 75 will be used as a press. For safety's sake, the piston must not move unless both of the operator's hands are out of the way of the press. That can be achieved by a circuit (fig. 81) in which the press will only be actuated if two separate push-buttons are depressed simultaneously, each by only one hand. The spring-return of the control valve in this case is itself a safety feature. In case of power failure, the spring will cause the valve to shift and restore the cylinder to its rest position.

Figure 82 shows a press operated by a double solenoid-actuated valve. To operate the cylinder, one must again press two push-buttons (1 and 2) at a time; but, note that upon the release of these push-buttons (or in a power failure), the valve (and hence the cylinder) will not return to 0 automatically. To return the cylinder to its former position, one must operate the other set of push-buttons (3 and 4) simultaneously. Safety for the operator is therefore provided on the return, as well as the forward, stroke.

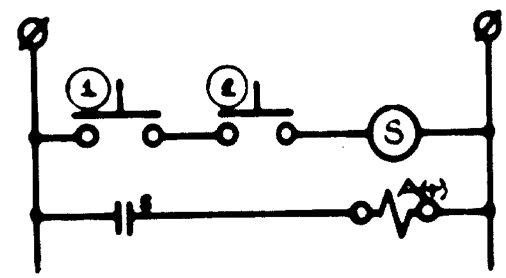


Figure 81. Safety circuit. Cylinder will not operate unless operator pushes switch 1 with one hand and switch 2 with the other

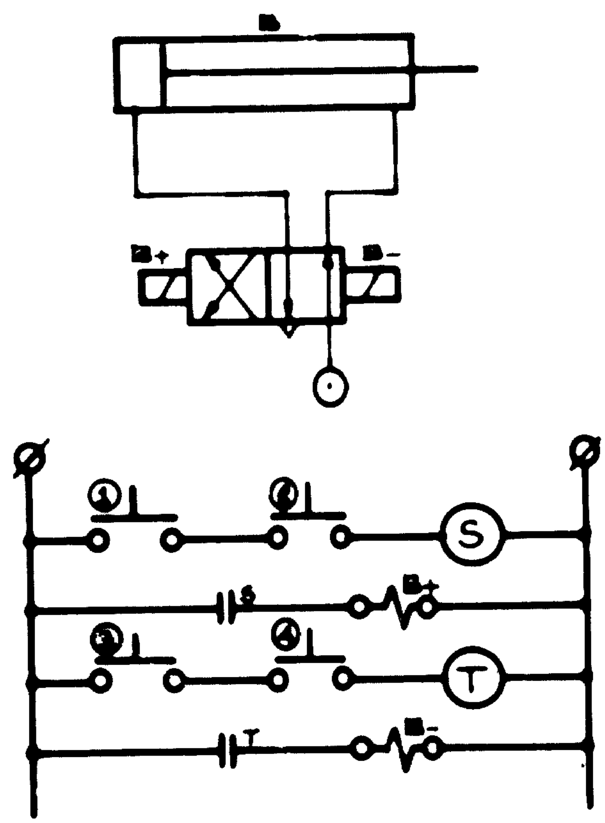


Figure 82. Cylinder press operated by a double solenoid valve and provided with safety switches in both stroke directions

Figure 83 shows a cylinder that has two strokes per cycle, the first short and the second long.

When the "on" push-button is depressed, relay R_1 and solenoid $B_{(+)}$ are energized simultaneously. The piston will therefore go forward until it reaches its mid-stroke position 2, where switch a_2 is actuated, energizing R_2 and cutting off the solenoid valve. The piston now returns to its former position and, as soon as a_0 is actuated, goes forward again, but this time for its full stroke, until a_1 is reached. Normally closed relay R_4 is opened thereby, and the piston retracts fully to its rest position. End of cycle. (The actuator of switch a_2 does not operate on the reverse stroke of the piston.)

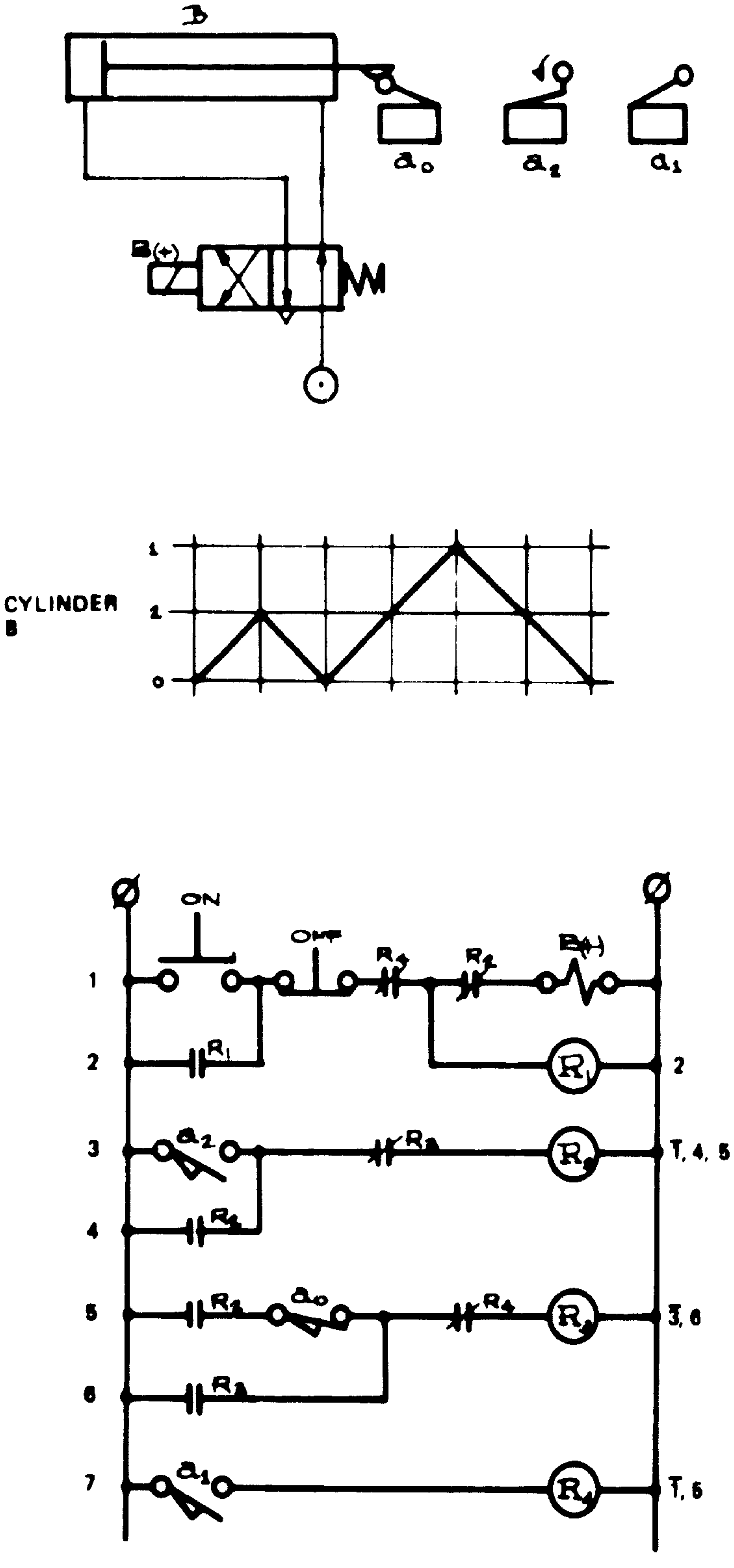


Figure 83. Pneumatic circuit, time-motion diagram and electrical circuit of cylinder with two successive strokes of different lengths

VII. Examples of low-cost automation applications

In this chapter, some examples of LCA applications will be presented. Although the examples are for particular requirements, the circuits can also be modified for application to other needs. As was stated earlier in this manual, LCA is quite flexible in application; hence, one circuit can be utilized for several other different requirements so long as the motions needed for the components are similar.

A. Fire-hose clamp

One of the most useful items that can be adapted for use in a furniture or joinery shop LCA system is the simple fire-hose. Since a fire-hose can normally withstand an internal pressure of 20 atm, one can readily inject compressed air (normally at 10 atm) into a length of it and have a very effective yet cheap clamp. Because of their flexibility, such fire-hose clamps can easily clamp even curved wooden components. The only adaptation necessary is to close each end in some way and attach a tire-valve fitting.

An example is the clamping frame in figure 84, which is used to hold window or door frames together while the glue dries. One has only to plug in the fire-hose line into an air header and clamping occurs. Unplugging the line releases the pressure.

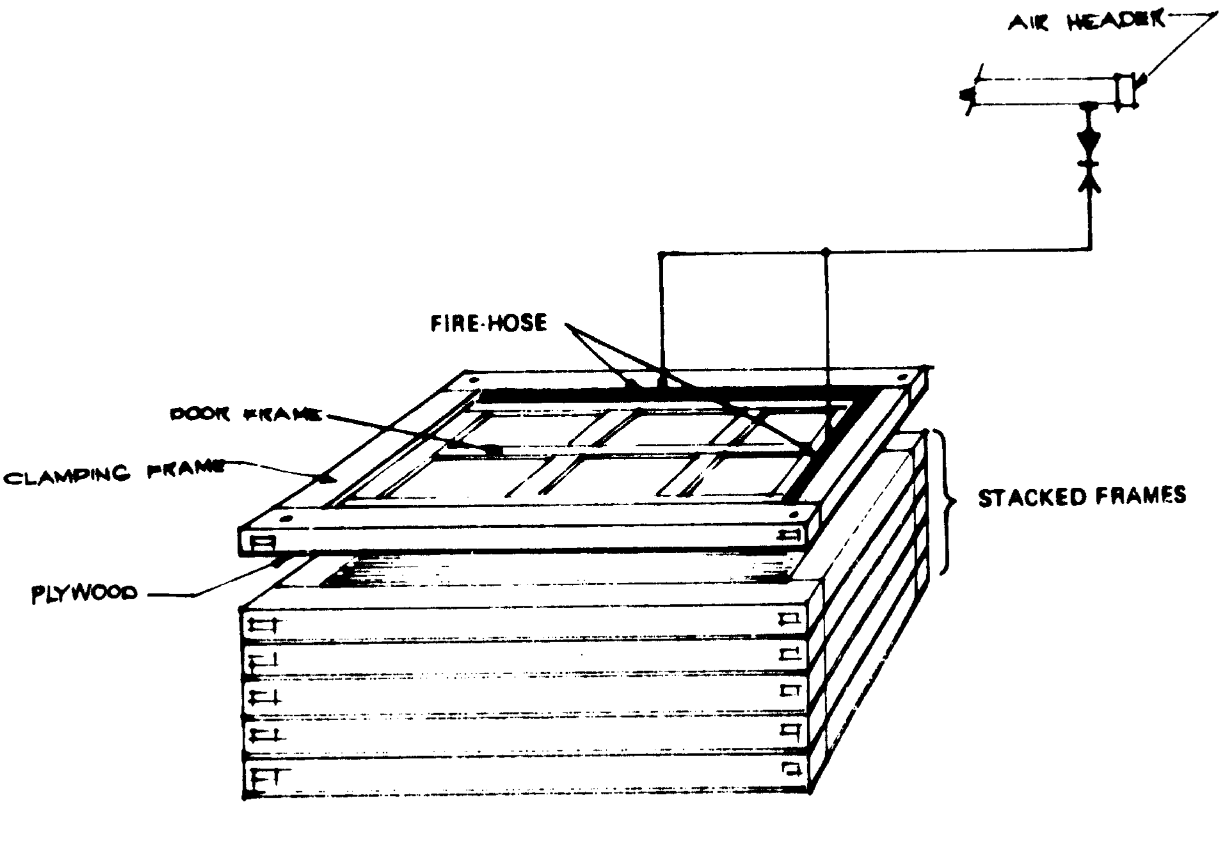


Figure 84. Fire-hose clamp

This fire-hose set-up eliminated the use of many hand clamps, which sometimes damaged the finish of the product, and actually increased labour productivity in one firm by as much as 30 per cent.

Investment cost

20 clamping frames	$56
Fire-hose (scrap)	
Fittings	30
Total	$86

Conditions before LCA

Labour cost	$0.06 per frame
Capacity	16 frames/day

Conditions after LCA

Labour cost	$0.04 per frame
Capacity	21 frames/day

Benefits

Savings in labour cost $0.02 per frame
Investment recovered after producing 4,300 frames (8 months)
Increased capacity and improved quality
Space saving due to more compact stacking

B. Fire-hose edge binder

This time the fire-hose is used with other components (electro-pneumatic) in a simple edge binder used for veneering the edges of a panel, as shown in figure 85. When the "on" button is depressed, the fire-hose is inflated. When enough pressure has built up in the fire-hose, the welding machine and the timer are turned on by R_2. The welding machine is connected to a thin copper plate that heat-sets the veneer. The timer, after a predetermined time, switches the welding machine and the hose valve off, unclamping the work.

Investment cost

Approximate cost of the components is $40.

Benefits

Better heating-in-place of the veneer, improving the quality of the product and increasing production by 20 per cent.

C. Door-frame assembler

For assembling door frames, the pneumatic set-up incorporating an air-cylinder and a fire-hose in figure 86 can be used. Pushing the "on" button activates air cylinder A. After a definite pressure is achieved, the fire-hose is pressurized, completing the assembly of the door-frame. Pushing the "off" button releases the clamps.

In a company that applied the set-up shown, door assembly capacity increased by almost four times with the same number of personnel. The following data pertains to a factory producing window frames.

Investment cost

LCA components	$130
Jigs	150
Fire-hose (scrap)	–
Total	$280

Conditions before LCA

Labour cost	$0.04 per frame
Capacity	21 frames/day

Conditions after LCA

Labour cost	$0.008 per frame
Capacity	104 frames/day

Benefits

Savings in labour cost $0.032 per frame
Investment recovered in three months
Quality improved

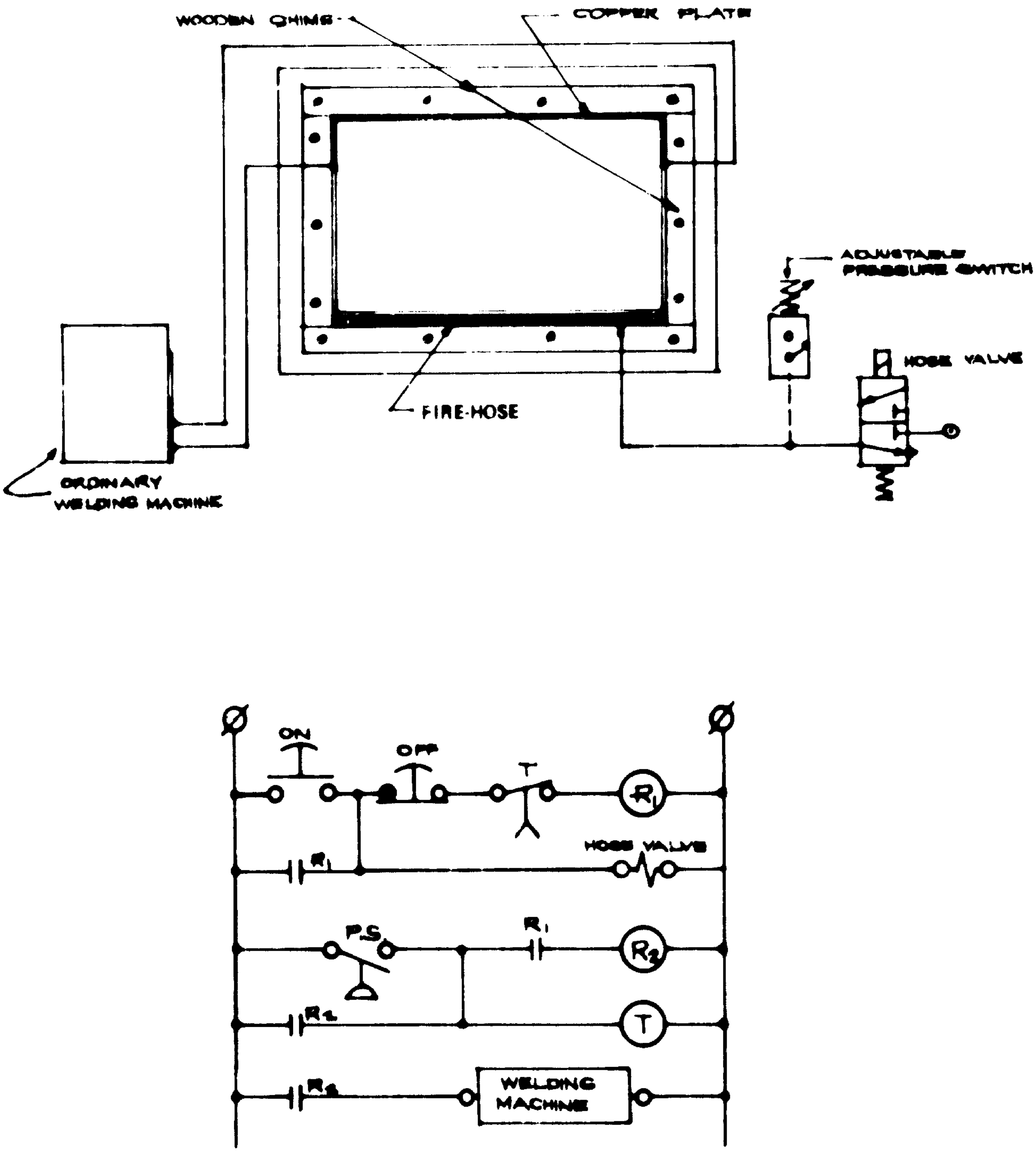


Figure 35. Fire-hose edge binder

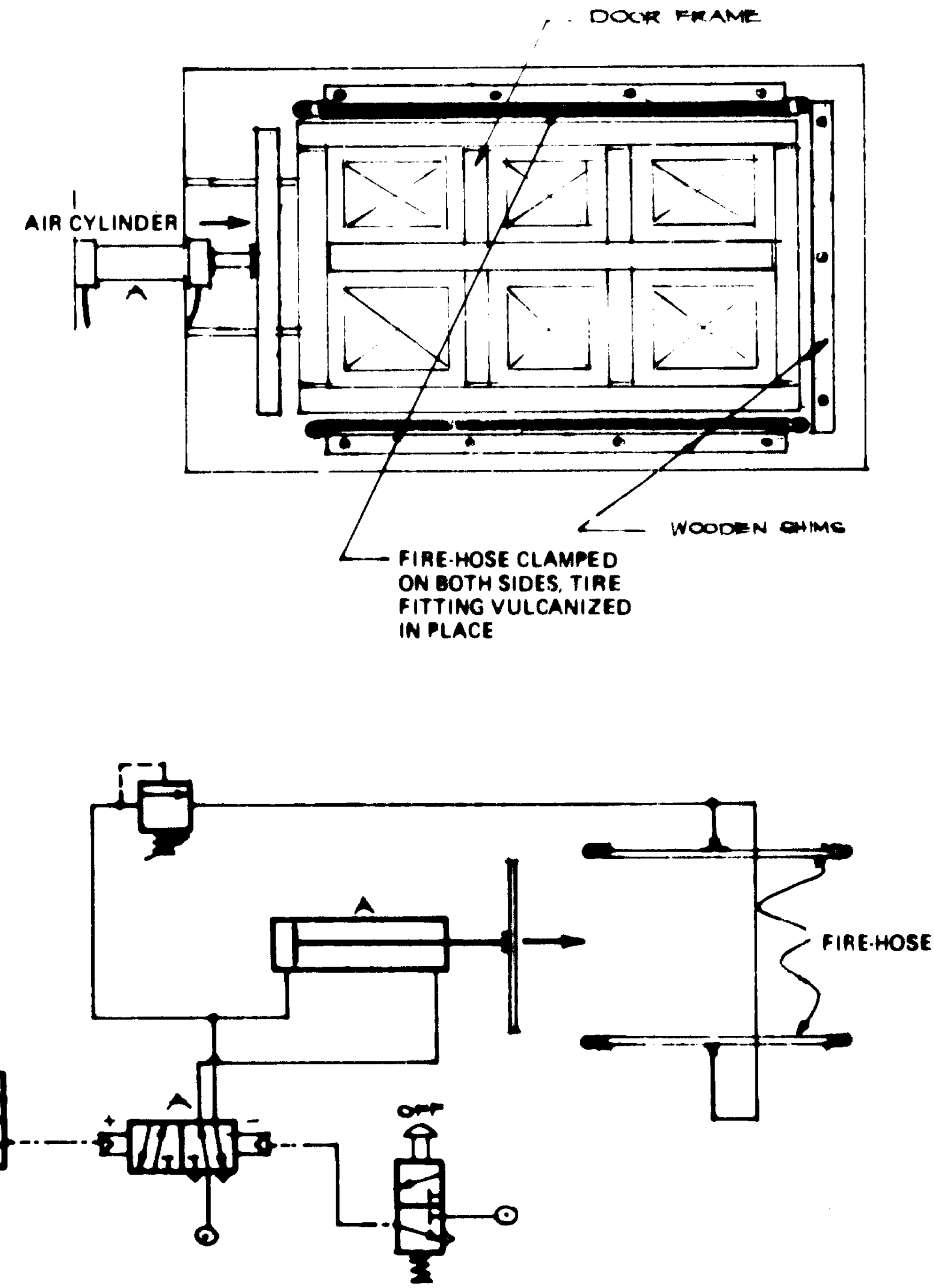


Figure 86. Door-frame assembler

D. Pneumatic spike driver

Nailing operations can usually be improved by the use of pneumatic nailing guns. However, at times the nailing requirement calls for longer nails (from 4 in.) or spikes, which cannot be conveniently loaded into such guns. In the absence of available standard pneumatic nailers, the system shown in figure 87 is suggested when the need is for nailing equipment that can drive spikes. Although slower than standard nailing equipment, the scheme can still alleviate irritating nailing problems. It is easy to adapt the scheme to specific needs.

The approximate cost is $450, of which $250 is for the LCA components and $200 for jigs, fixtures, etc.

