OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

06948

ID/154/Rev.1

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

LOW-COST AUTOMATION FOR THE FURNITURE AND JOINERY INDUSTRY

304

UNITED NATIONS

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna

LOW-COST AUTOMATION FOR THE FURNITURE AND JOINERY INDUSTRY

UNITED NATIONS
New York, 1982

Preface

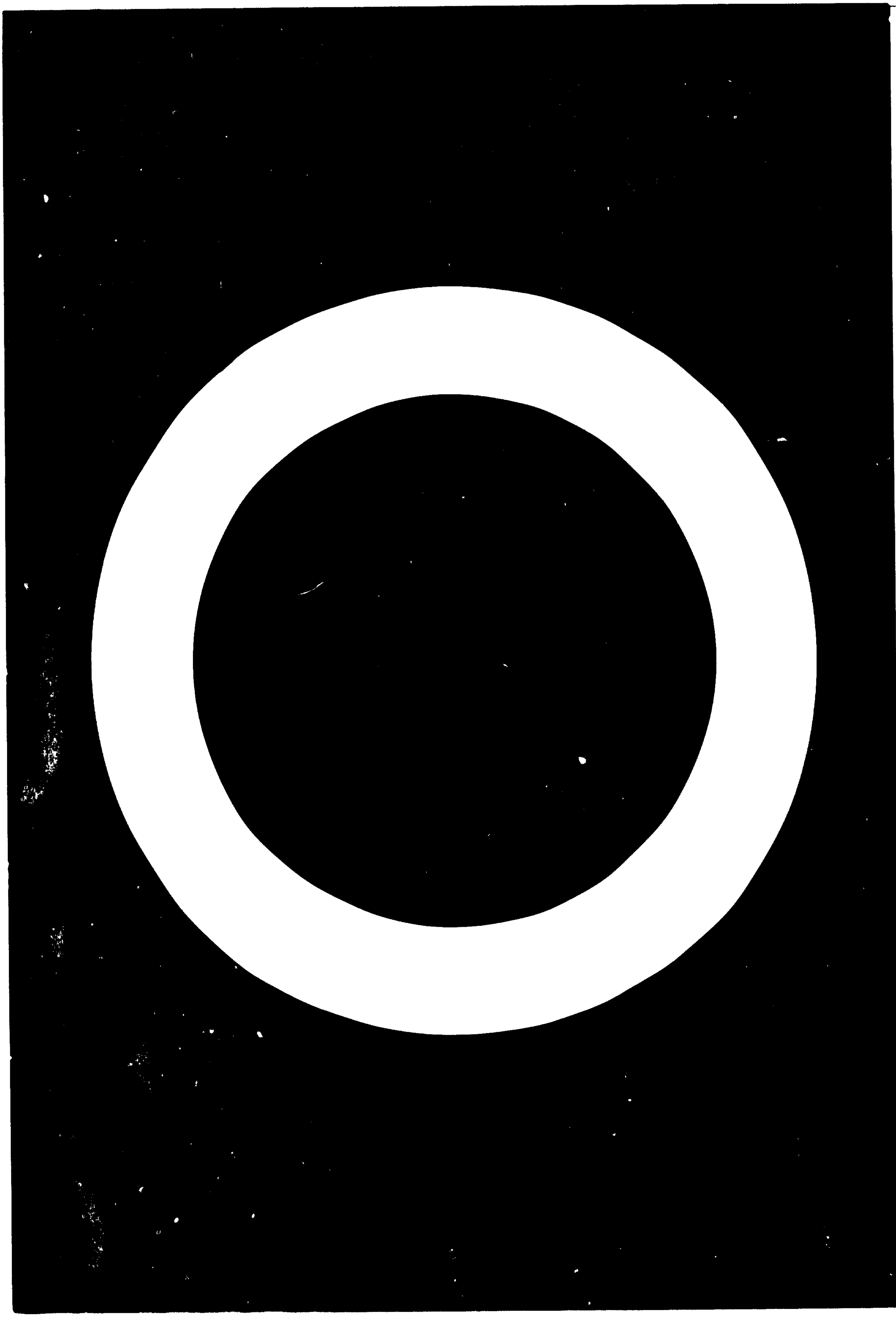
To meet demand and competition effectively, the furniture and joinery industry in developing countries must modernize its equipment and methods. In developing countries where capital is limited, low-cost automation can help solve this problem.