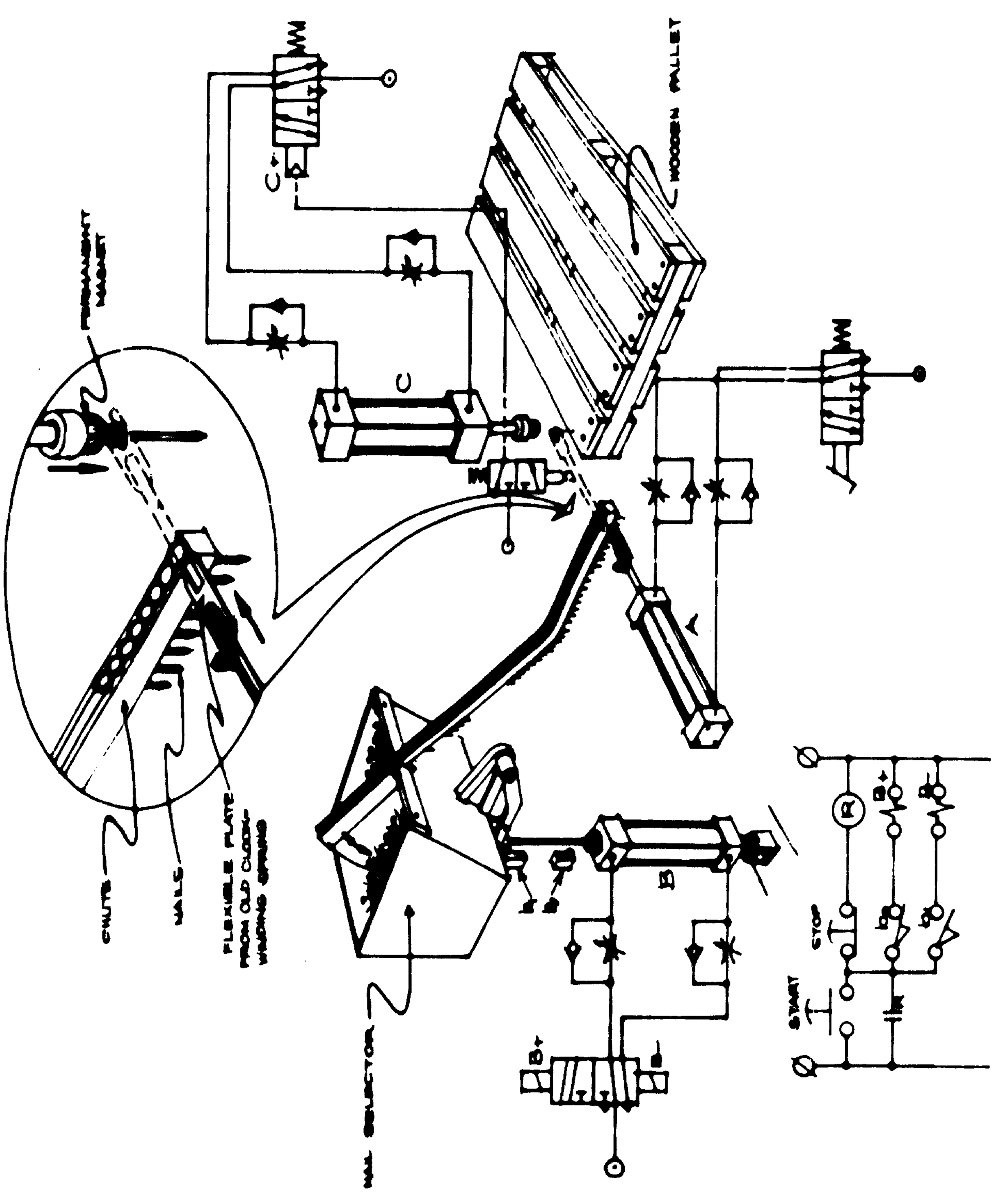


Figure 87. Pneumatic spike driver

E. Pneumatic impact riveter

By making use of an impact cylinder, tremendous instantaneous forces can be achieved. For example, a 4-in. impact cylinder supplied with air at 7 atm pressure can deliver a force of approximately 2 tons. Impact cylinders may be used for riveting purposes and for the insertion of metal connector plates.

The set-up in figure 88 speeded up the job of riveting the legs of folding chairs in a furniture shop metal department. **Warning!** The impact cylinder can cause serious injury to persons who accidentally have their hands in the way. The safety circuit shown must not be left out. It works as follows: The operator must push both valves A and B at the same time, using one hand on each valve, to actuate the cylinder. Pushing the valves one after the other will not actuate the cylinder.

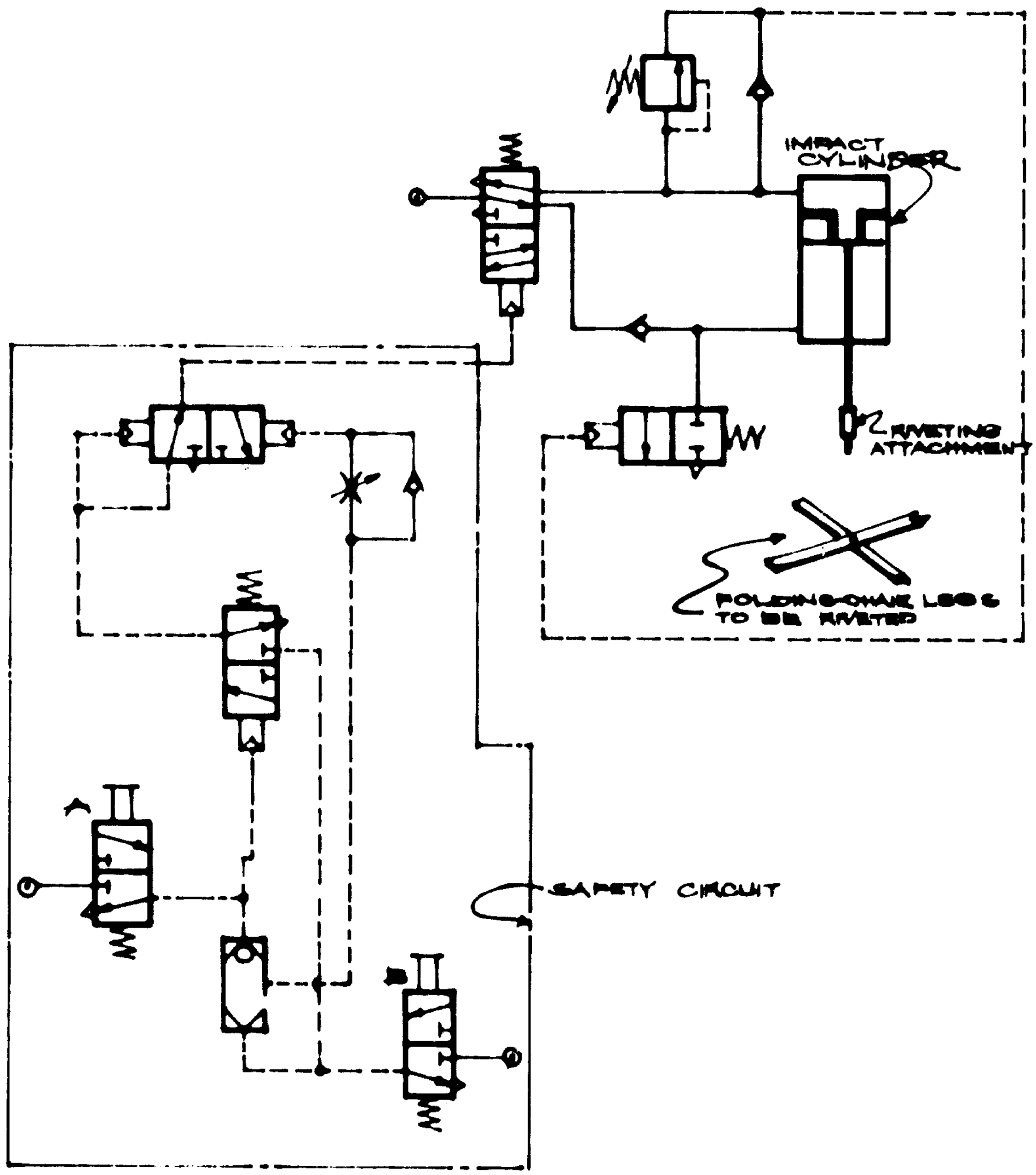


Figure 88. Pneumatic impact riveter

In a company which made use of the device, the following benefits were achieved:

Investment cost

The set-up costs approximately $250.

Conditions before LCA

Capacity	120 chairs/day
Labour cost (two men, one to position rivet, the other to set it)	$0.01 per chair

Conditions after LCA

Capacity	600 chairs/day
Labour cost (two men, as before)	$0.05 per chair
Power cost	$0.002 per chair

Benefits

Savings $0.038 per chair
Investment recovered in two weeks
Riveting quality improved

F. Thicknesser feeding mechanism

A feeding mechanism using an air-over-oil system is more precise in positioning than a purely pneumatic system, since oil is not compressible. In figure 89, it is really oil, pushed by compressed air, that moves the piston of cylinder A. When the "on" button is depressed the stack of boards is lifted by that cylinder until the topmost board actuates limit switch S. That causes valve Y to shut off valve X, which in turn cuts off the flow of oil in cylinder A, stopping its upward movement. Then, cylinder B retracts and pulls the topmost board into the thicknesser and, when limit switch b_0 is actuated, goes forward again. (Cylinder B is equipped with an ordinary bicycle wheel with a ratchet type of sprocket so that it can slide the wood in only one direction.) When the topmost board has been fed and is no longer on the stack, switch S opens, and the cycle repeats until all the boards in the stack have been fed.

Investment cost

LCA components	$150
Components and fixtures made in the shop	100
Total	$250

Conditions before LCA

Number of operators	2 (one feeds, the other stacks machined lumber)
Total wages	$4.20 per day
Fixed cost of machine	$83 per year
Utilization of machine (direct productive time)	50 per cent

Conditions after LCA

Number of operators	1 (feeder no longer needed)
Utilization of equipment	90 per cent

Benefits

Savings in labour cost	$2.10 per day
Savings by improved machine utilization	$33.20 per year

G. Automatic drilling

One of the most common tools used in a furniture or joinery factory is the drill. It finds many uses for drilling ordinary holes and dowel holes and for mortising.

The action required in an automated drilling process is a fast approach of the drill bit to the work and, once the object to be drilled has been reached, a controlled feed. Also, when the correct hole-depth has been reached, there must be a fast withdrawal of the bit. Effective clamping of the work is also important, particularly since it helps prevent accidents.

Figure 90a shows how an antiquated drilling set-up was automated to give better performance. A pneumatic cylinder in tandem with an oil checking cylinder was incorporated to obtain fast approach and controlled feed. The adjustment of the nut for the tandem will determine how far the fast approach will go. Adjusting the location of the microswitch determines the depth of drilling.

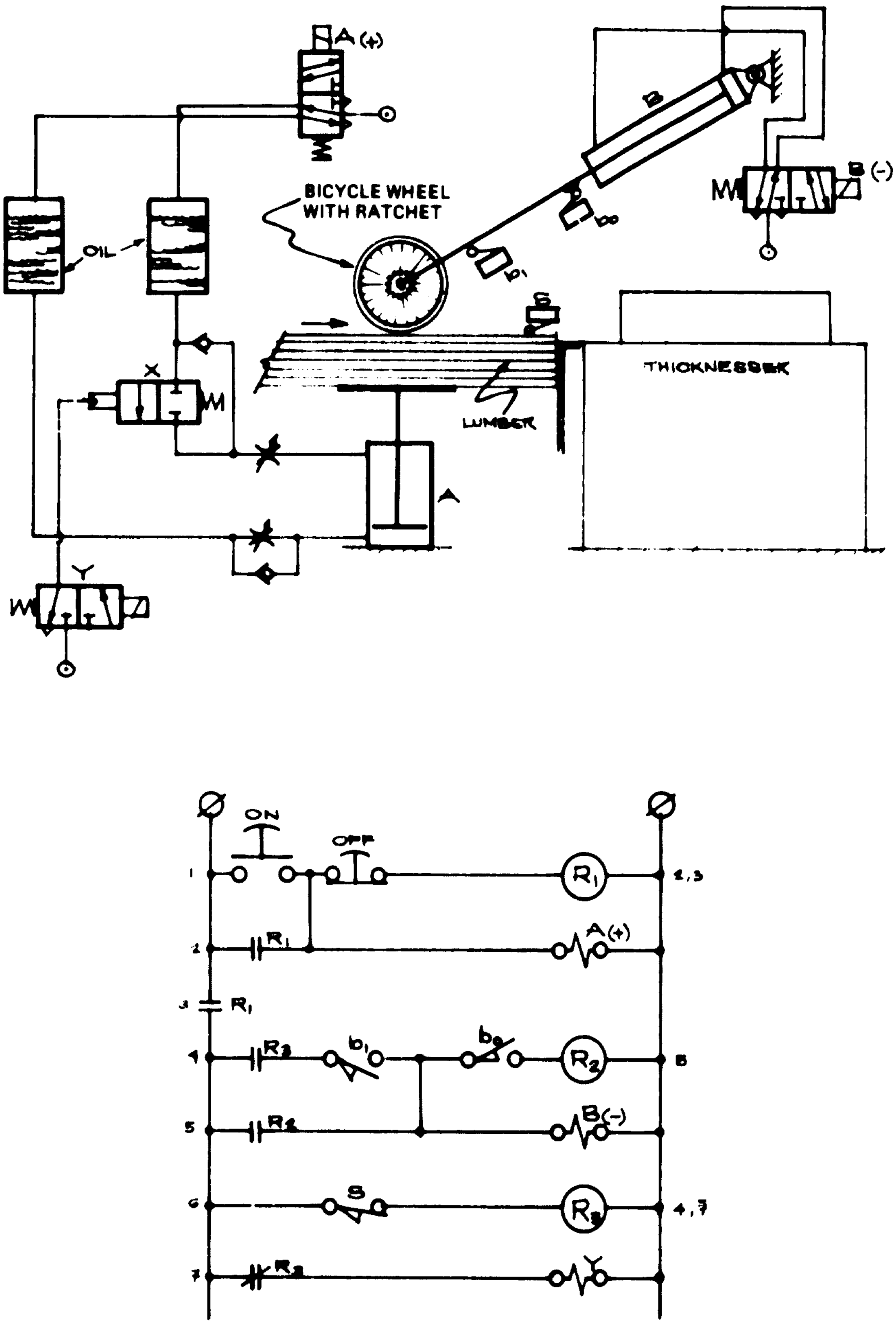


Figure 30. Thicknesser feeding mechanism

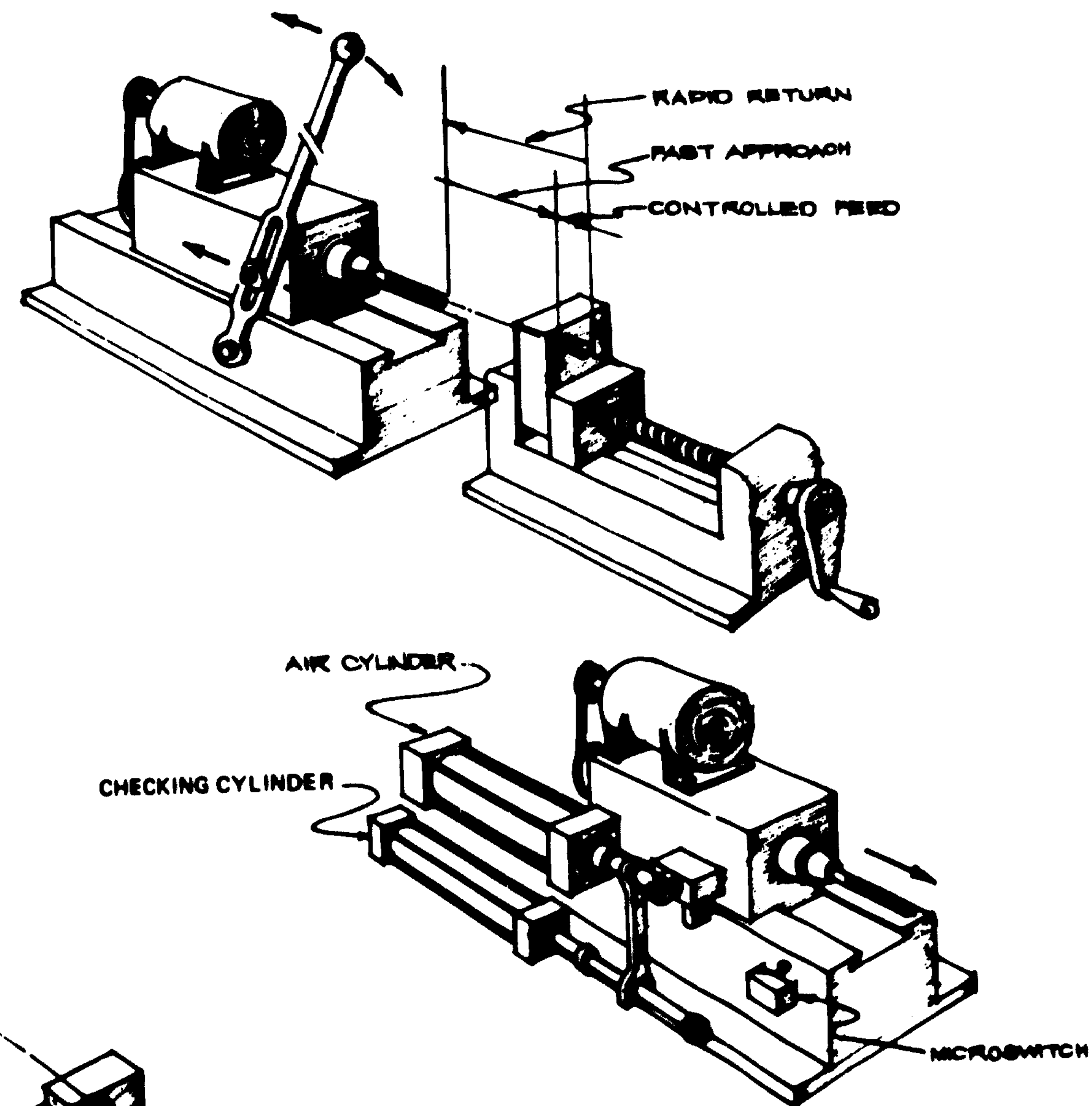


Figure 98a. Automated drill set-up: comparison with original set-up

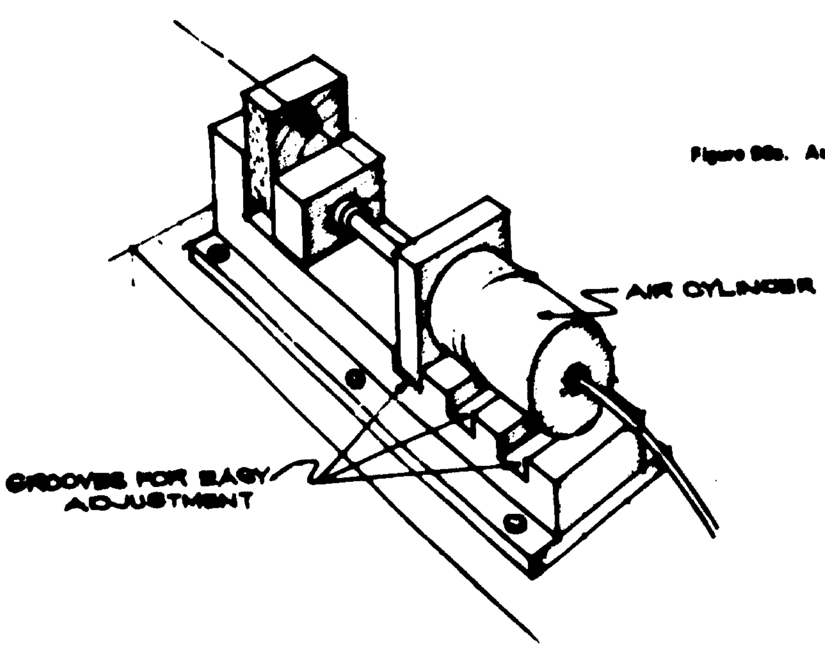


Figure 98b. Automated drill set-up: pneumatic clamp

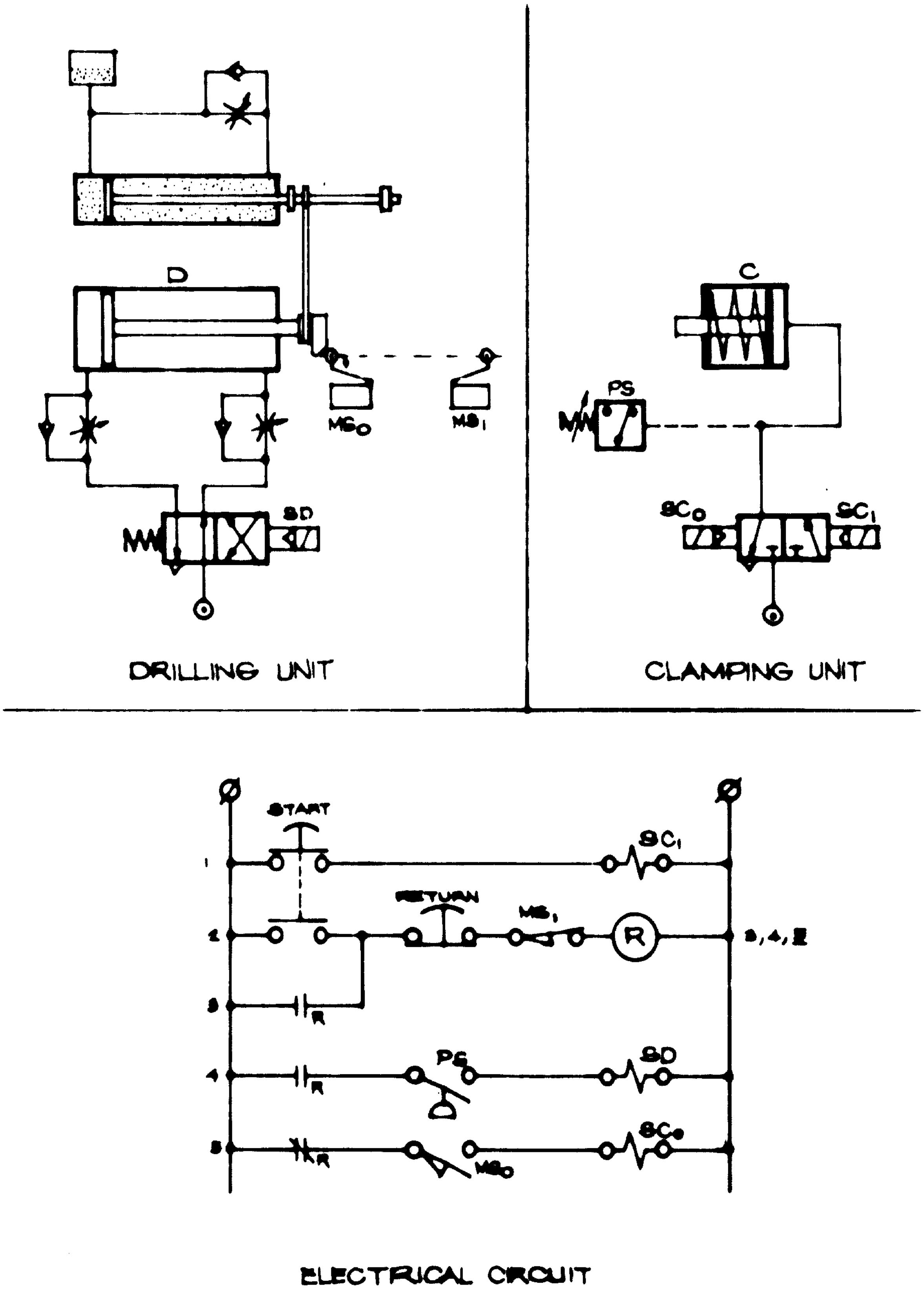


Figure 58a. Automated drill set-up: pneumatic and electrical circuit diagrams

Figure 90b shows how the clamp also was converted to pneumatic operation. It can be seen from the diagrams in figure 90c that pressing the "start" button operates the clamp, but pressure switch PS ensures that drilling will not occur unless the workpiece is firmly clamped. Once the proper hold-depth has been reached, MS_1 causes the drill to retract, after which MS_0 causes the clamp to release.