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 that misconception. It is also the aim of this manual to show furniture and joinery companies that they can gain the benefits of automation in their factories at relatively low cost and that their own personnel can carry out the installation of automation devices, usually on existing machines.

The arrangement of the material is such that chapters I-III and perhaps IV and VIII will probably be of particular interest to managers, and chapters IV-VIII will be most useful to technicians and engineers. Chapter IX 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 expressed in this manual are those of the authors, W. J. Santiano, a low-cost automation consultant, and H. P. Brion, a furniture and joinery industry consultant, both of whom work in the Philippines. Their views do not necessarily reflect those of the secretariat of the United Nations Industrial Development Organization (UNIDO).

This revised edition has been produced to include material prepared by H. P. Brion for a seminar held by UNIDO at Beijing, China, in April 1981.



CONTENTS

Annexes

I. What low-cost automation means

Originally conceived in Europe in 1957, low-cost automation (LCA) was one of the factors that transformed Europe into a community of highly industrialized countries from an economy characterized by lack of skill, lack of capital and splintered markets. At the time, C. Linsky and R. de Groot, working through the Organisation 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 low-cost automation

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 sohpisticated, 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 "grey area" of a possible improvement. LCA fills precisely that area (figure 1).

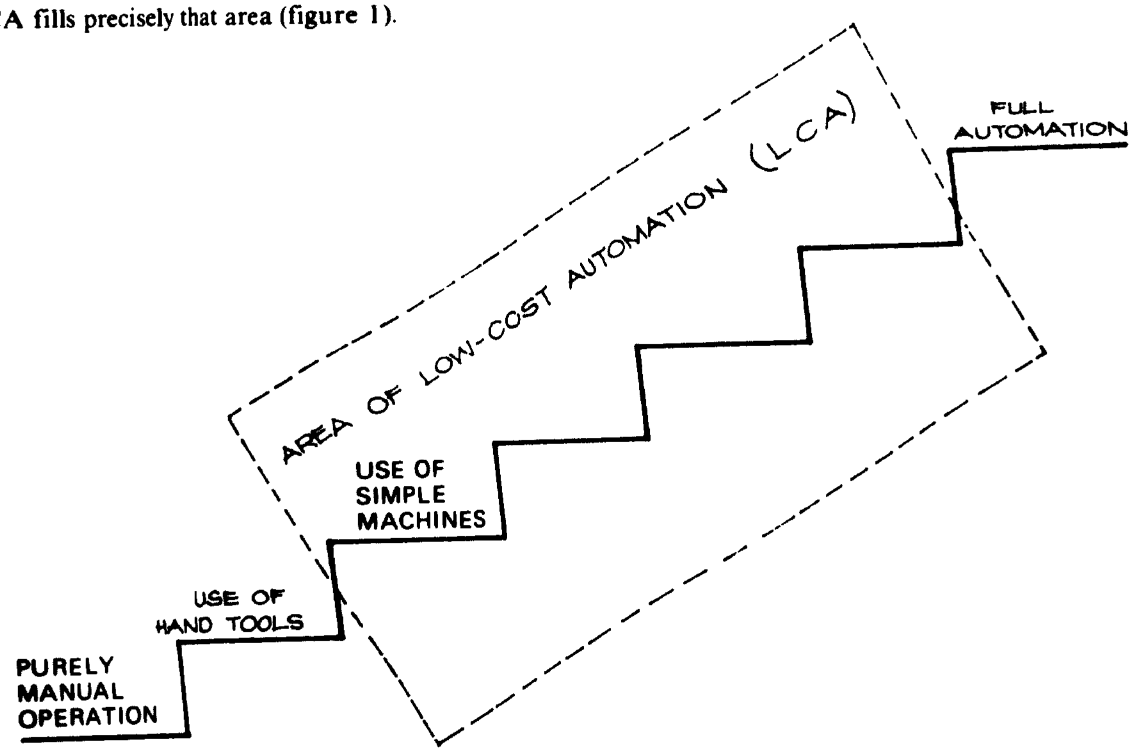


Figure 1. The location of LCA in the progression from purely manual to fully automatic operation