Investment cost

The approximate cost of the attachments is $160.

Benefits

A three-fold increase in the capacity of a mortising operation has been achieved with this set-up.

H. Automated drill press

Figure 91a shows another ordinary drill press which was equipped with an air cylinder and an oil checking cylinder. The circuit diagram in figure 91b indicates the possibility of having one-stroke or multiple-stroke operation, the former for ordinary drilling, the latter for successive mortising with a chisel-drill mortiser.

Approximate cost of the components is $100.

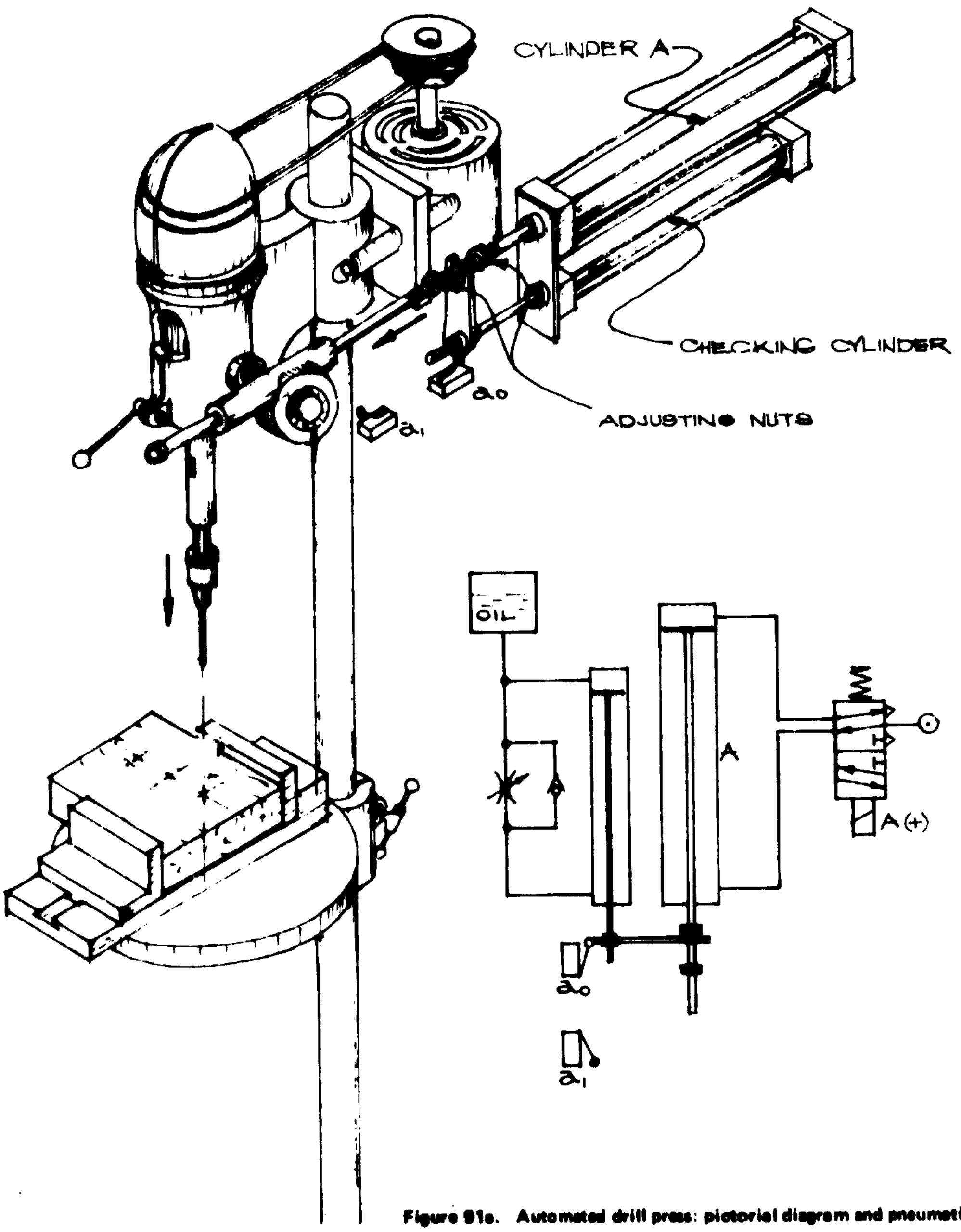


Figure 91a. Automated drill press: pictorial diagram and pneumatic circuit

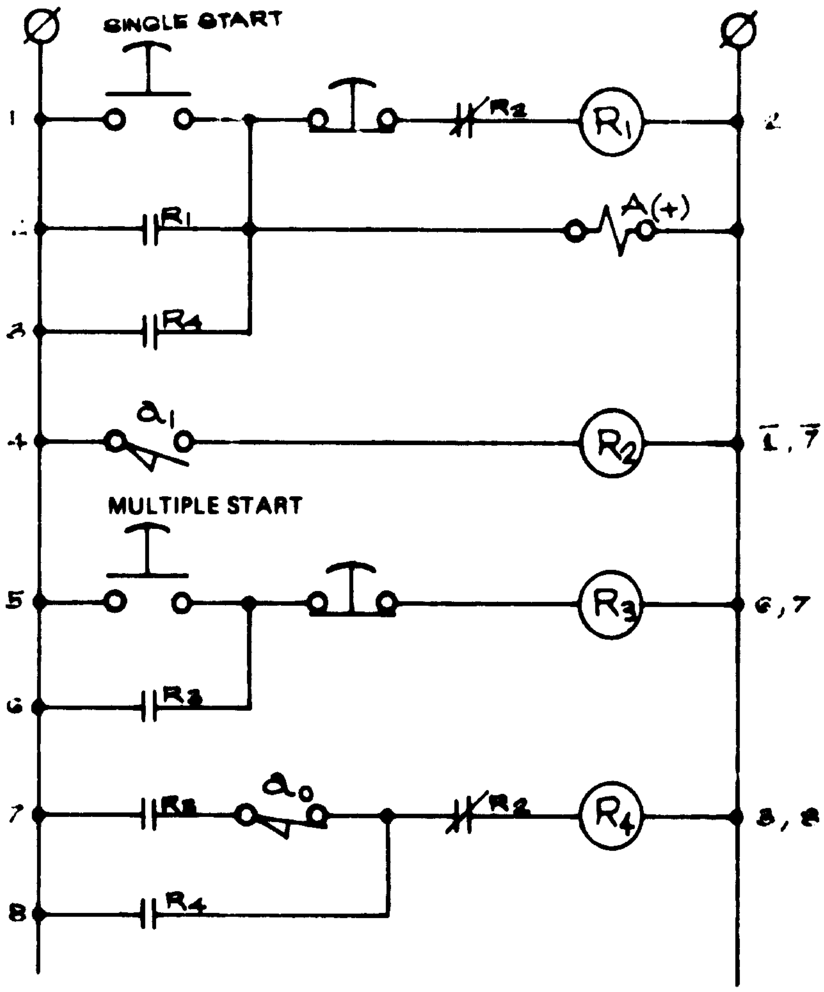


Figure 91b. Automated drill press: electrical circuit diagram

I. Automatic drilling with automatic feed and ejection

Another drilling set-up for simple drilling or making dowel holes, or even one-stroke mortising (drill-chisel type), is shown in figure 92a. Time-motion diagrams for the set-up are in figure 92b.

This example is a step higher in the ladder of automation since automatic feed and ejection of the workpiece are incorporated. However, in this set-up the dimensions of the workpiece must be uniform, since they determine the accuracy of hole location.

Feeding is performed by cylinder A through the magazine. When the workpiece is in position, valve a_1 (fig. 92c) causes cylinder B to clamp it, after which drilling starts. (Although figure 92a shows an ordinary air cylinder C as the motive force for drilling, it may be advisable to have an oil checking cylinder with it for the reasons given previously.) Having reached the hole-depth predetermined by the location of valve c_1, the drill retracts, and ejection by cylinder D occurs. The trap-door shown in the drawing (fig. 92a) assures non-interference between feeding and ejection.

Investment cost

The pure pneumatic solution of figure 92c would cost approximately $280 for the components. Converting the controls to an electrical system would lower the cost in components by as much as 60 per cent.

Benefits

This adaptation of LCA increased the output of one company by a factor of more than 6.5. (See chap. III, sect. C.) Also, instead of using two skilled mortisers in the purely manual operation before, only one semi-skilled operator to load the magazine was subsequently required.

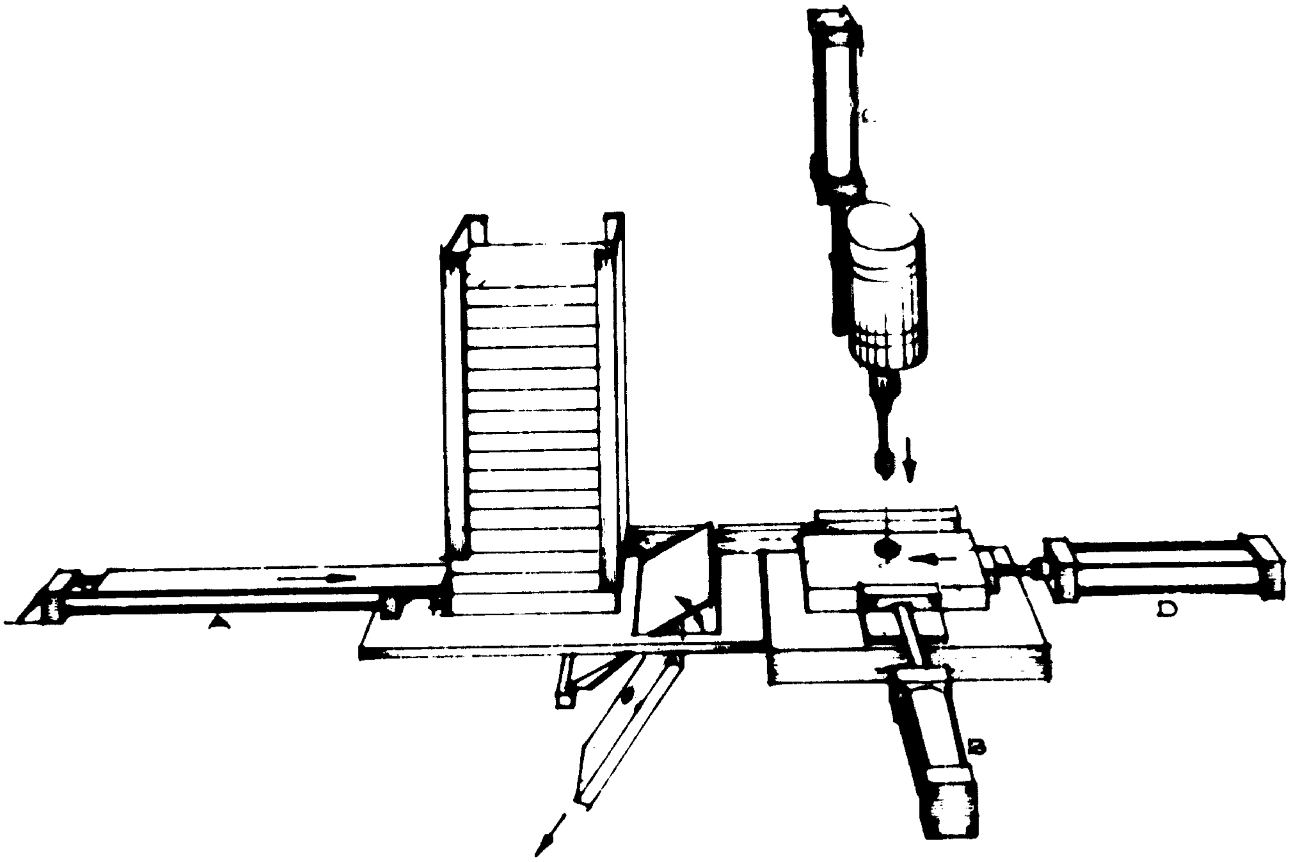


Figure 92a. Automatic drilling with automatic feed and ejection: pictorial diagram

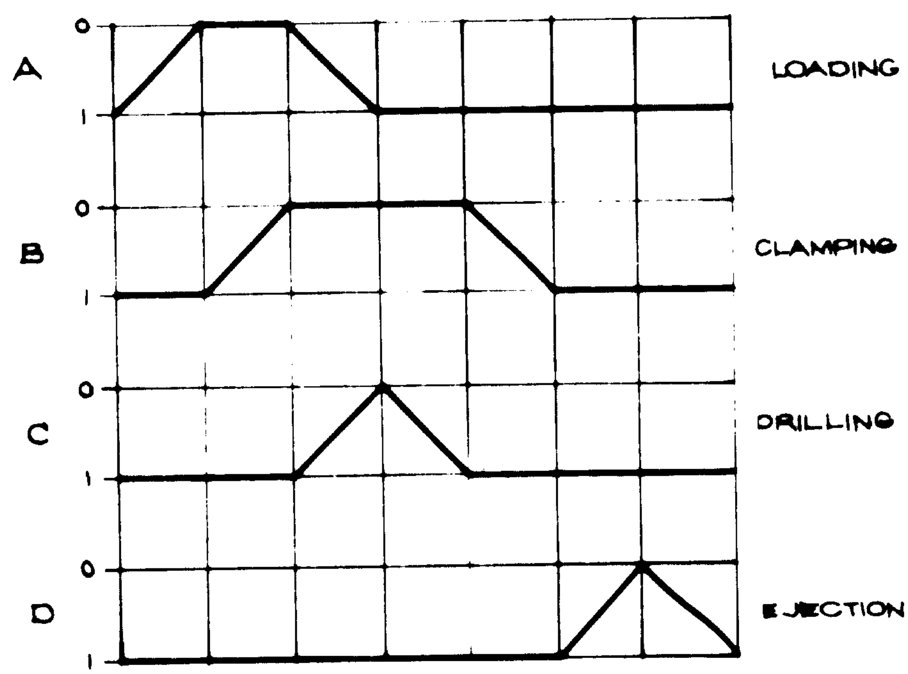


Figure 92b. Automatic drilling with automatic feed and ejection: time-motion diagram

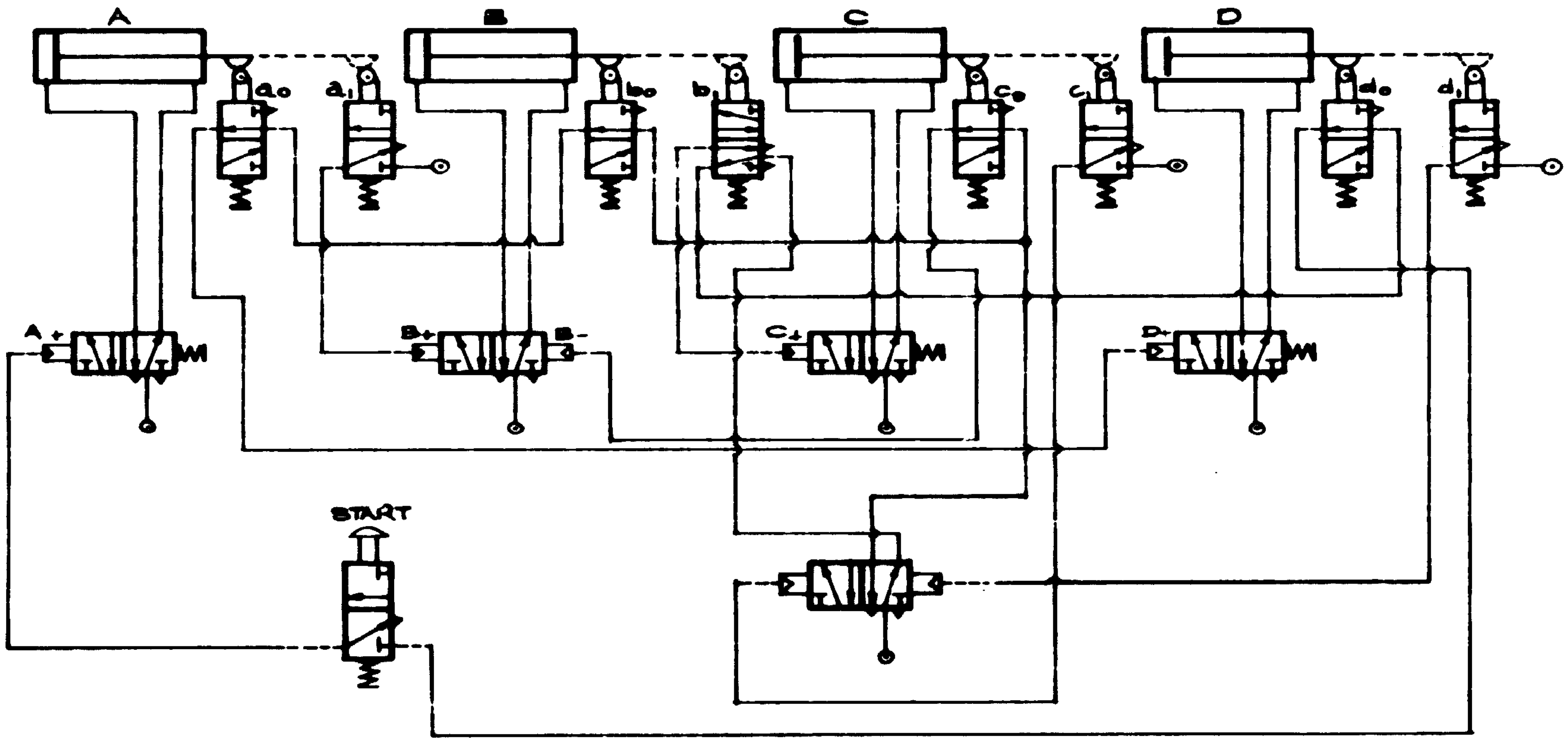


Figure 32c. Automatic drilling with automatic feed and ejection: pneumatic circuit

J. Dowel-hole drilling

Sometimes, dowel holes must be drilled with precise spacing to ensure a good fit of mating parts. An LCA solution to the problem is shown in figures 93a-93c. Once the system is turned on, the piece to be drilled positioned and the start button pressed, clamping occurs (cylinder D). When enough clamping force has been achieved (as relayed by pressure switch PS), the first hole is drilled and the drill is retracted. After that, cylinder A moves forward a distance determined by the location of limit switch a_1, and another hole is drilled. Then cylinder B takes over, moving the drill a distance determined by b_1 for the third dowel hole. (The depth of the dowel holes is determined by the location of limit switch c_1.) When cylinder C retracts from the third hole, cylinders A and B go back to their original positions and cylinder D unclamps. The system is ready again for a repetition of the cycle.

A built-in safety feature of the set-up is that in case of power failure, the drill retracts.

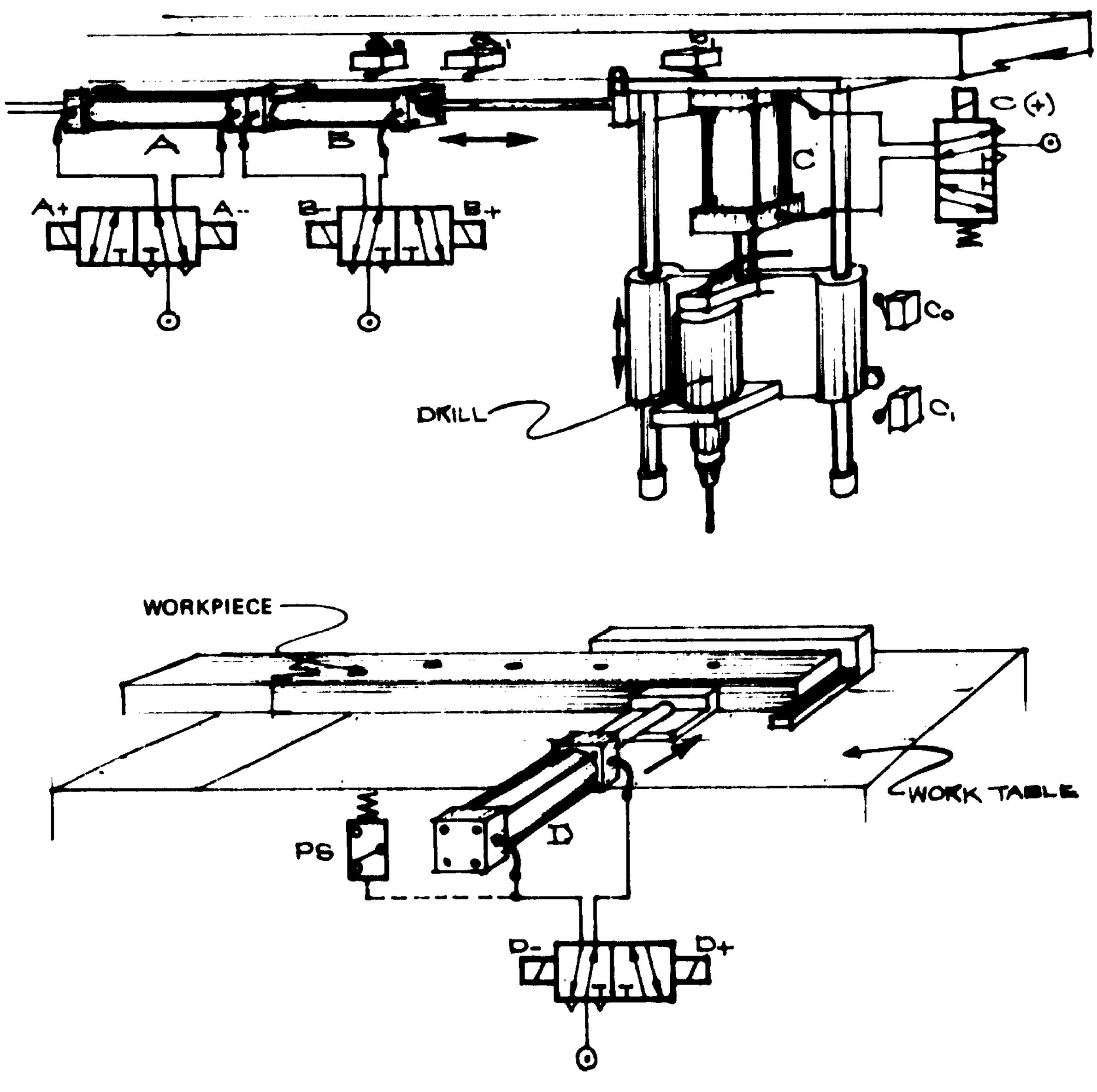


Figure 93a. Dowel-hole driller: pictorial diagram

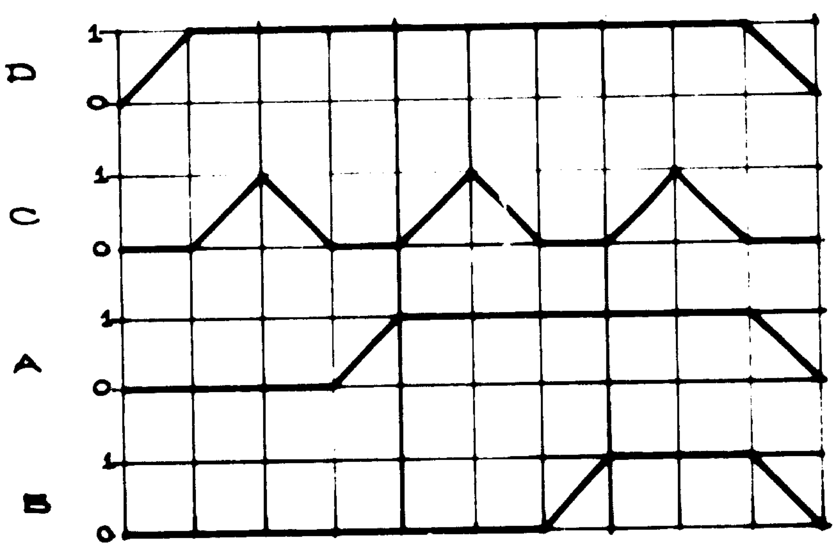


Figure 93b. Dowel-hole driller: time-motion diagrams

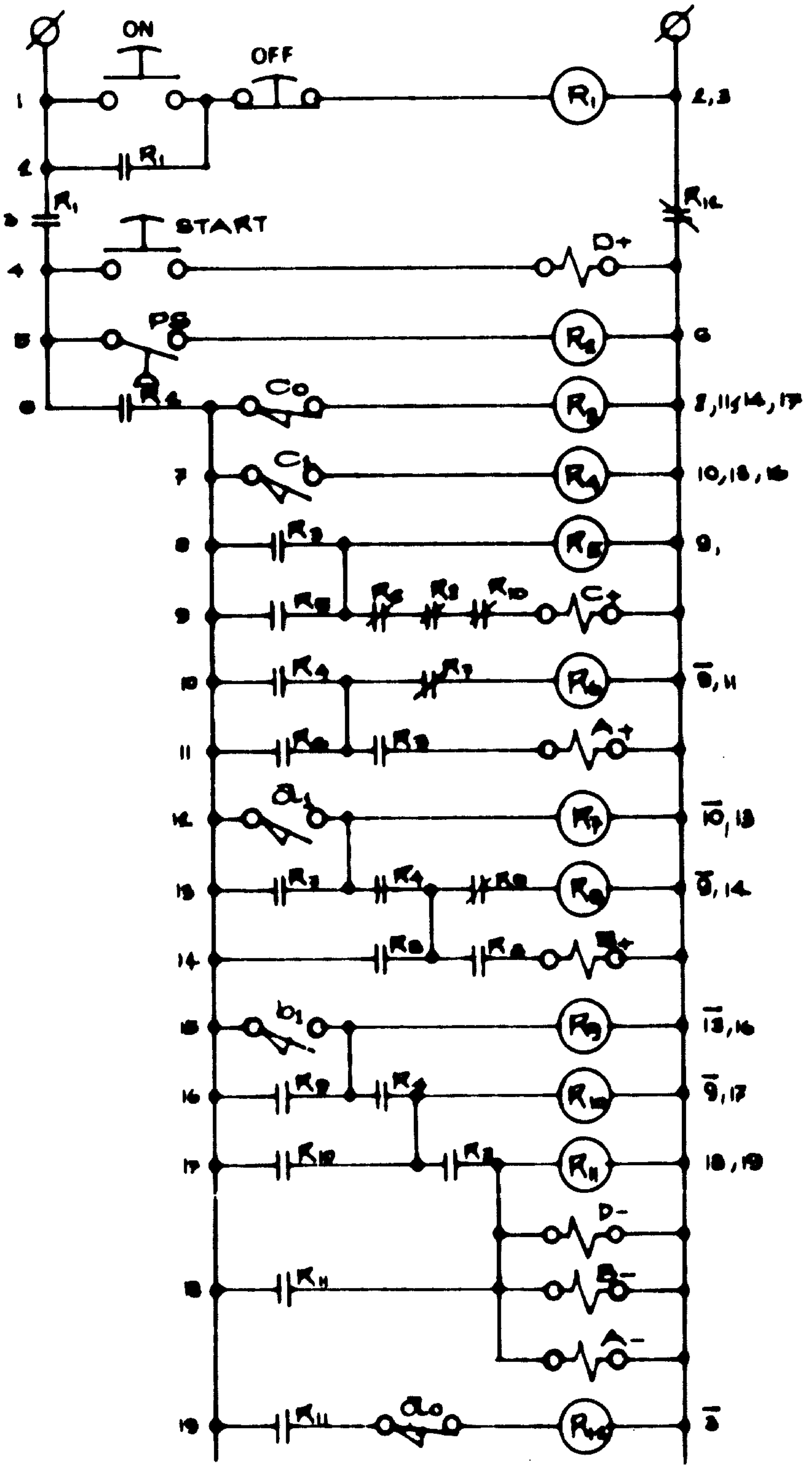


Figure 93a. Dowel-hole driller: electrical circuit diagram

Investment cost

LCA components	$180
Cost of constructing frames for set-up	120
Total	$300

Conditions before LCA

Cost of rejects due to misaligned holes	$4.00 per day
Capacity (2 skilled operators)	150 units/day

Conditions after LCA

Cost of rejects	$0.80 per day
Capacity	450 units/day

Benefits

Number of operators reduced to one (semi-skilled) for loading equipment only
Investment recovered in three months, from the savings on rejects and labour only

K. Door-lock mortiser

The automatic door-lock mortiser shown in figures 94a and 94b ensures uniformity and quality of work. Checking cylinders are used to obtain precise feeding speed for the router and mortiser. Everything is automatic from the time the "start" button is actuated, which is done after setting up the door on the locating jig. Limit switch b_1 determines the depth of mortising.

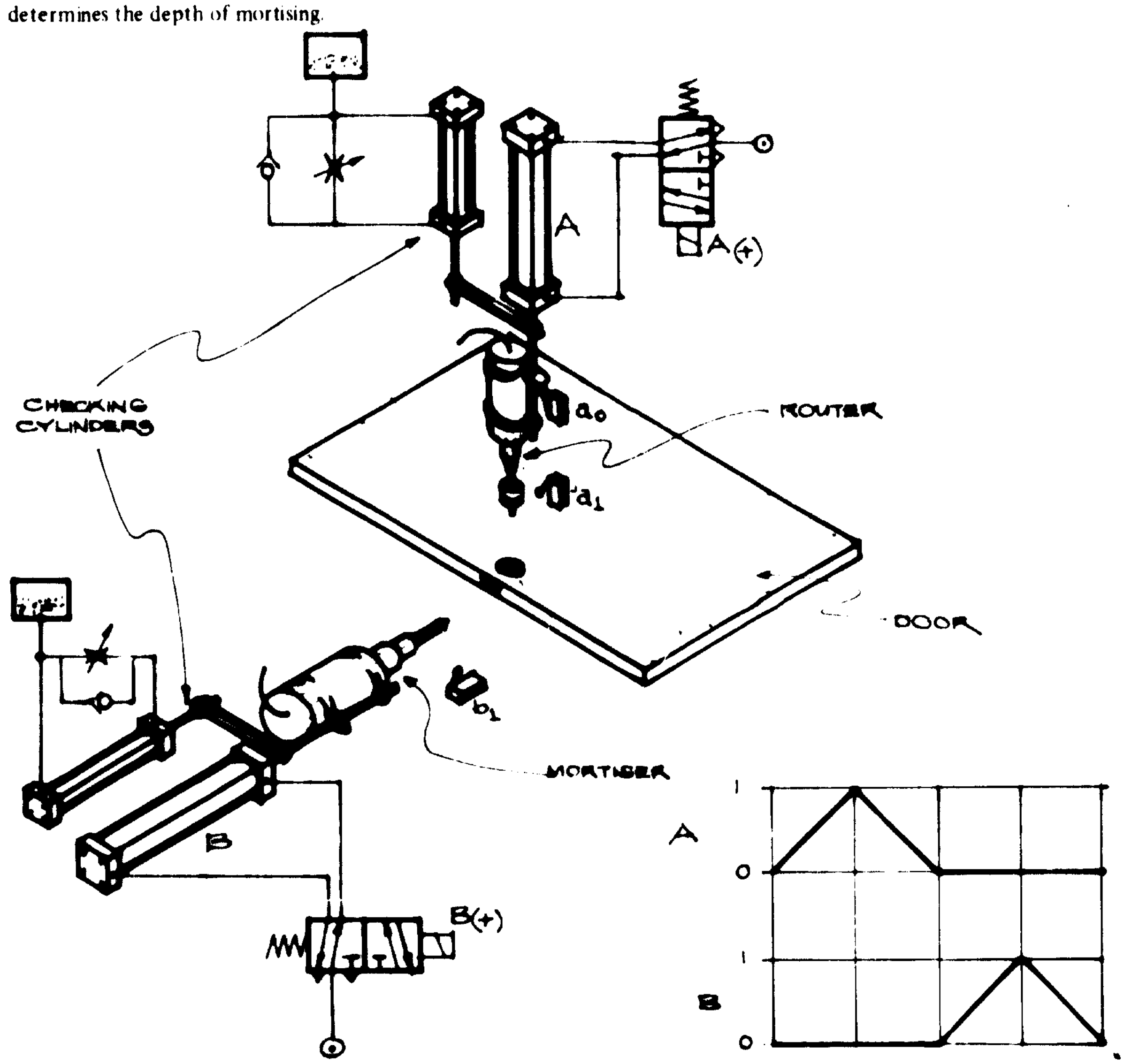


Figure 94a. Door-lock mortiser: pictorial and time-motion diagram

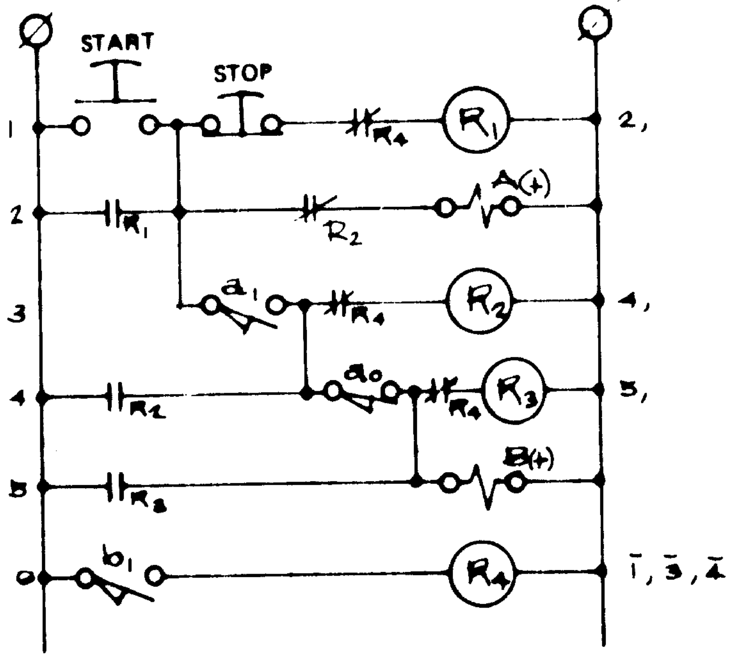


Figure 94b. Door-lock mortiser: electrical circuit diagram

Investment cost

Approximate cost of the components is $200.

Benefits

Production may be increased by as much as 300 per cent by this LCA application.

L. Multiple operations on an indexing table

Sometimes a manufacturer may need to perform several operations on a single workpiece (e.g., a part for a toy). By the use of a standard indexing table, several operations like drilling, mortising or tapping can, in effect, be performed at the same time.

As shown in figure 95a, the workpiece can be manually placed at point 0 and, subsequently, different operations can be done at different points in a step-by-step manner by the various tools. The net effect, after one cycle (with continuous loading) is that of a simultaneous multiple operation, or in other words, every time the machine is loaded, one finished product is unloaded.

Figures 95b and 95c respectively show a typical circuit and control console for the indexing table.

Investment cost

The approximate cost of an indexing table system is $450, depending on the accuracy of indexing desired.

Benefits

Depending on the number of operations, production can be increased by a factor of five. Also, products will be uniform.

M. Glue applicator

An automatic gluing set-up is illustrated in figure 96. By means of a magazine and cylinder A, pieces of wood can be fed to the worker whenever he actuates the 5-port, 2-position, foot-operated, spring-returned valve. While the wood is being fed to the worker, valve G opens and lets glue from the reservoir flow onto the wood. The set-up ensures uniformity of application of the proper amount of glue on the workpiece. This is achieved by means of adjusting the speed of feeding and selecting the glue-nozzle size.