B. Why low-cost automation 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.

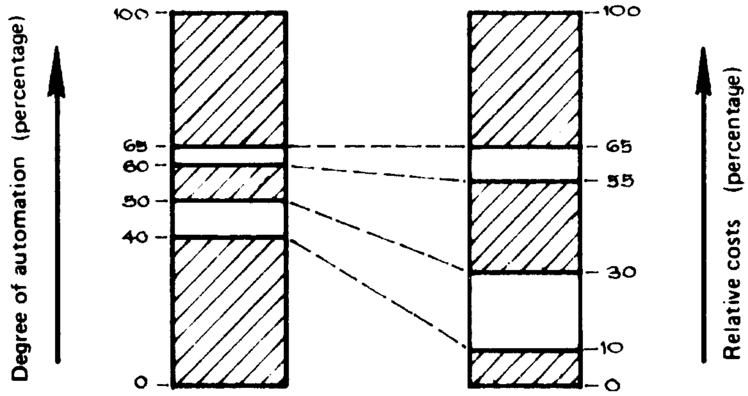


Figure 2. Relative cost of partial automation

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 requirements 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 as difficult as its 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 connections, reservoirs, filters, lubricators, heat exchangers, mufflers.

Electrical equipment

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

Controllers: limit switches; various types of relays (latch relays, time-relays, overload 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 problems in maintaining quality that are extremely difficult to solve. Workers, even though skilled, tend to get tired, careless, or distracted and thereby adversely affect the quality of the output. LCA by reducing human interference in an operation to that level which is just sufficient, can therefore be a great step towards improving quality. LCA can be usefully applied even in materials handling operations, where quality can be impaired.

The point can be illustrated by two examples of how one furniture manufacturer solved problems related to quality 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 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.

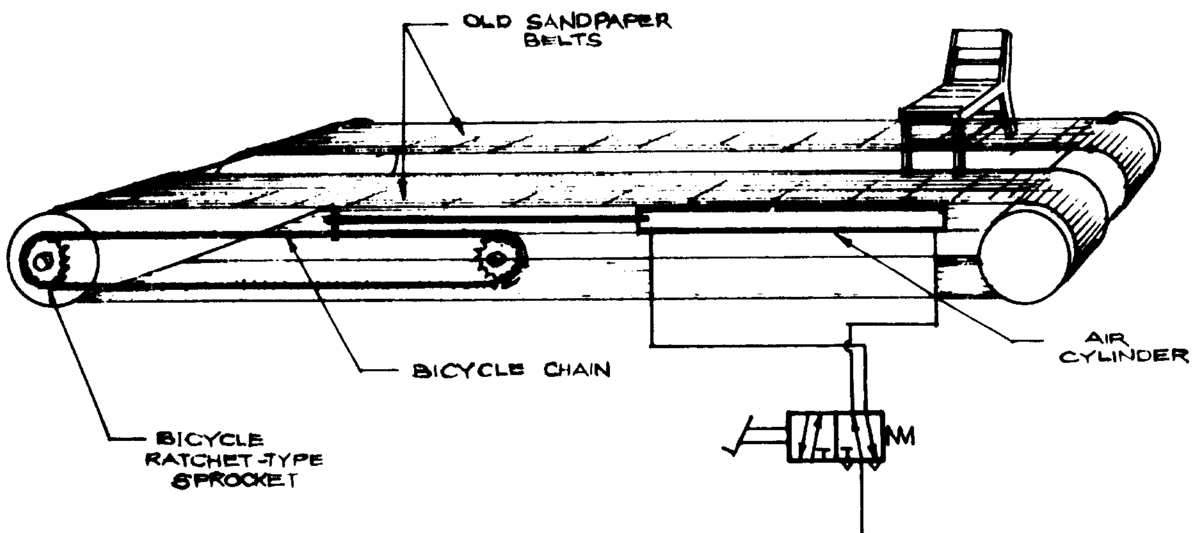


Figure 3. Chair conveyor system

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

The cost of the project was about $110.[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 worker's 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 doing a good upholstering job.