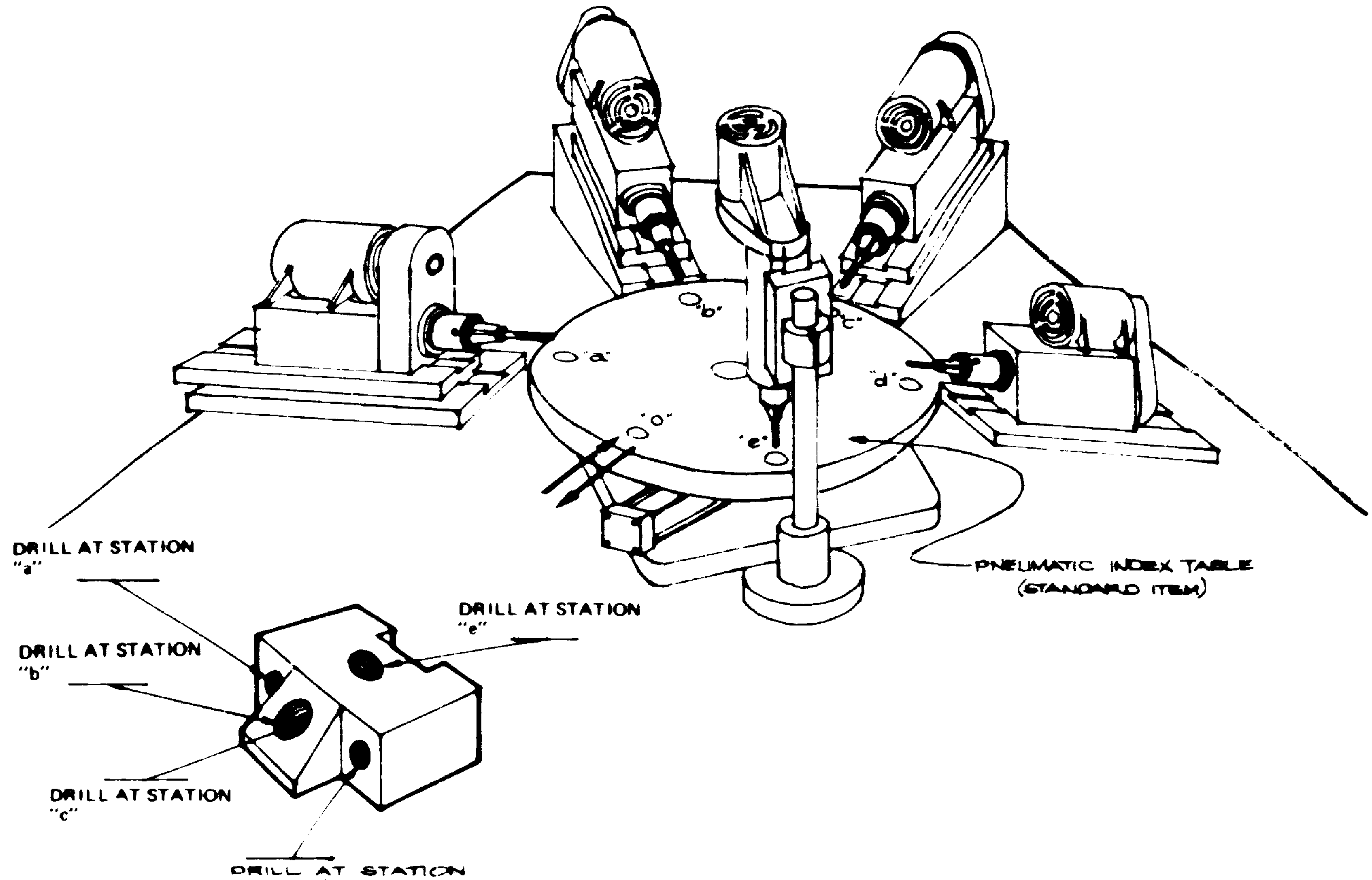


Figure [illegible]a. Indexing table: pictorial diagram

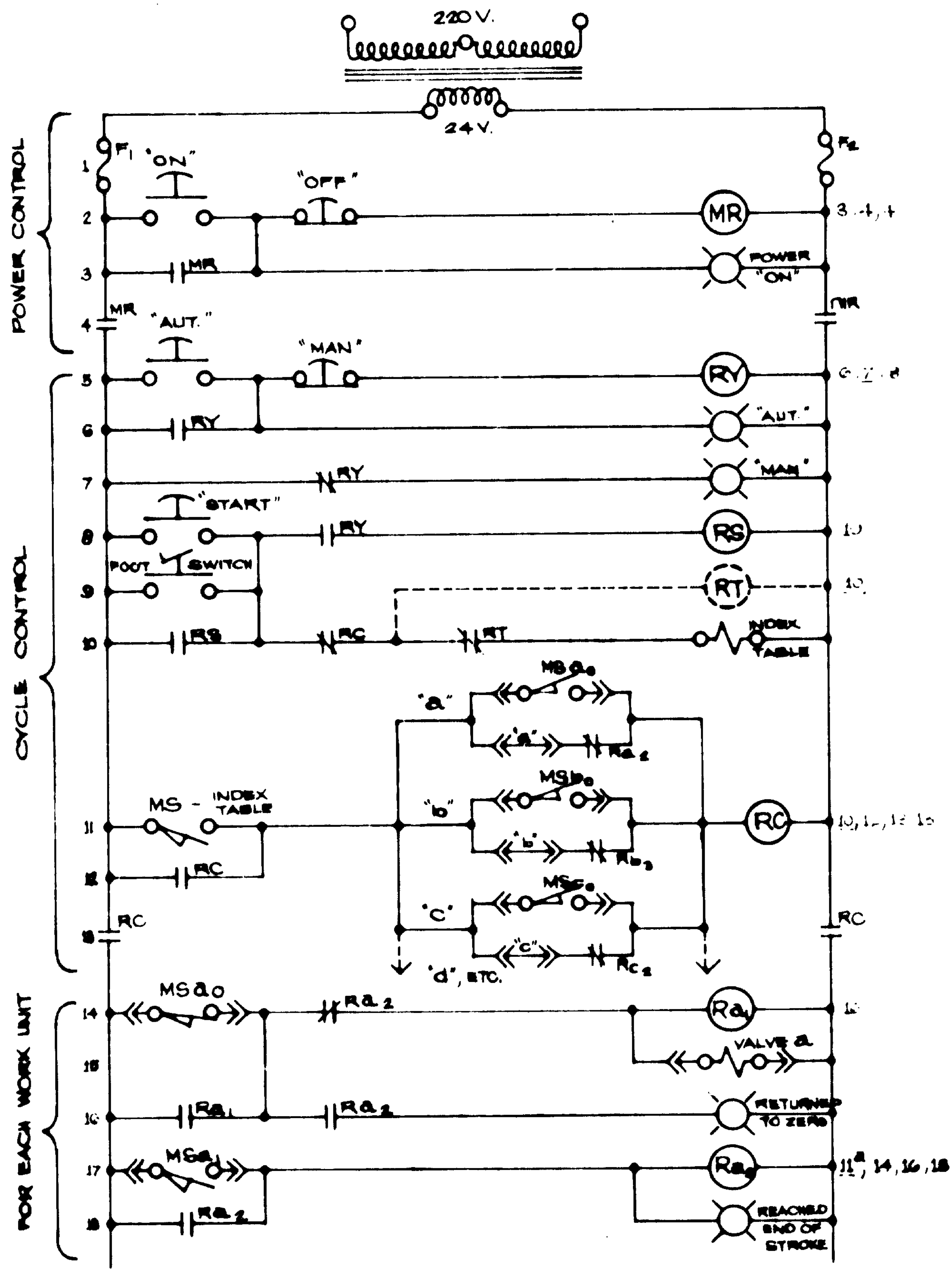


Figure 96b. Indexing table: typical circuit

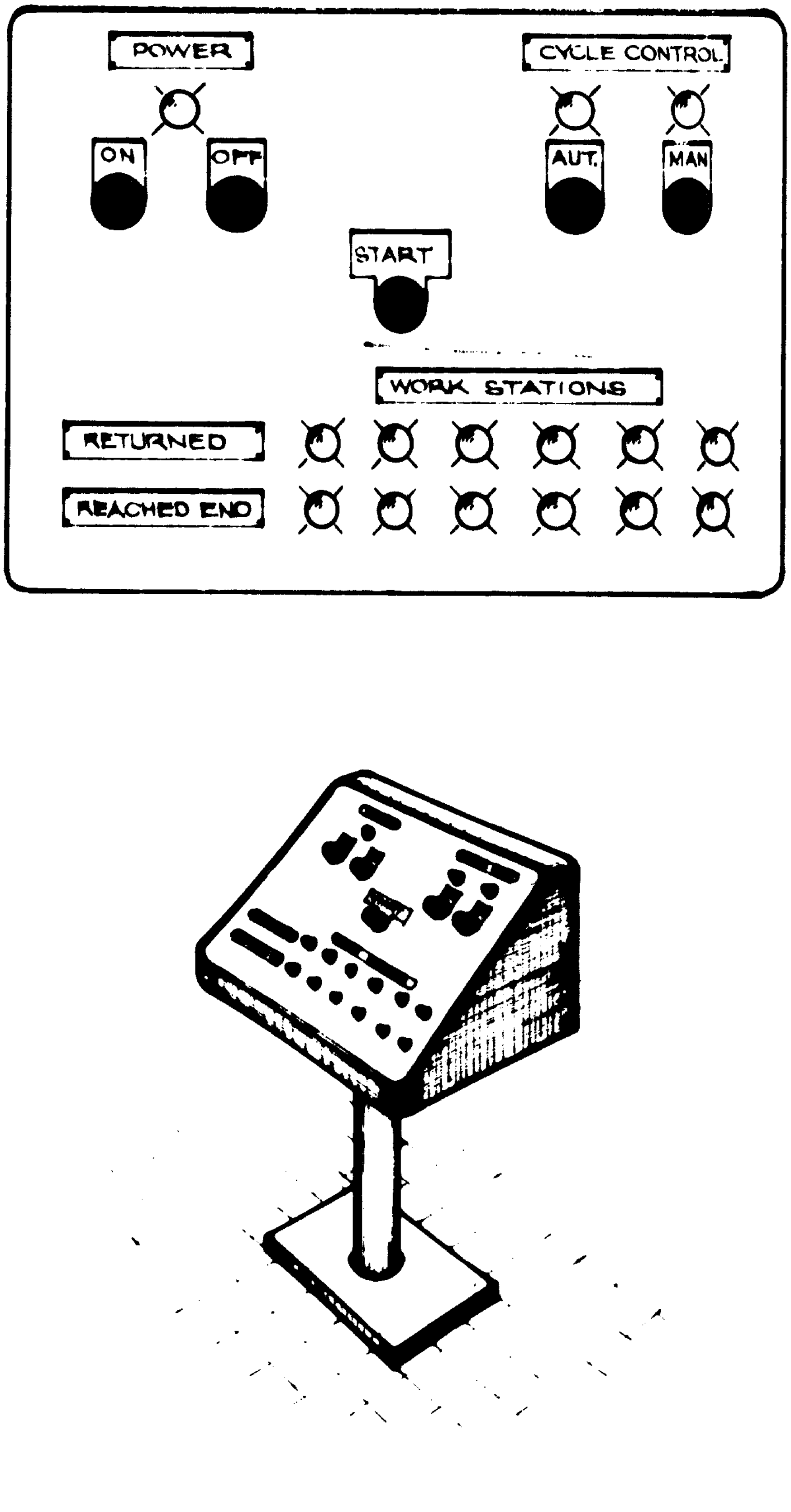


Figure 55a. Indexing table: typical control console

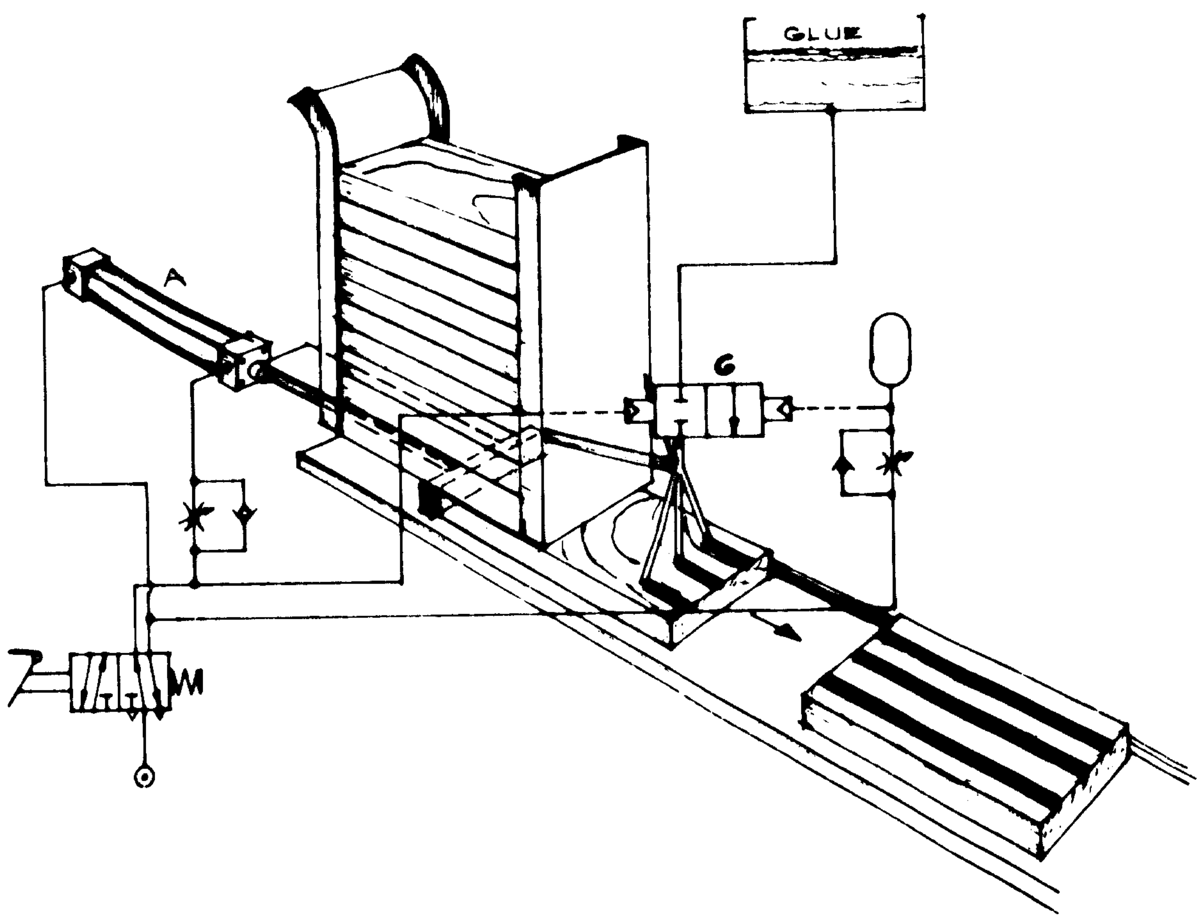


Figure 96. Glue applicator

Investment cost

Cost of the components is approximately $70

Benefits

A company that adapted the scheme saved $1,800 a year on glue alone. Also, labour cost was reduced by as much as $1,300 a year. Hence, the company became more competitive and could think of expanding.

N. Beverage-case partition slotter

In a certain factory, one of the most troublesome operations in making wooden beverage cases was the fabrication of the partitions (nests). It was time-consuming and unsafe, and quality control was difficult. The partitions were slotted at three points to a predetermined depth by three parallel saws against which the partition was fed up to a certain distance.

Figures 97a-97c show the LCA solution. The stack of partitions to be slotted was placed in a magazine, from which the pieces were fed automatically to the saw blades in an upright position.

Investment cost

The total cost of the project was $600.

Benefits

The new system increased production by 500 per cent and greatly improved quality. As an added bonus, the capacity increase made negotiation of an export contract for the components possible.

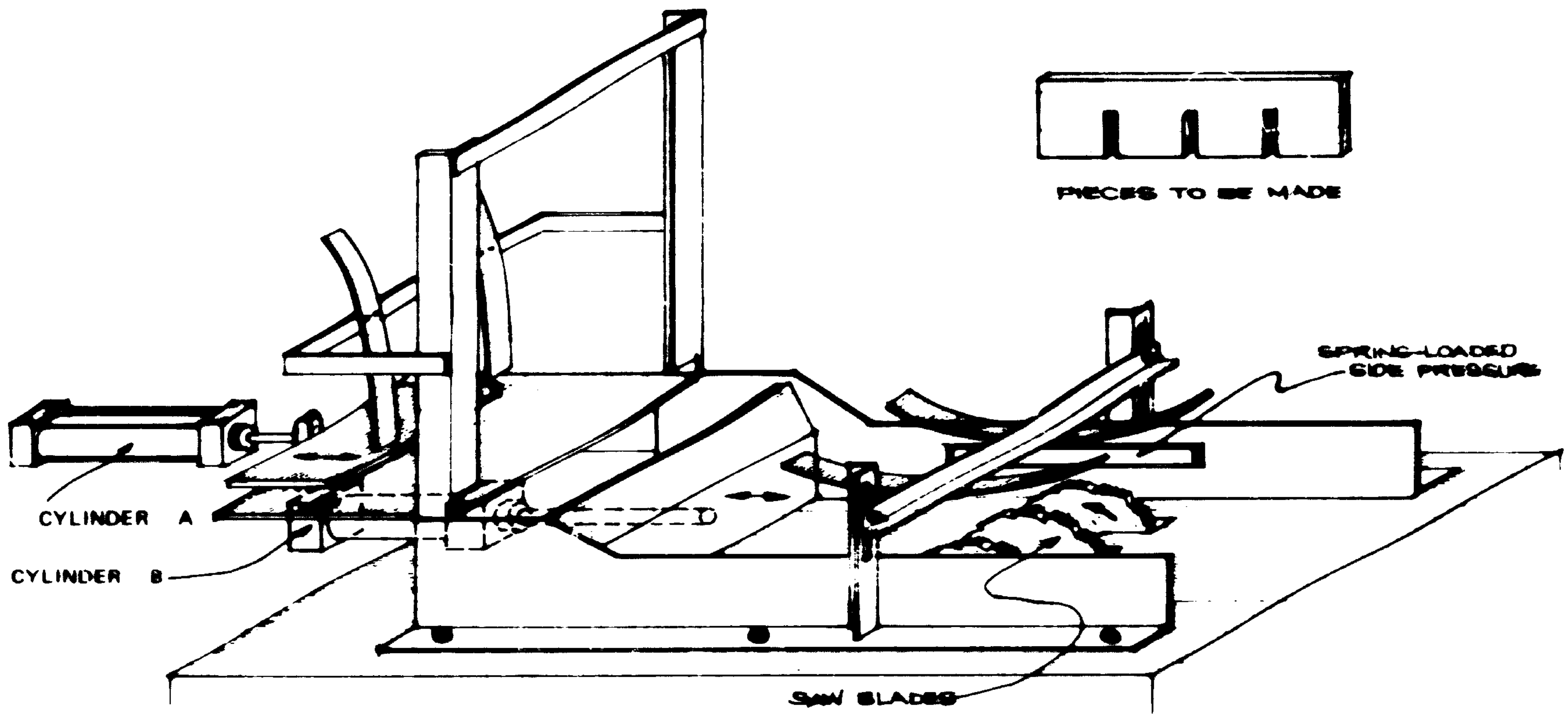


Figure 97a. Beverage-case partition slotter: general view

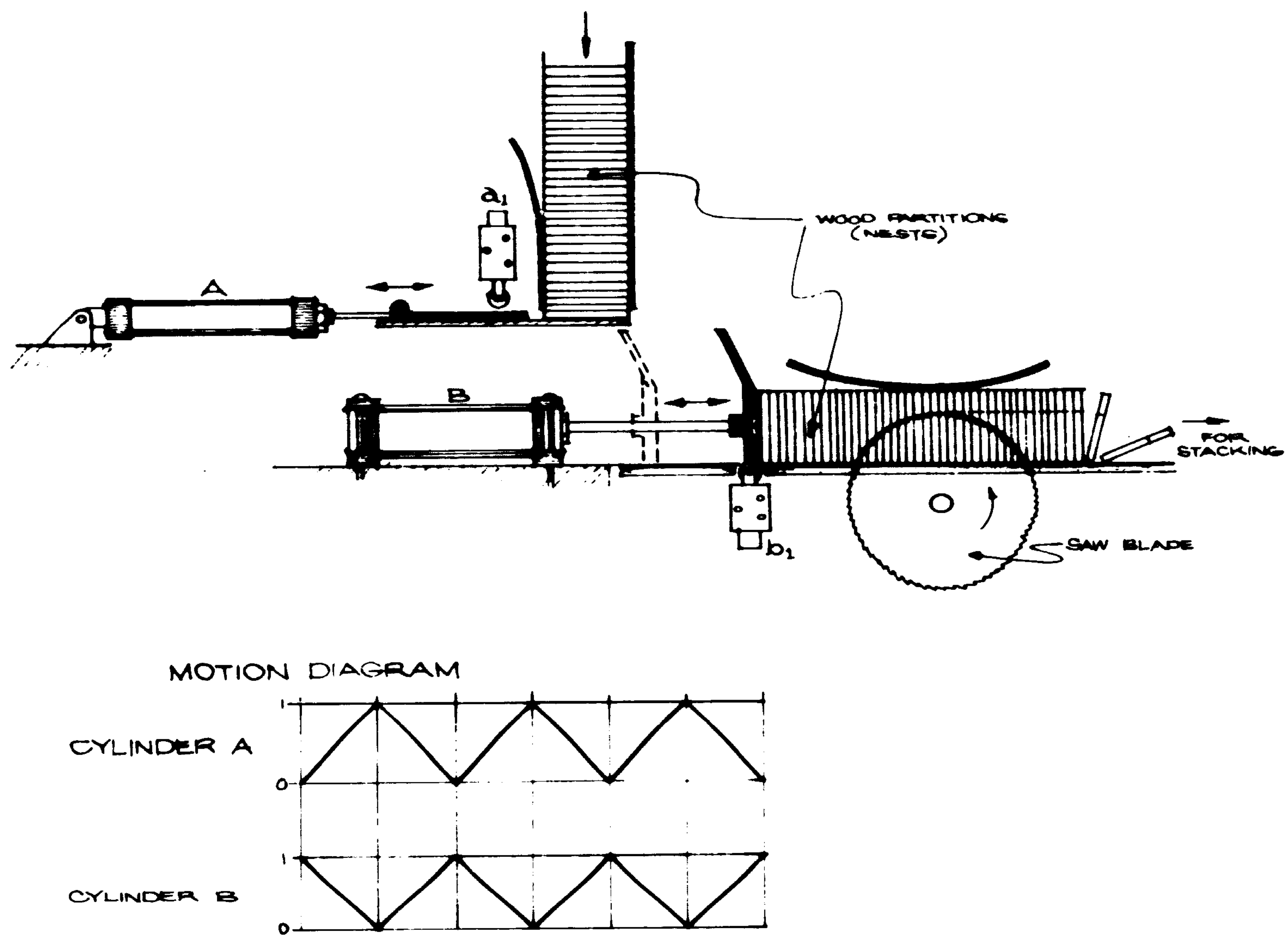


Figure 97b. Beverage-case partition slotter: side view and time-motion diagram

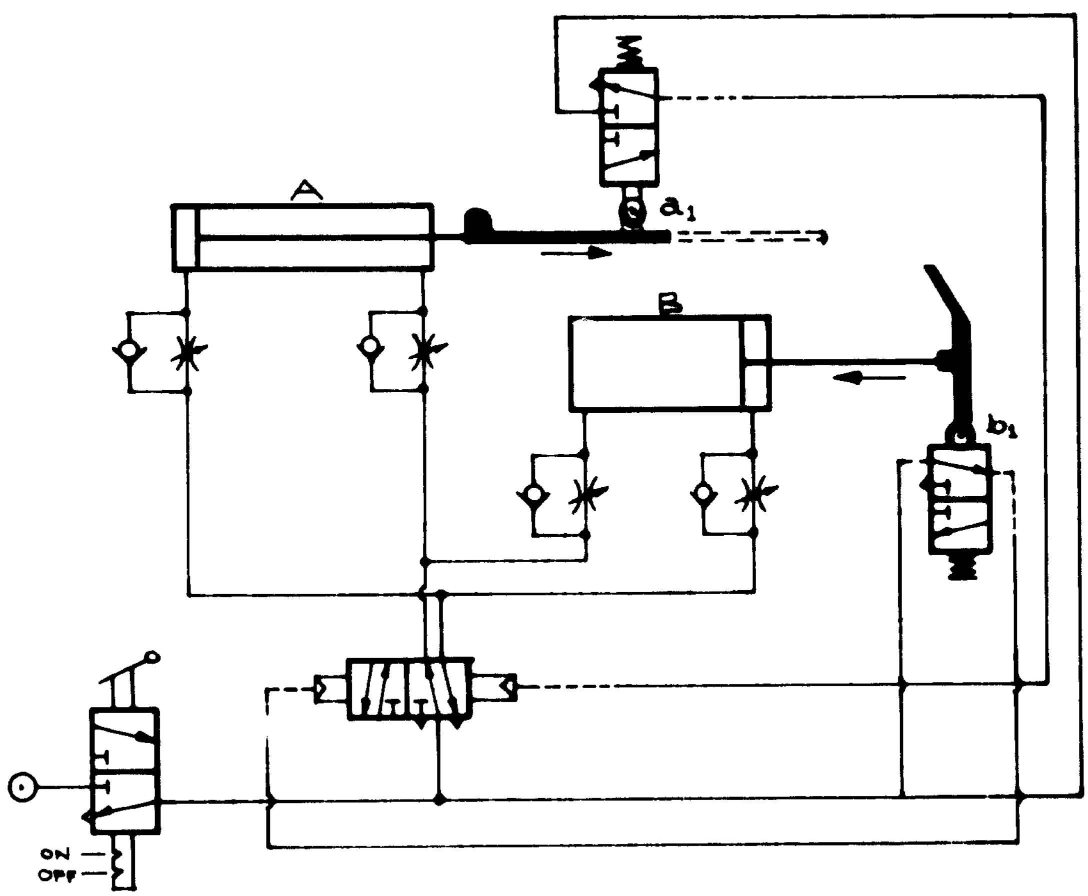


Figure 97c. Beverage-case partition slotter: pneumatic circuit diagram

O. Radio-TV cabinet slotter

Figures 98a-98c show an LCA machine used by a radio-TV cabinet manufacturer to perform the troublesome operation of cutting slots in a plywood speaker baffle cover. Formerly, slotting was done with a router. The plywood panel was pushed through the router with a wooden guide at its edge to ensure straight slots. Many of the finished pieces had to be rejected.

In the LCA solution, the slots are cut with a power saw that feeds itself (by means of cylinder B) through the plywood. The air-over-oil cylinder A feeds the plywood through successive slotting in an accurate manner. It is necessary to use air-over-oil to obtain accurate positioning of the slots (not possible with a purely pneumatic set-up). The location of the limit switches determines the location of the slots. Also, depending on the number of slots desired, more limit switches, with their corresponding relays, can be added to the circuit.

Investment cost

The total cost of the project was $800.

Benefits

This LCA solution increased the capacity of the plant by 250 per cent, and the number of rejects was reduced to a negligible amount, which meant a saving of $4,000 per year. More important, less skilled personnel could now be hired to do the operation.

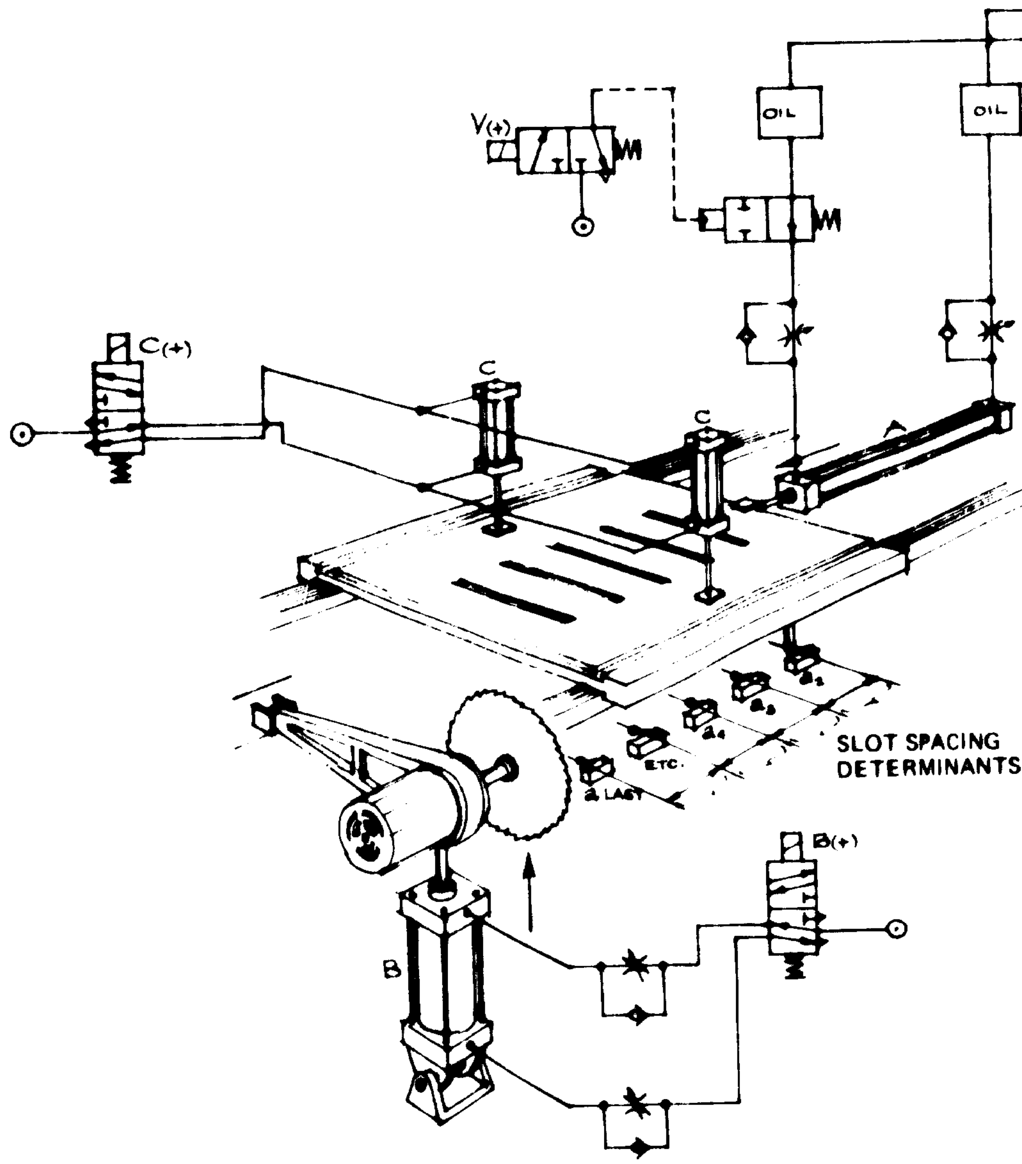


Figure 96a. Radio-TV cabinet slotter: pictorial diagram

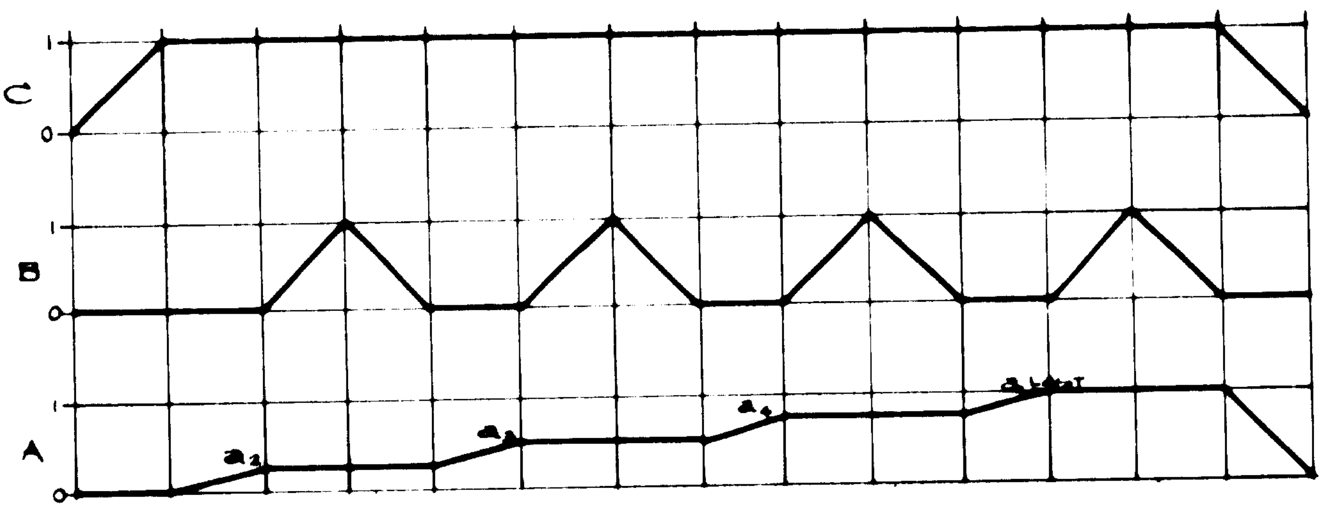


Figure 96b. Radio-TV cabinet slotter: time-motion diagram

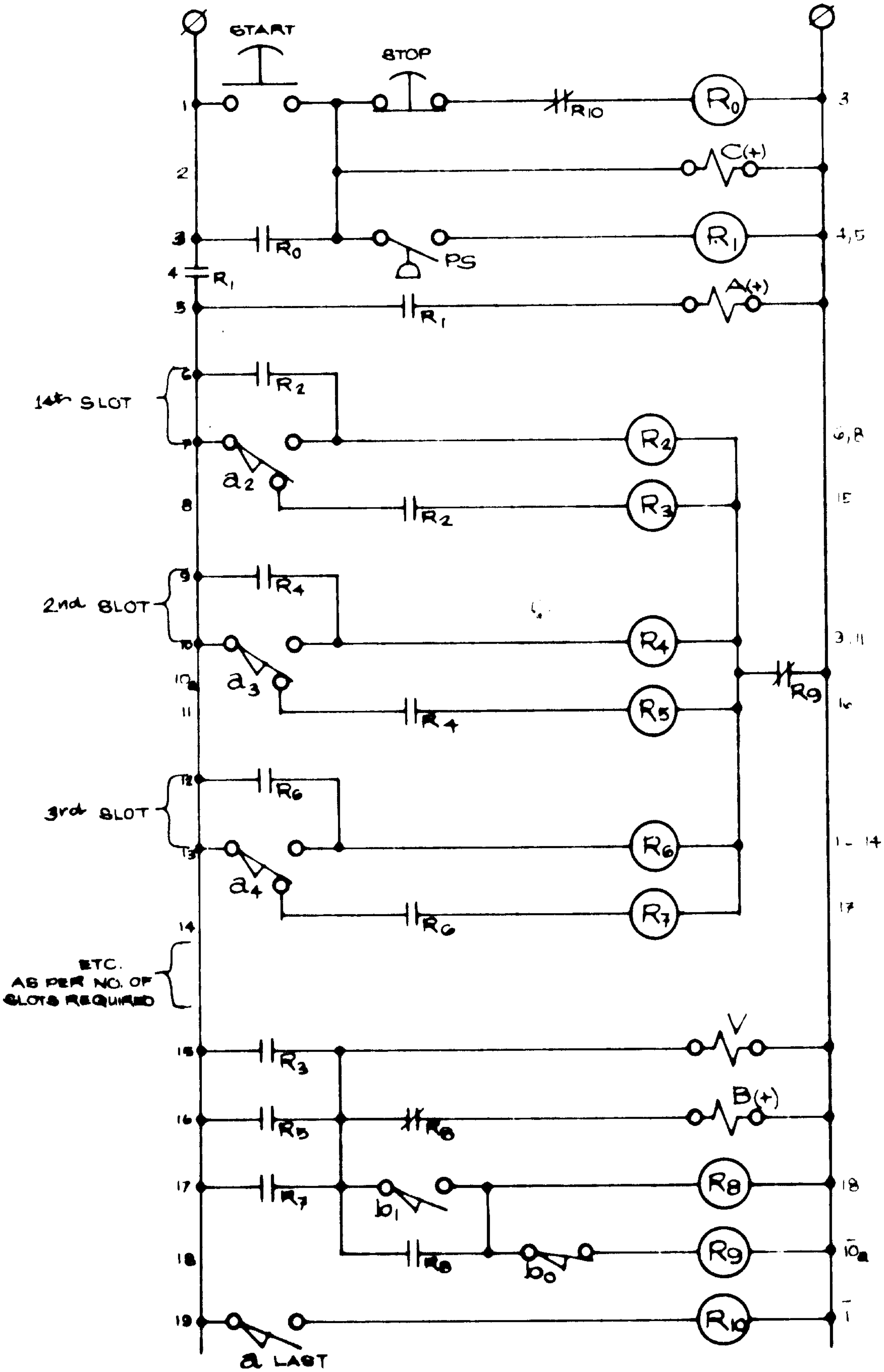


Figure 38c. Radio-TV cabinet slotter: electrical circuit

P. Thickness selector

Sometimes a manufacturer has the problem of sorting short pieces of wood for a particular product. For example, a factory making low-cost folding chairs from wood scraps was having difficulties in sorting out the pieces that had the correct thickness for the chairs. Manual sorting was too time-consuming and inaccurate.

Figures 99a and 99b show an automated thickness selector that solved the problem. After valve H is set to the required thickness, cylinder A pushes out relatively thick pieces while allowing thinner ones to pass through.

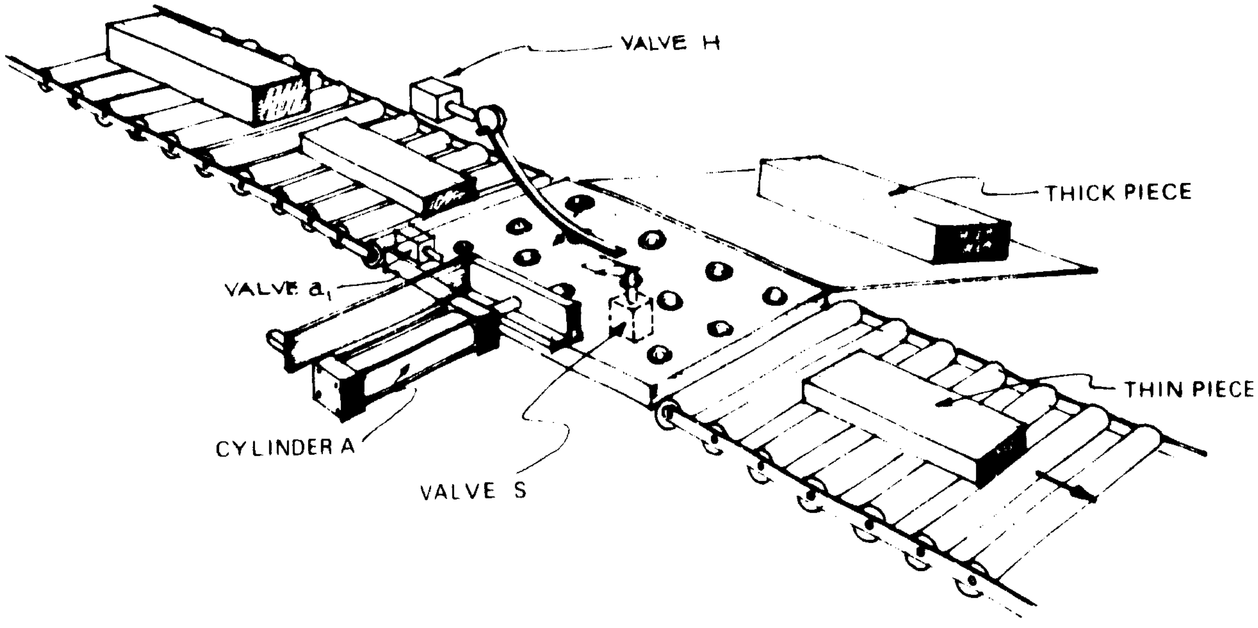


Figure 99a. Thickness selector: general view

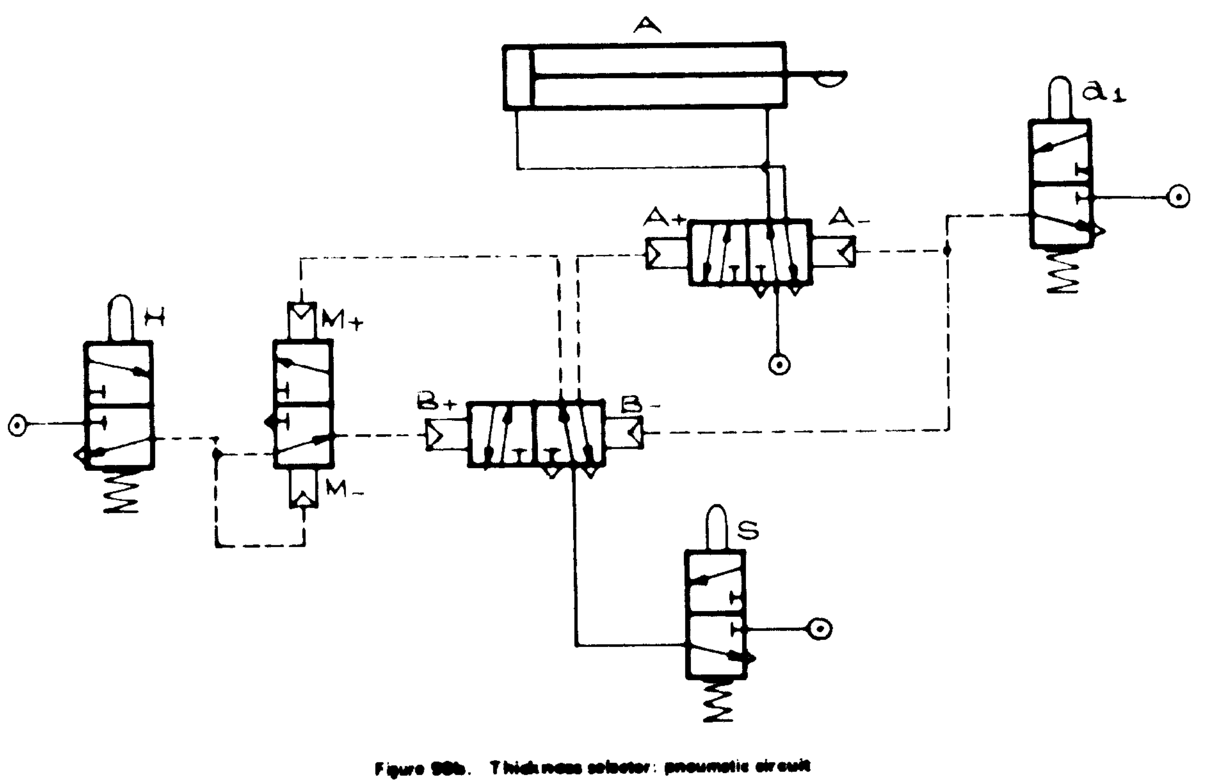


Figure 99b. Thickness selector: pneumatic circuit

Investment cost

The pneumatic components cost $80, the old roller conveyors, nothing.

Benefits

Wood selection became 200 per cent faster and more reliable.

Q. Upsetting machine

In the production of louvers, the ends of the wood slats should be upset to facilitate their entry into the corresponding mortises. When done manually with wedge-type cutting tools, upsets can have these defects:

(a) A portion of the upset end is broken when pushed against the mortise;

(b) Assembly leads to a messy squeezing out of glue, resulting in an additional cleaning process.

By means of the LCA solution illustrated in figures 100a-100d, correct upsetting can be accomplished at a relatively fast rate and with more dependable quality.

As shown, wood slats for jalousies are fed from a magazine by means of cylinder A. Once in position, the dies are pressed against both ends of the slats by cylinders B and B', after which cylinder C clamps the slats so that the dies can be withdrawn properly.

The cost of project is approximately $700, which can be recovered in five months.

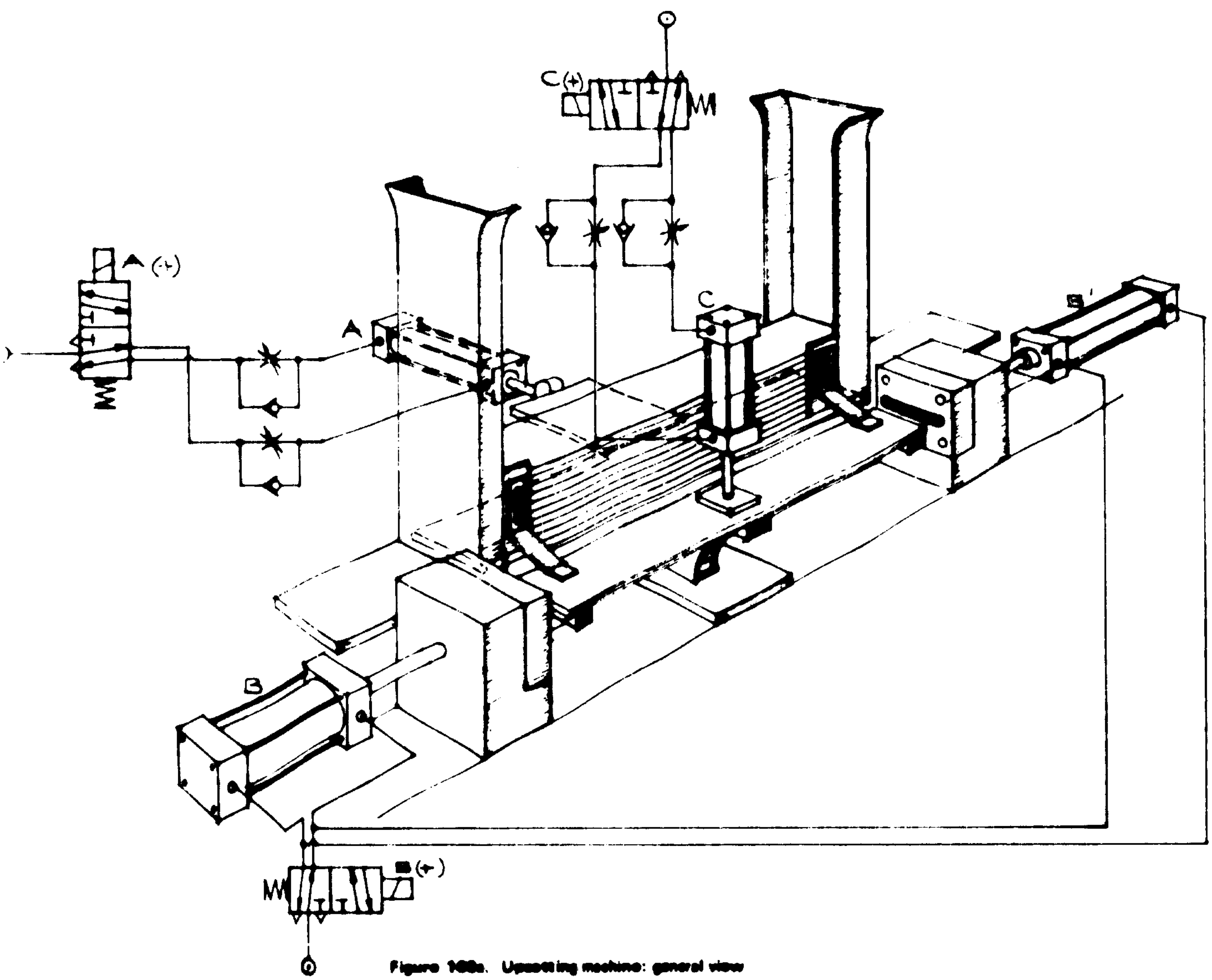


Figure 100a. Upsetting machine: general view

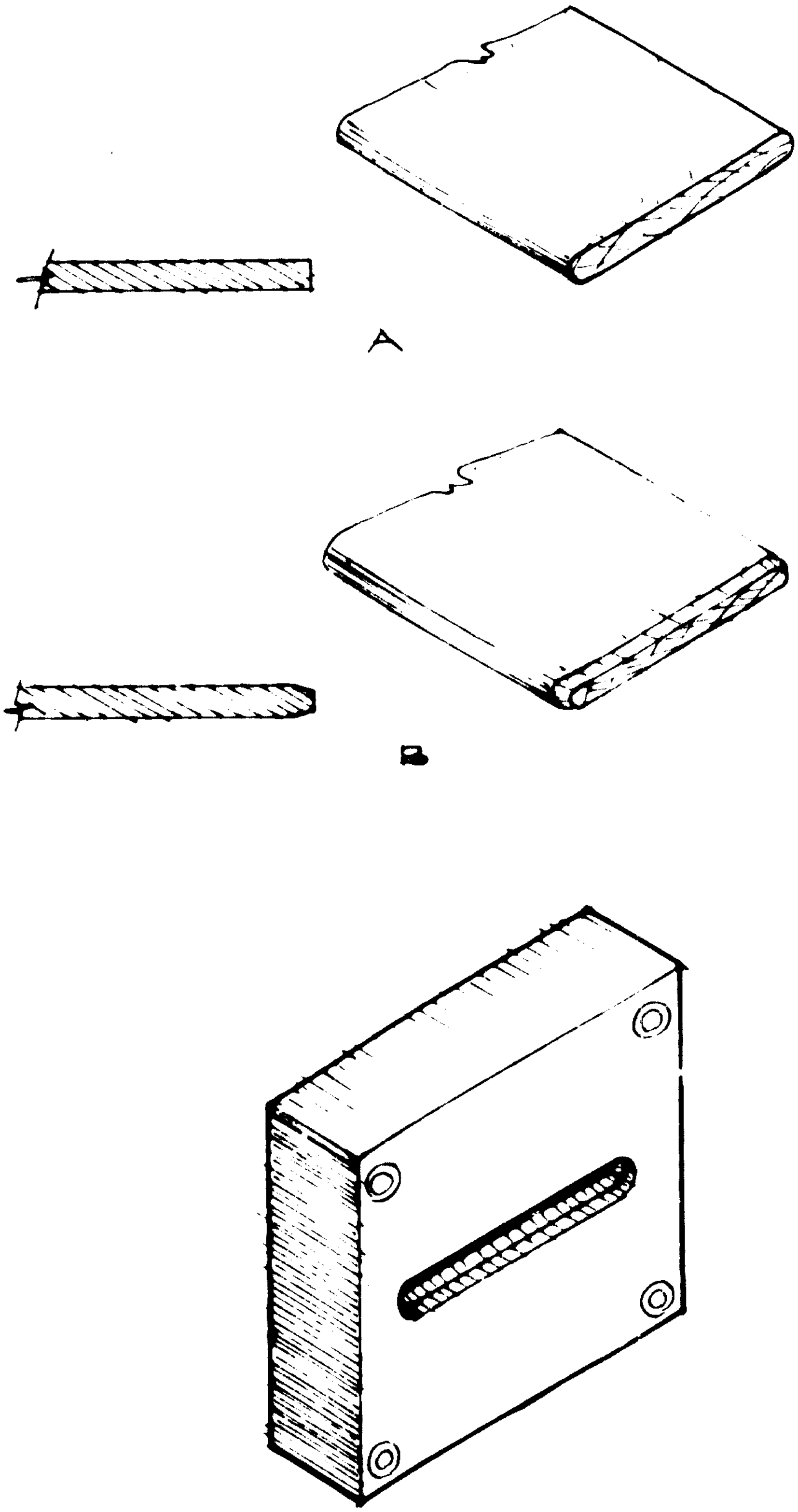


Figure 100b. Upsetting machine: die

C-280

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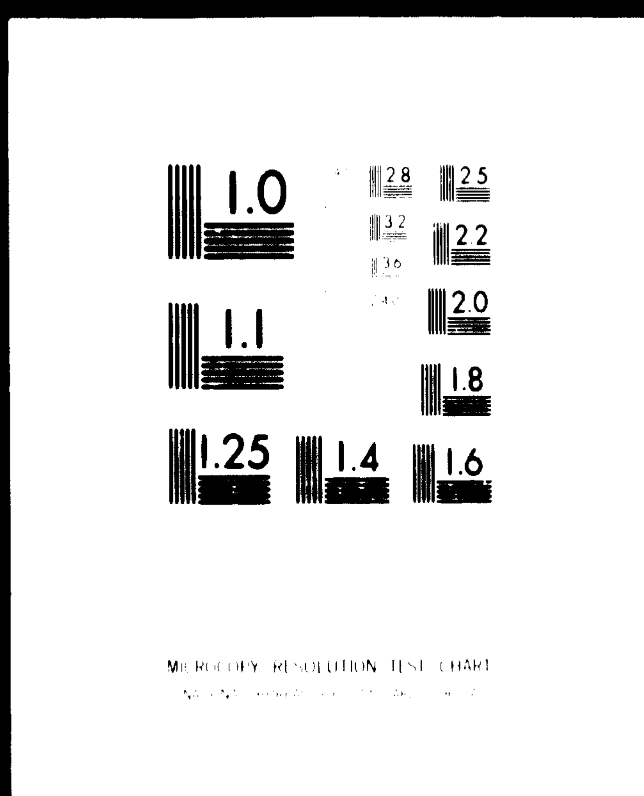
2 OF 2