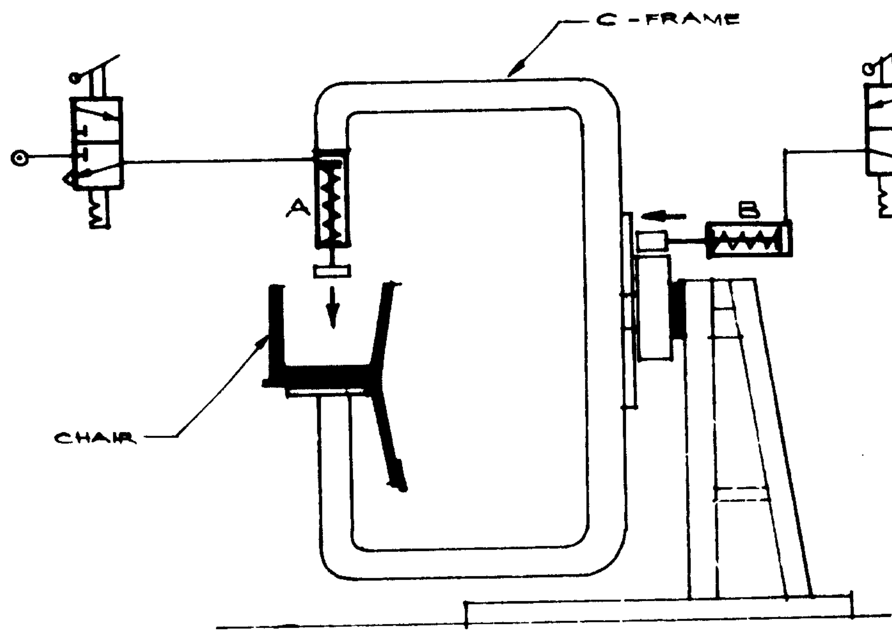


Figure 4. Chair manipulator

The manipulator, which cost approximately $312, besides solving the problem of maintaining quality also permitted a threefold increase in production capacity.

Other examples of enhancement of quality through LCA can be found in chapter IX, sections A, H, I, J, K, L and M.

B. Utilization of labour

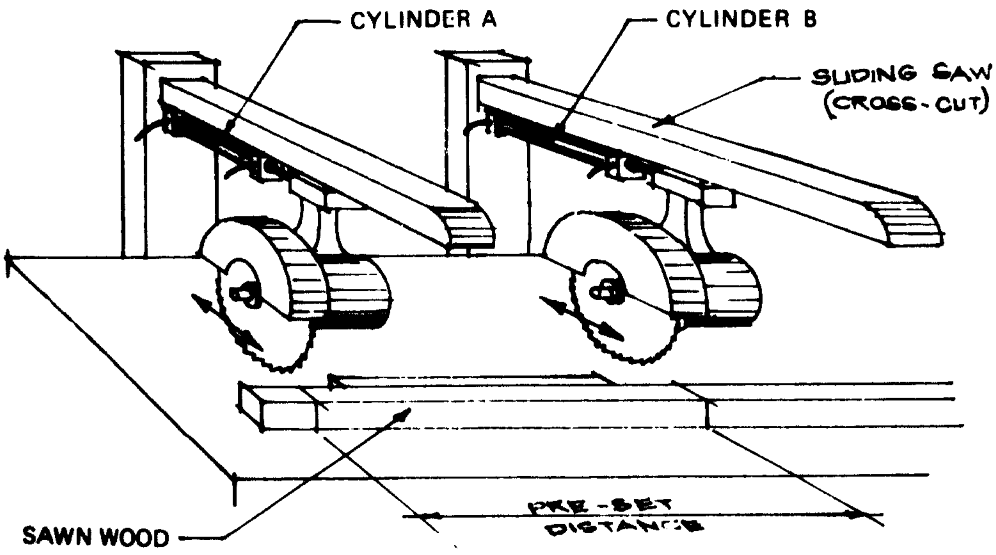
In many furniture shops, skilled workers are underutilized. That is, they spend 40-60 per cent of their time performing activities that do not require their valuable skills. On the other hand, the many unskilled or semi-skilled workers who could do those tasks cannot be employed because the manufacturers 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.

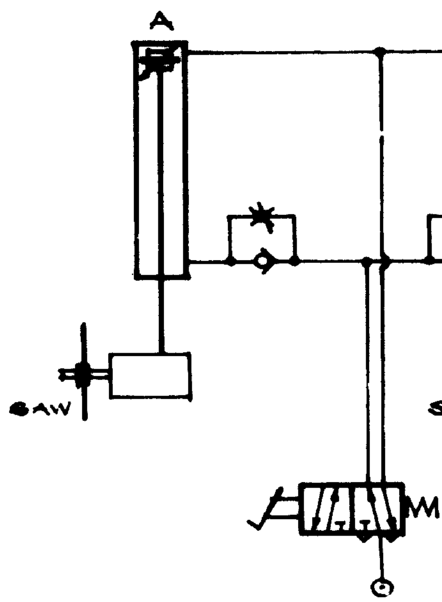
In the LCA solution, use was made of two sliding cross-cut saws located a definite distance apart. The cross-cut saws were already available in the plant. Figure 5*(a)* shows how the two sliding saws were provided with air cylinders, and figure 5*(b)* is a schematic diagram of the pneumatic circuit. 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 saving of $22.20 per week was realized because there were fewer rejects.

The cost of the components for the project was $300.

[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 every part of its 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.

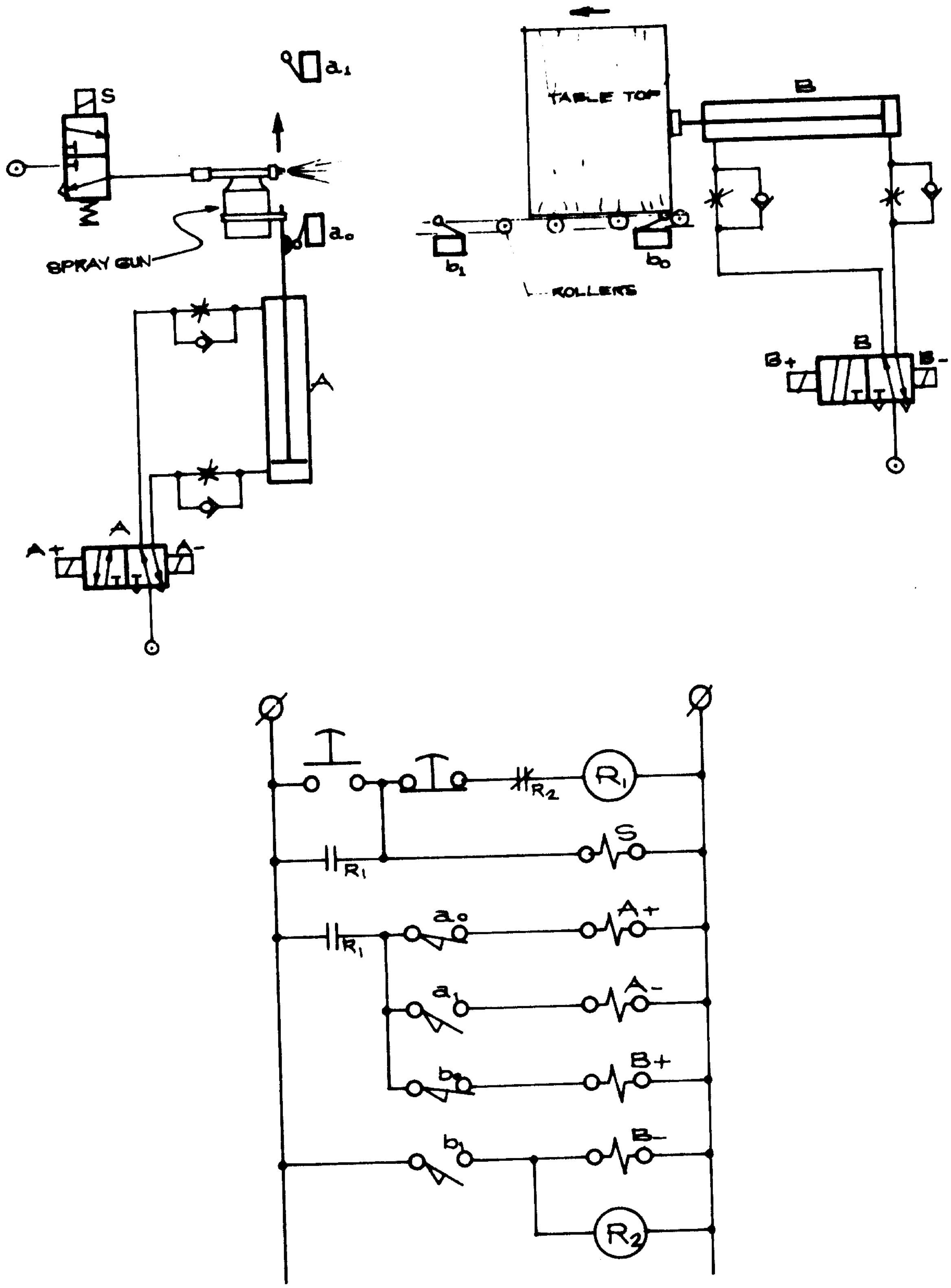


Figure 6. Automatic panel sprayer

The cost of the project was approximately $575, which was recovered through the savings in varnish (15 per cent) in 5 months.