DO

06948



24x

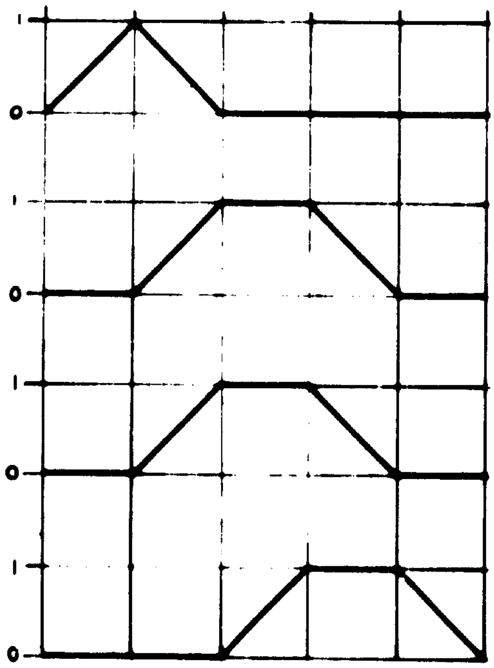


Figure 106a. Upsetting machine: time-motion diagram

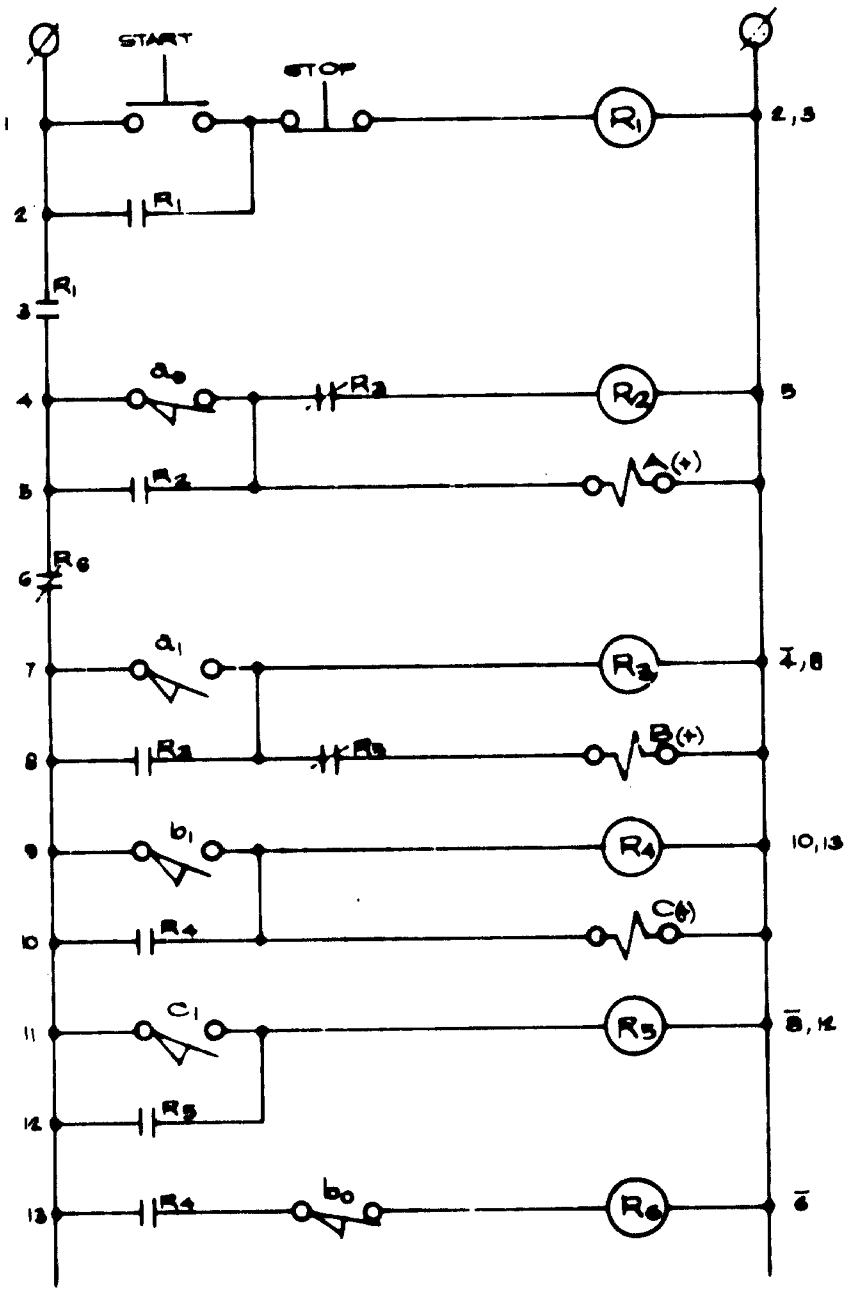


Figure 168d. Upsetting machine: electrical circuit

R. Return conveyor

Usually, two operators run a thicknesser. One feeds the machine while the other catches the output and hands it back to the first operator for refeeding. That is an example of wasteful manpower utilization. By incorporating a forward and return conveyor, together with a pneumatic cylinder, the return of machined workpieces can be simplified and the labour requirement reduced to one operator. (See fig. 101.) The output of the thicknesser (or a similar equipment) is caught by the outgoing conveyor. When the wood reaches the angled stopper, it falls into the return conveyor for remachining. The air-cylinder is actuated by the foot-operated valve to let the finished pieces through.

The pneumatic components cost approximately $40.

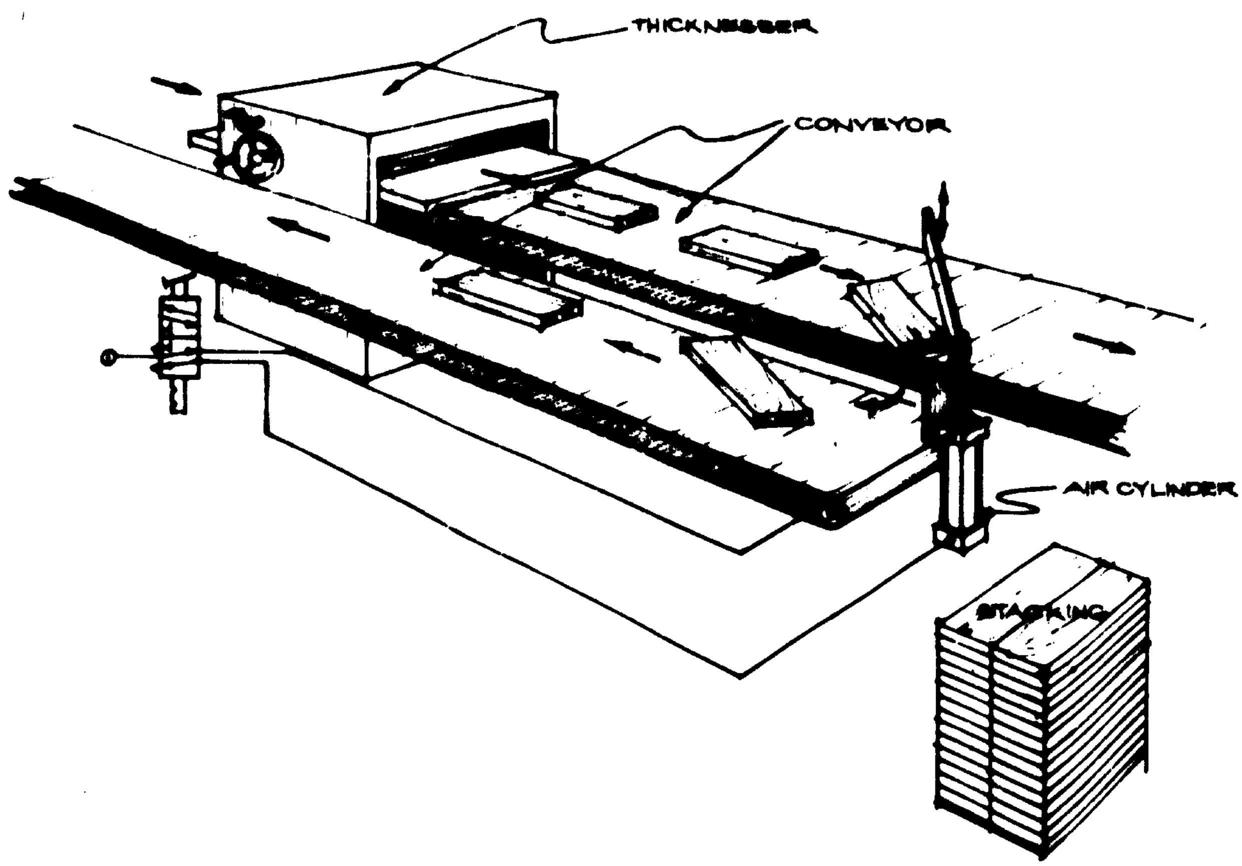


Figure 101. Return conveyor

S. Contour router

For cutting definite forms from flat pieces of wood, the set-up in figure 102 will be most useful, especially when large quantities are involved. The workpiece is fitted tightly into the work-frame and the latter positioned on the router bed. When the air-cylinder is actuated, the sprocket moves the work-frame, the air-cylinder acting as a guide. The shape that is cut out is determined by the shape of the chain track.

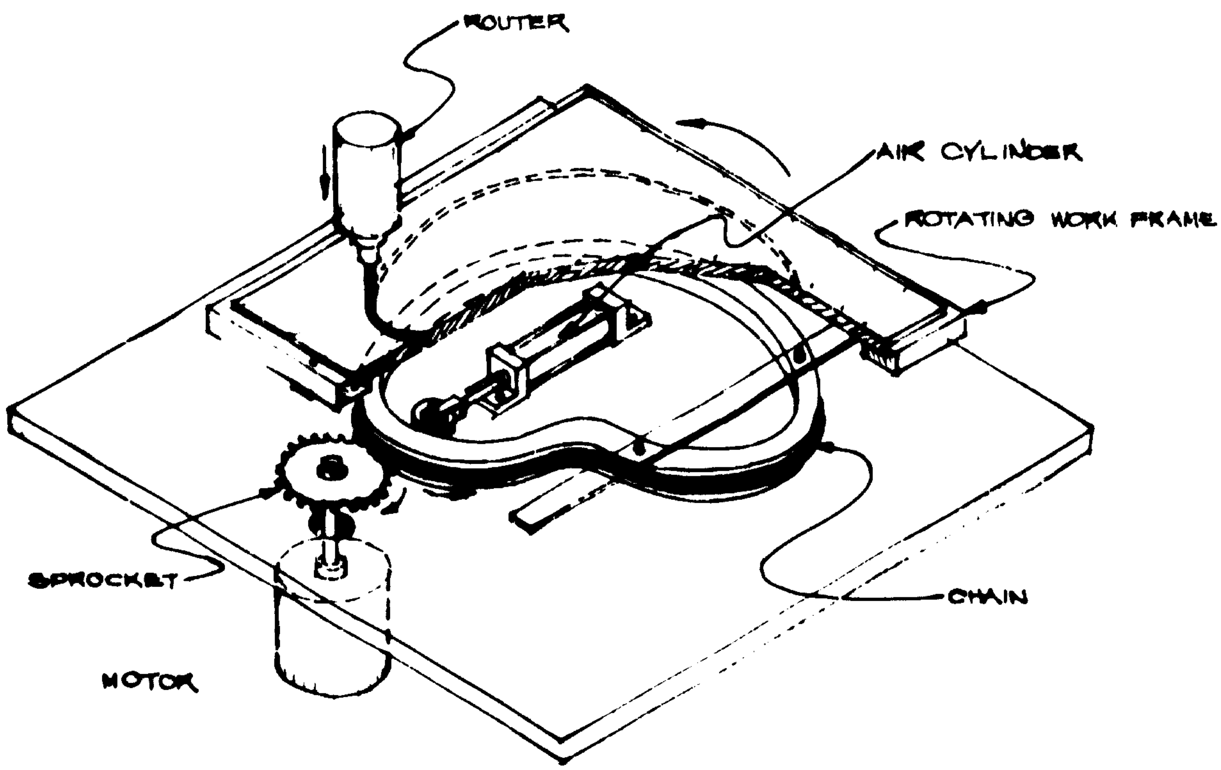


Figure 102. Contour router

Investment cost

The LCA components cost approximately $180.

Benefits

An increase of production of 400 per cent can be expected, and the work will be uniformly high in quality.

T. Copying attachment

Figures 103a and 103b illustrate an LCA copying attachment for ordinary wood lathes. Since tool movement must be precise, hydraulic devices are used. That makes the solution rather expensive ($1,000), and it is justifiable only for rather special purposes, probably not for merely increasing productivity.

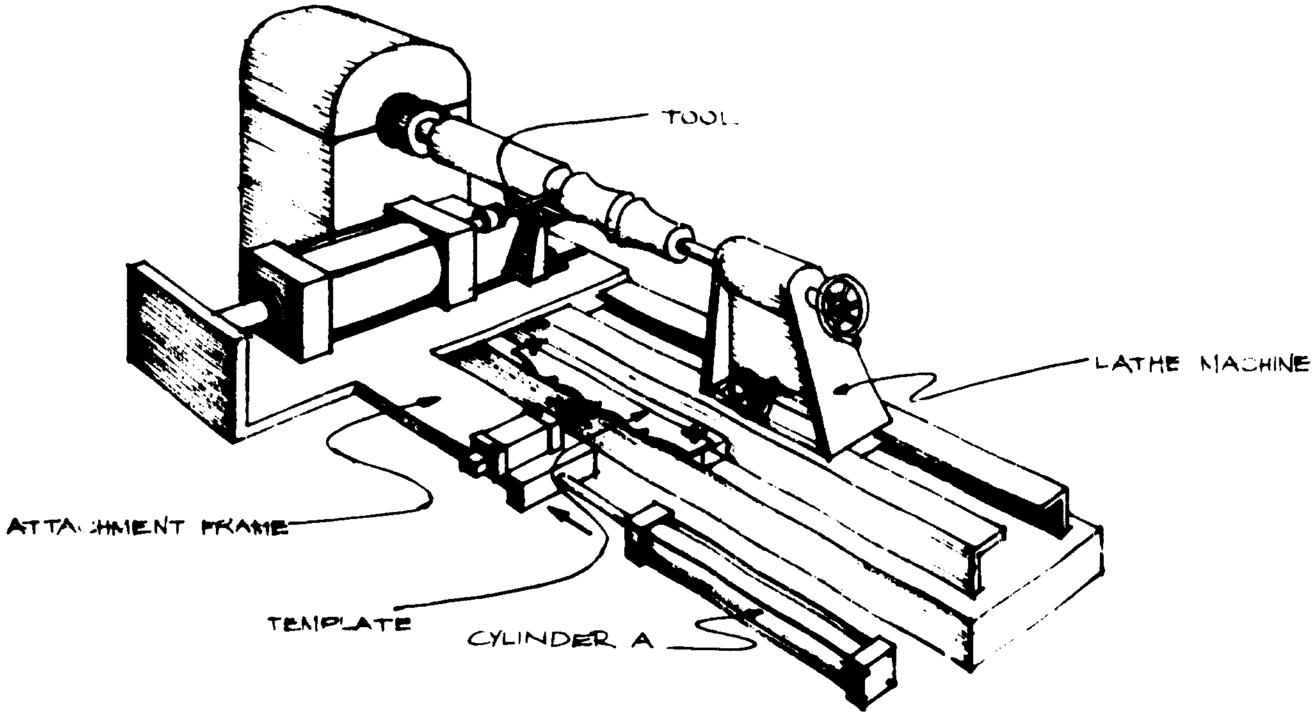


Figure 103a. Copying attachment: general view

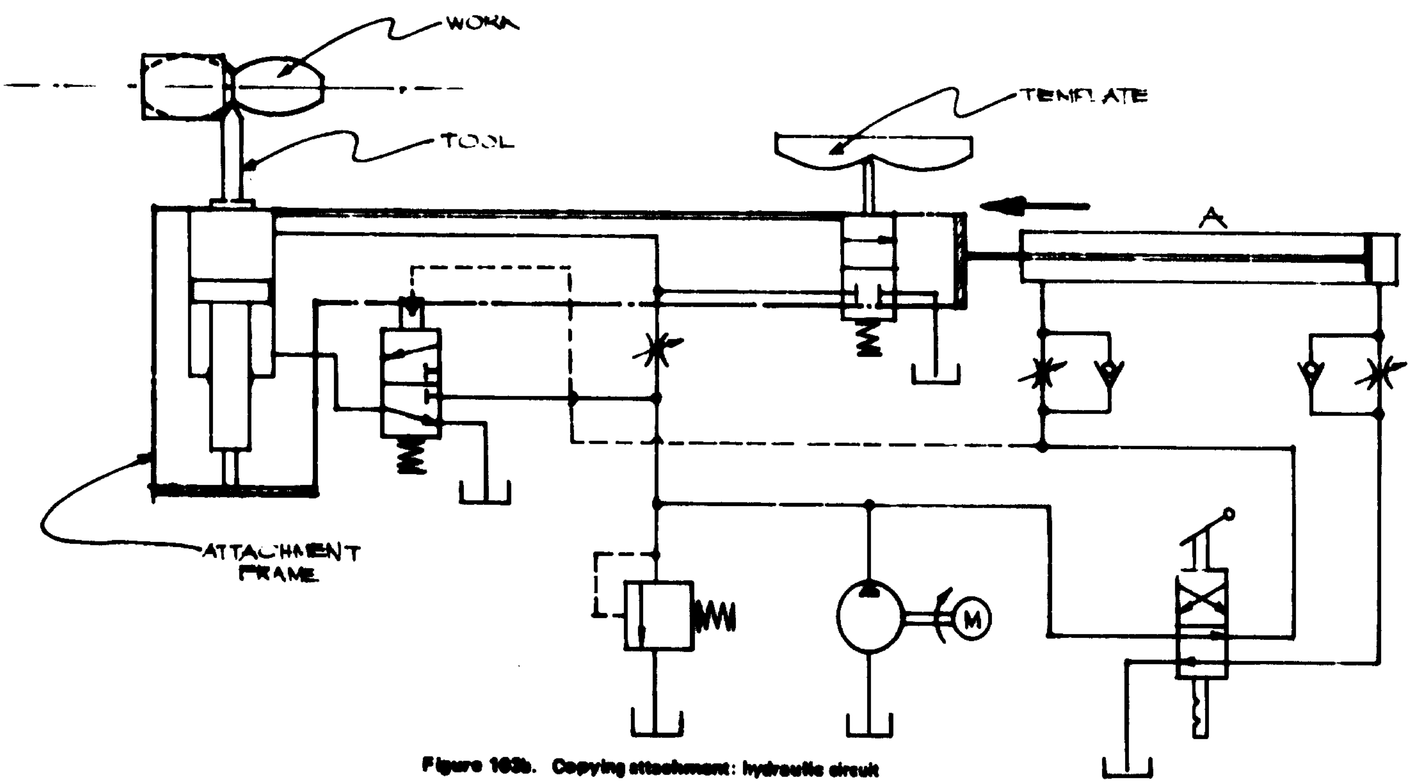
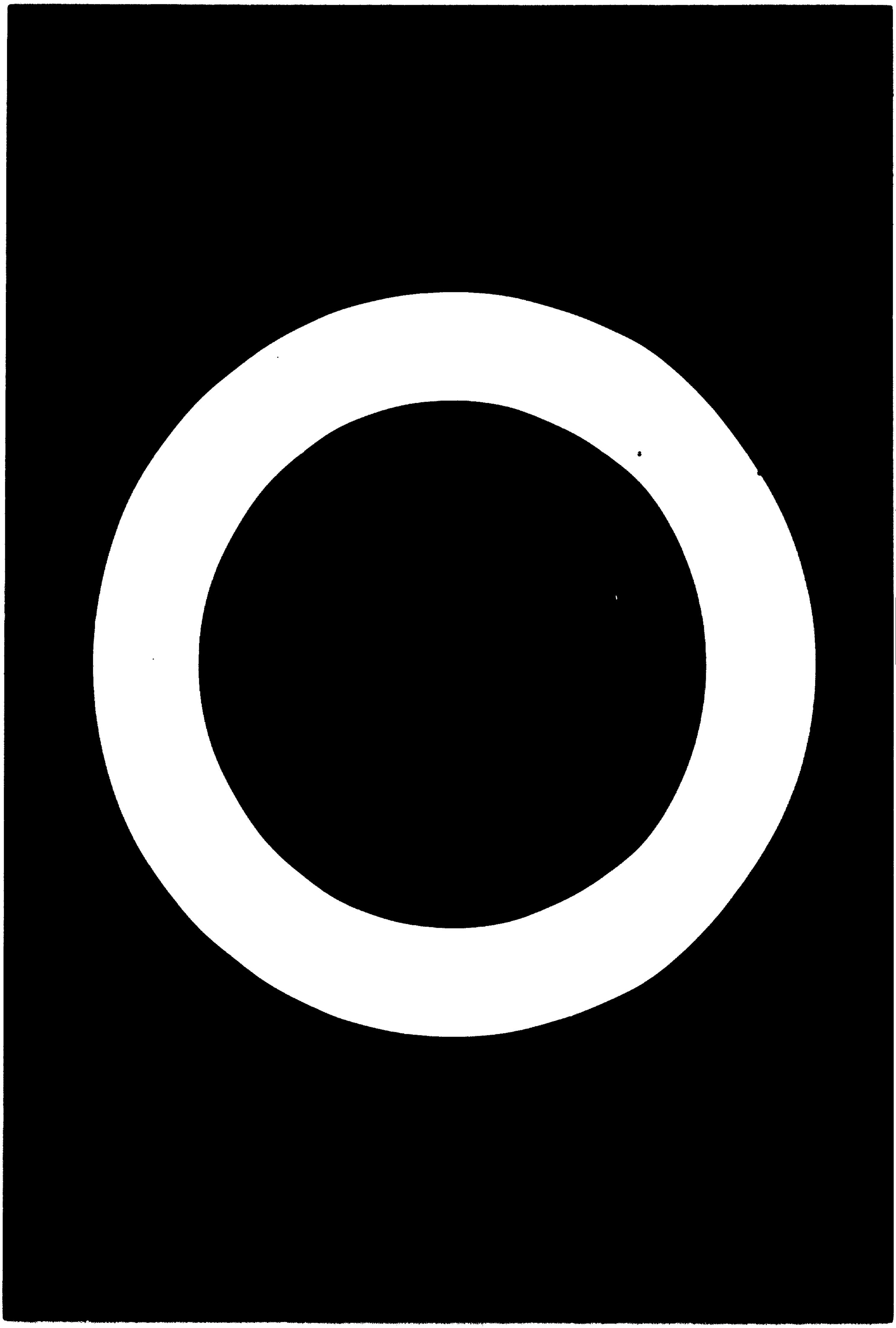