Other examples resulting in materials savings through LCA can be found in chapter IX, section L.

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.

By simply making use of a pneumatic clamp (figure 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 $97.

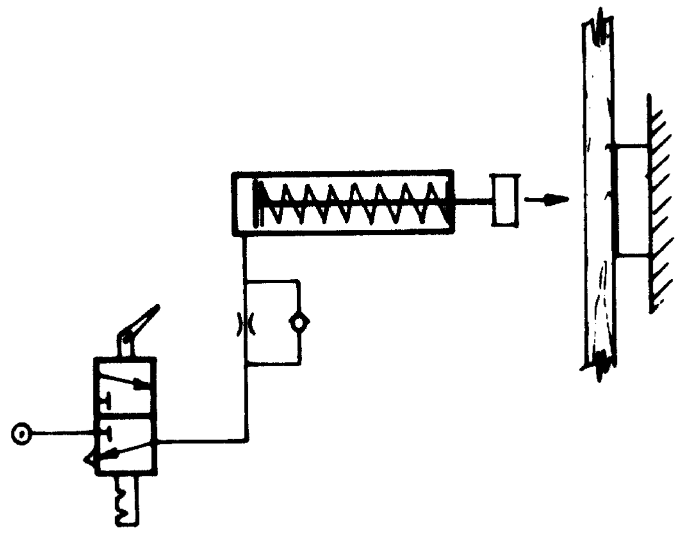


Figure 7. Pneumatic clamp

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 given in chapter IX, 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 $290.

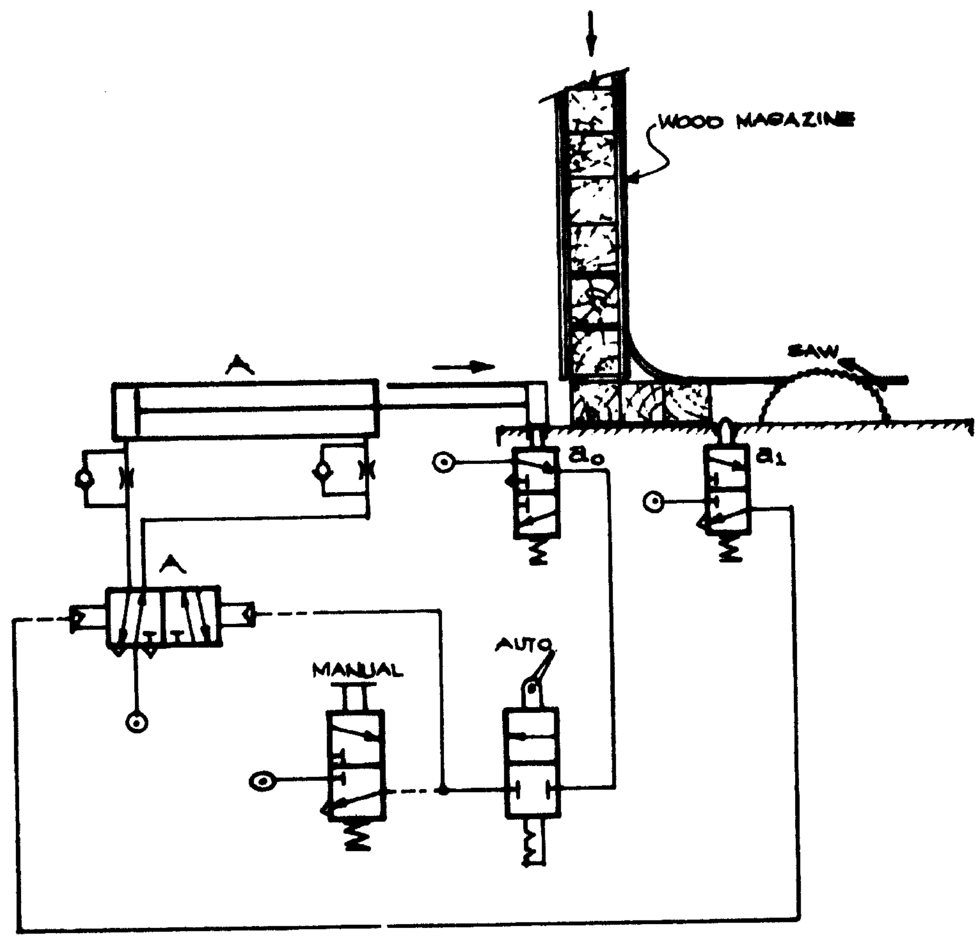


Figure 8. Table-saw feeder

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 pre-requisites;
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 with 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 pre-requisites

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.