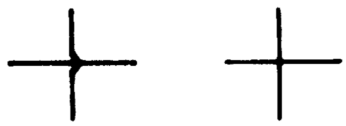
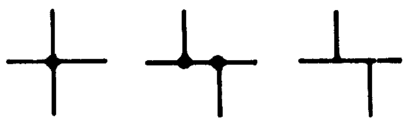
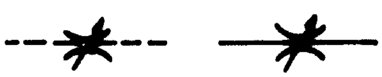
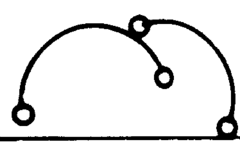
Figure 103b. Copying attachment: hydraulic circuit

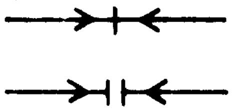
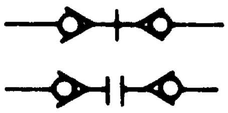
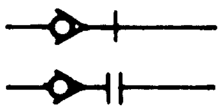
Annex I

SOME STANDARD CIRCUIT SYMBOLS

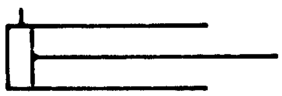
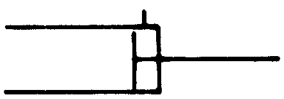
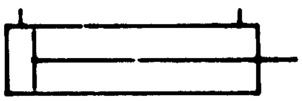
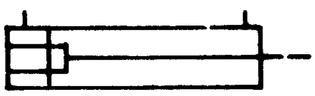
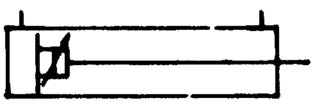


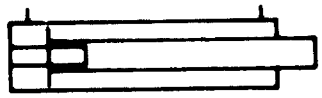
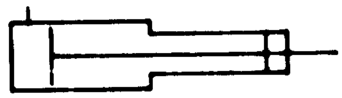
FLOW LINES and FLOW CONNECTIONS

SYMBOL	DESCRIPTION
	SOLID LINE - MAIN LINE
	DASHED LINE – PILOT LINE
	IMAGINARY LINE – EXHAUST OR DRAIN LINE
	CENTRE LINE – ENCLOSURE OUTLINE
	LINES CROSSING–(90° INTERSECTION NOT NECESSARY)
	LINES JOINING – (90° INTERSECTION NOT NECESSARY)
	FLOW DIRECTION – HYDRAULIC MEDIUM
	FLOW DIRECTION – GASEOUS MEDIUM
	LINES WITH FIXED RESTRICTION
	LINES WITH ADJUSTABLE RESTRICTION
	FLEXIBLE LINE

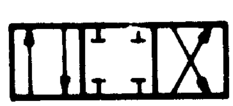
SYMBOL	DESCRIPTION
	PLUGGED PORT, TEST STATION, POWER TAKE-OFF
 CONNECTED DISCONNECTED	QUICK DISCONNECT WITHOUT CHECKS
 CONNECTED DISCONNECTED	QUICK DISCONNECT WITH CHECKS
 CONNECTED DISCONNECTED	QUICK DISCONNECT WITH ONE CHECK

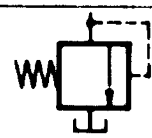
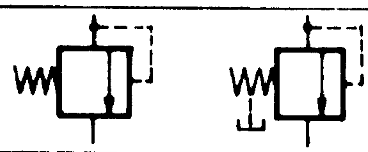
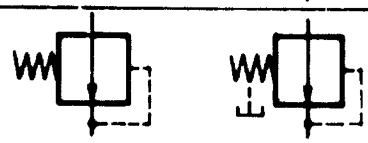
LINEAR & ROTARY POWER DEVICES

	SINGLE-ACTING, PUSH TYPE
	SINGLE-ACTING, PULL TYPE
	DOUBLE-ACTING SINGLE-END ROD
	DOUBLE-ACTING DOUBLE-END ROD
	FIXED CUSHION, ADVANCE and RETRACT
	ADJUSTABLE CUSHION, ADVANCE ONLY

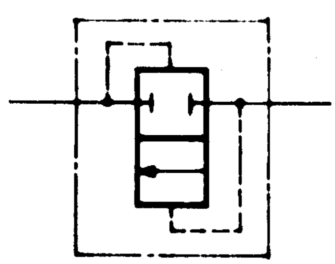
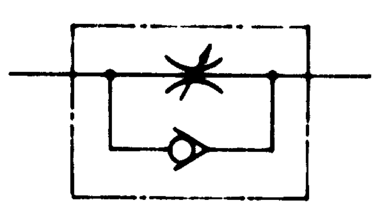
SYMBOL	DESCRIPTION
	DOUBLE-ACTING, BIG ROD WITH CUSHION, ADVANCE AND RETRACT
	PRESSURE INTENSIFIER
	HYDRAULIC OSCILLATOR
	PNEUMATIC OSCILLATOR

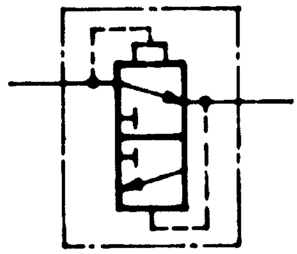
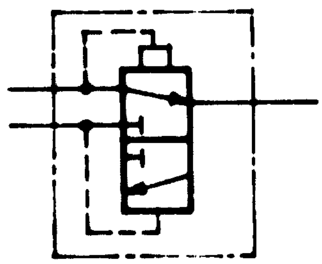
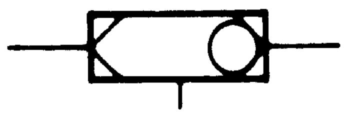
PNEUMATIC DIRECTIONAL VALVES

	2/2 TWO-PORT, TWO-POSITION
	ON-OFF, SIMPLIFIED
	3/2 THREE-PORT, TWO-POSITION
	4/2 FOUR-PORT, TWO-POSITION
	5/2 FIVE-PORT, TWO-POSITION, SAME FUNCTION AS FOUR-PORT EXCEPT EXTRA PORT CAN BE USED FOR EXTRA FUNCTION (e.g. BLOWING OFF DUST)
	4/3 FOUR-PORT, THREE-POSITION CENTRE POSITION CLOSED

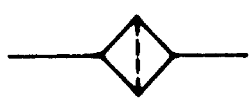
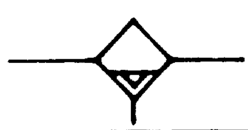
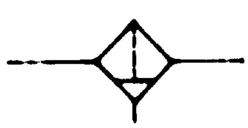
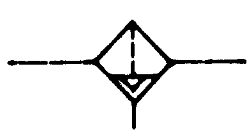
SYMBOL	DESCRIPTION
	5/3 FIVE-PORT, THREE-POSITION, TWO PORTS OPEN TO PRESSURE IN CENTRE POSITION
	4/3 FOUR-PORT, THREE-POSITION, ONE PORT OPEN TO EXHAUST IN CENTRE POSITION
	PRESSURE-RELIEF VALVE, SIMPLIFIED SYMBOL
	SEQUENCE VALVE
	PRESSURE-REDUCING VALVE

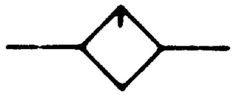
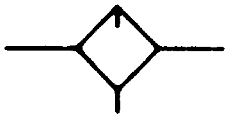
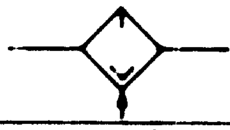
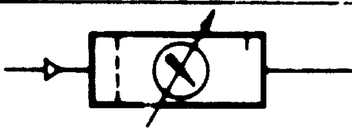
PNEUMATIC AUXILIARY VALVES

	CHECK-VALVE, COMPOSITE SYMBOL FLOW TO THE RIGHT IS BLOCKED; FLOW TO THE LEFT IS PERMITTED
	CHECK-VALVE SIMPLIFIED SYMBOL
	FLOW-CONTROL VALVE, ADJUSTABLE, WITH FLOW TO THE RIGHT CONTROLLED; FLOW TO THE LEFT BYPASSES CONTROL

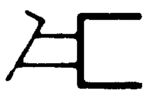
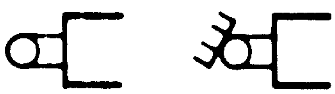
SYMBOL	DESCRIPTION
	QUICK-EXHAUST VALVE
	SHUTTLE VALVE
	SHUTTLE VALVE (SIMPLIFIED)

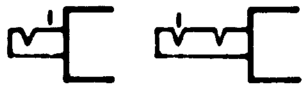
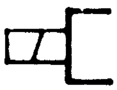
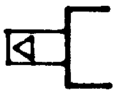
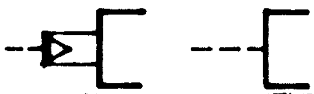
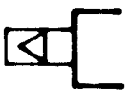
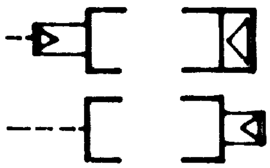
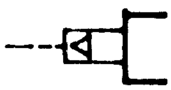
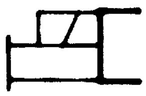
AIR-PREPARATION UNITS

	FILTER - STRAINER
	SEPARATOR WITH MANUAL DRAIN
	SEPARATOR WITH AUTOMATIC DRAIN
	FILTER-SEPARATOR WITH MANUAL DRAIN
	FILTER-SEPARATOR WITH AUTOMATIC DRAIN

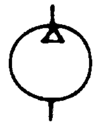
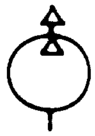
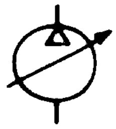
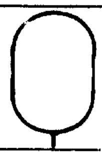
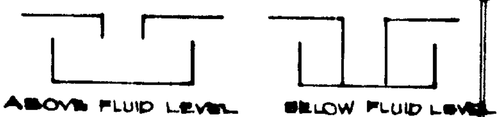
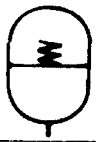
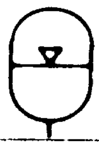
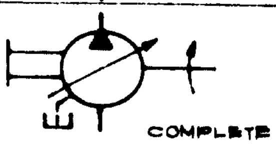
SYMBOL	DESCRIPTION
	LUBRICATOR, LESS DRAIN
	LUBRICATOR WITH MANUAL FILLING
	LUBRICATOR WITH AUTOMATIC FILLING
	AIR LINE COMBINATION F-R-L SIMPLIFIED (TRIO UNIT)

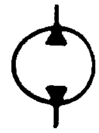
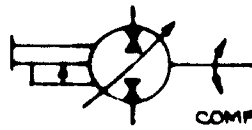
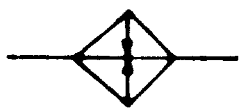
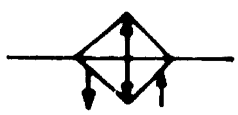
VALVE ACTUATORS

	MANUAL GENERAL SYMBOL
	PUSH BUTTON
	LEVER
	PEDAL OR TREADLE
	MECHANICAL (CAM, TOGGLE ETC.)
	SPRING

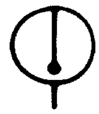
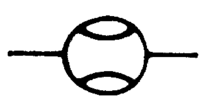
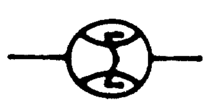
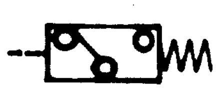
SYMBOL	DESCRIPTION
	DETENT (LINE INDICATES WHICH DETENT IS IN USE)
	SOLENOID
	INTERNAL PILOT SUPPLY
 COMPLETE SIMPLIFIED	REMOTE PILOT SUPPLY
	INTERNAL PILOT EXHAUST
 COMPLETE SIMPLIFIED	PILOT DIFFERENTIAL
	PILOT EXHAUST TO ATMOSPHERE
	AND COMPOSITE SOLENOID AND PILOT
	OR COMPOSITE SOLENOID OR MANUAL OVERRIDE
	AND/OR COMPOSITE SOLENOID AND PILOT OR MANUAL OVERRIDE
	AND/OR COMPOSITE SOLENOID AND PILOT OR MANUAL OVERRIDE AND PILOT

ENERGY OR POWER SOURCE

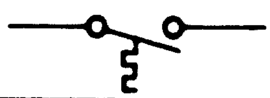
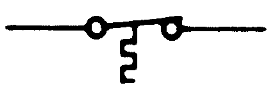
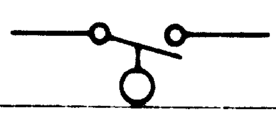
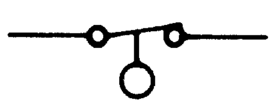
SYMBOL	DESCRIPTION
	COMPRESSOR, FIXED DISPLACEMENT
	VACUUM PUMP, FIXED DISPLACEMENT
	COMPRESSOR, VARIABLE DISPLACEMENT
	RECEIVER
	ACCUMULATOR
	RESERVOIR
	RESERVOIR WITH CONNECTING LINES
	ACCUMULATOR, SPRING-LOADED
	ACCUMULATOR, GAS-LOADED
	PUMP UNI-DIRECTIONAL, VARIABLE DISPLACEMENT, NON-COMPENSATED
	PUMP BI-DIRECTIONAL, VARIABLE DISPLACEMENT, NON-COMPENSATED

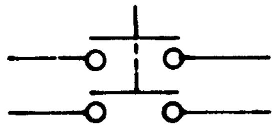
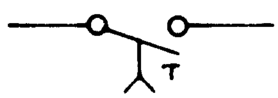
SYMBOL	DESCRIPTION
 SIMPLIFIED	PUMP BI-DIRECTIONAL, VARIABLE DISPLACEMENT, PRESSURE-COMPENSATED
 SIMPLIFIED	PUMP-MOTOR UNI-DIRECTIONAL, FIXED DISPLACEMENT, NON-COMPENSATED
 COMPLETE	PUMP-MOTOR BI-DIRECTIONAL, VARIABLE DISPLACEMENT, PRESSURE COMPENSATED
	HEATER INSIDE TRIANGLES INDICATE INTRODUCTION OF HEAT
	COOLER INSIDE TRIANGLES INDICATE HEAT DISSIPATION

SUPPLEMENTARY EQUIPMENT

	PRESSURE GAUGE
	THERMOMETER
	FLOW METER
	INTEGRATING FLOW METER
	PRESSURE SWITCH

ELECTRIC SWITCHES

SYMBOL	DESCRIPTION
	PUSH-BUTTON SWITCH, NORMALLY OPEN (NO)
	PUSH-BUTTON SWITCH, NORMALLY CLOSED (NC)
	CAM-OPERATED LIMIT SWITCH, NO
	CAM-OPERATED LIMIT SWITCH, NC
	TEMPERATURE-OPERATED LIMIT SWITCH, NO
	TEMPERATURE-OPERATED LIMIT SWITCH, NC
	PRESSURE-OPERATED LIMIT SWITCH, NO
	PRESSURE-OPERATED LIMIT SWITCH, NC
	FLOAT-OPERATED SWITCH, NO
	FLOAT-OPERATED SWITCH, NC
	FLOW-OPERATED SWITCH, NO

SYMBOL	DESCRIPTION
	FLOW-OPERATED SWITCH, NC
	DOUBLE-POLE, SINGLE-THROW, PUSH-BUTTON SWITCH, NO
	RELAY COIL
	RELAY CONTACTS, NO
	RELAY CONTACTS, NC
	TIMER RELAY
	TIMER-OPERATED CONTACTS, NO
	TIMER-OPERATED CONTACTS, NC

Annex II

APPROXIMATE PRICES OF SOME PNEUMATIC COMPONENTS

The prices in the following list are the rounded average of prices charged by serveral suppliers in the Federal Republic of Germany, the Netherlands, and the United Kingdom of Great Britain and Northern Ireland in 1973. They must be regarded as approximate; prices vary, not only with time, but with the supplier and type of construction (components designed for rough service or high precision cost more). These prices will nonetheless prove useful for comparing the prices of different components or of different sizes of the same component.

Control valves

	Port size (inch)	Price ($US)
5-port, 2-position		
Push-button-actuated, spring-returned	1/8	10.50
	1/4	15.20
Lever-actuated, spring-returned	1/8	11.00
	1/4	17.00
Foot-operated, spring-returned	1/8	11.20
	1/4	17.10
	1/2	34.80
Detent-position (push-pull)	1/8	10.50
	1/4	15.20
	1/2	28.00
Air-operated, spring-returned	1/8	9.20
	1/4	15.10
	1/2	30.20
	3/4	48.00
Double-air-actuated	1/8	9.00
	1/4	15.00
	1/2	30.00
	3/4	47.60
Solenoid-actuated, spring-returned	1/8	15.20
	1/4	25.45
	1/2	39.40
	3/4	47.95
Double-solenoid-actuated	1/8	30.20
	1/4	35.45
	1/2	52.50
5-port, 3-position	1/8	10.50
	1/4	17.75
	1/2	35.45
3-port, 2-position		
Push-button-actuated, spring-returned	1/8	7.25
	1/4	11.90
	1/2	21.70
Lever (cam)-actuated, spring-returned	1/8	8.55
Detent-position (push-pull)	1/8	8.55
	1/4	12.50
	1/2	23.00
Air-actuated, spring-returned	1/8	7.30
	1/4	12.50
	1/2	20.00
Double-air-actuated	1/8	7.30
	1/4	13.20
	1/2	22.35
Solenoid-actuated, spring-returned	1/8	18.40
	1/4	24.30
	1/2	34.15
Double-solenoid-actuated	1/8	23.00
	1/4	34.80
	1/2	44.90

Air-flow regulators

	Size (inch)	Price ($US)
Unidirectional air-flow regulator	1/8	2.50
	1/4	3.55
	1/2	7.25
	3/4	16.55
Non-return valve (ball-check)	1/8	1.45
	1/4	2.00
	1/2	2.80
	3/4	5.95
Shuttle valve	1/8	2.10
	1/4	2.50

Filter – pressure-regulator – lubricator (trio units)

Size (inch)	Price ($US)
1/2	50.00
3/4	70.00

Air cylinders

	Size (inch) Bore	Size (inch) Stroke	Price ($US)
Single-acting	3/4	1	3.30
	3/4	2	3.70

Air cylinders (continued)

	Size (inch) Bore	Stroke	Price ($US)
Single-acting (continued)	1-1/4	1-1/4	5.00
	1-1/4	2-1/4	5.25
	1-3/4	2	8.30
	2-1/2	2	11.05
Double-acting (non-cushioned)	1-1/4	1-1/2	5.00
	1-1/4	3	5.25
	1-1/4	4-1/2	5.65
	1-1/4	6	5.95
	2-1/2	3	9.95
	2-1/2	6	10.90
	2-1/2	9	11.85
	2-1/2	12	12.75
Double-acting (cushioned)	1-1/4	1-1/2	5.55
	1-1/4	3	5.80
	1-1/4	4-1/2	6.20
	1-1/4	6	6.45
	2-1/2	3	12.50
	2-1/2	6	13.80
	2-1/2	9	14.85
	2-1/2	12	15.75

	Size (inch) Bore	Stroke	Price ($US)
Heavy-duty double-acting	4	4	72.00
	5	4	85.45
	6	4	114.60
	8	4	174.20
	10	4	367.50
	12	4	443.65

	Energy rating (inch-tons at 80 psig)	Price ($US)
Impact	1/10	35.45
	1/4	55.15
	1/2	76.15
	1	157.50
	2	249.40

Miscellaneous

Item	Price ($US)
Index table, rotary, diameter 10 in., with 4, 6, 8, 12 or 23 stations	470

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ID/10	*Production Techniques for the Use of Wood in Housing under Conditions Prevailing in Developing Countries.* Report of Study Group, Vienna, 17-21 November 1969 United Nations publication, Sales No. E.70.II.B.32
ID/61	*Production of Prefabricated Wooden Houses* Keijo N. E. Tiusanen United Nations publication, Sales No. E.71.II.B.13
ID/72	*Wood as a Packaging Material in the Developing Countries* B. Hochart United Nations publication, Sales No. E.72.II.B.12
ID/79	*Production of Panels from Agricultural Residues.* Report of Expert Working Group Meeting, Vienna, 14-18 December 1970 United Nations publication, Sales No. E.72.II.B.4
ID/108	*Furniture and Joinery Industries for Developing Countries* *Part one: Raw Material Inputs* *Part two: Processing Technology* *Part three: Management Considerations*
ID/133	*Selection of Woodworking Machinery.* Report of a Technical Meeting, Vienna, 19-23 November 1973
UNIDO/LIB/SER.D/4	*UNIDO Guides to Information Sources No. 4: Information Sources on the Furniture and Joinery Industry*
UNIDO/LIB/SER.D/9	*UNIDO Guides to Information Sources No. 9: Information Sources on Building Board from Wood and other Fibrous Materials*

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