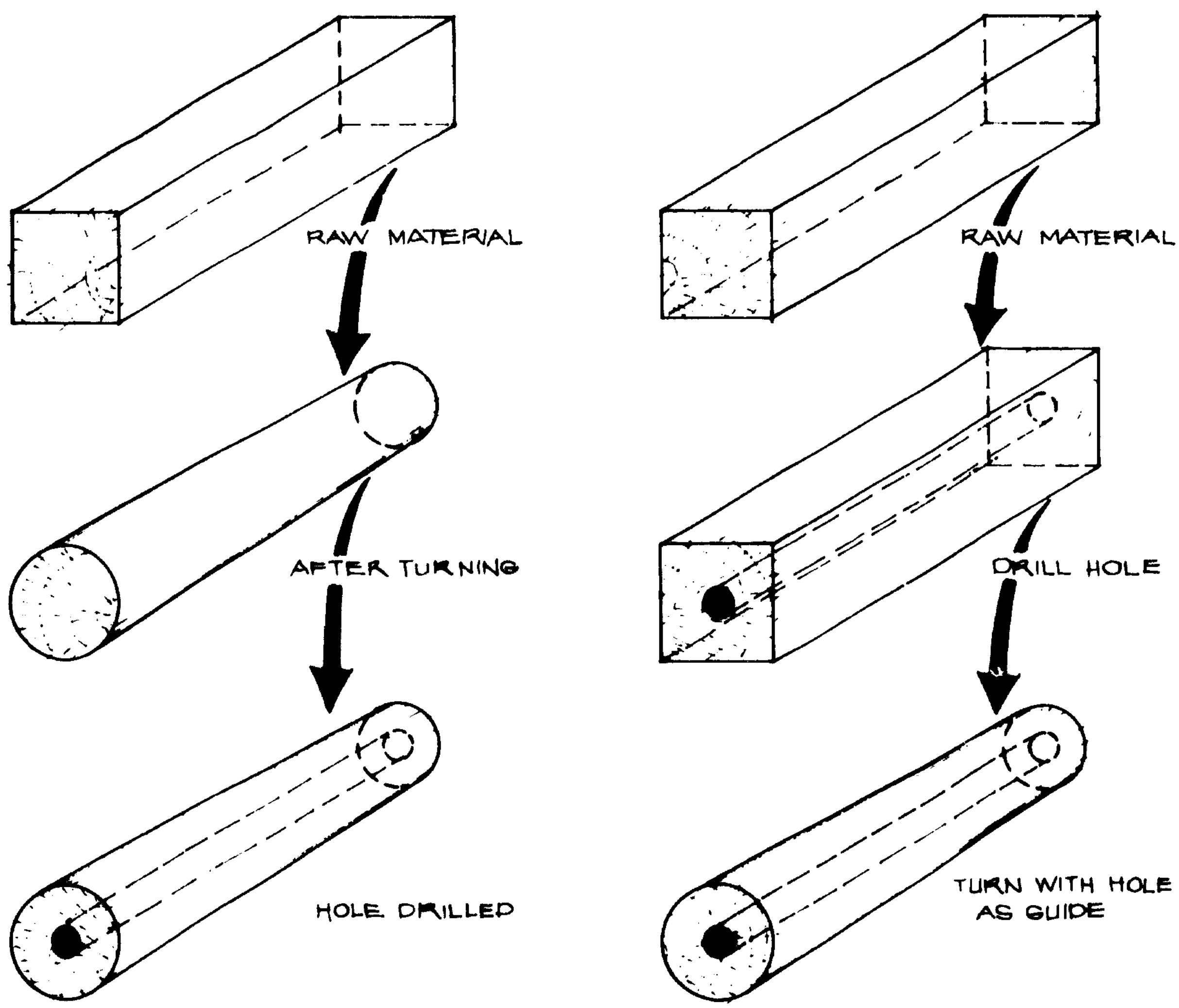
Sometimes, a mere simplification of production techniques through methods (or work) study can serve just as well as, if not better than, automation, as the example below will show.

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 figure 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.



CURRENT PROCESS SUGGESTED PROCESS

Figure 9. Comparison of process for making wooden legs for a bed. The suggested process produced accurately centred 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.

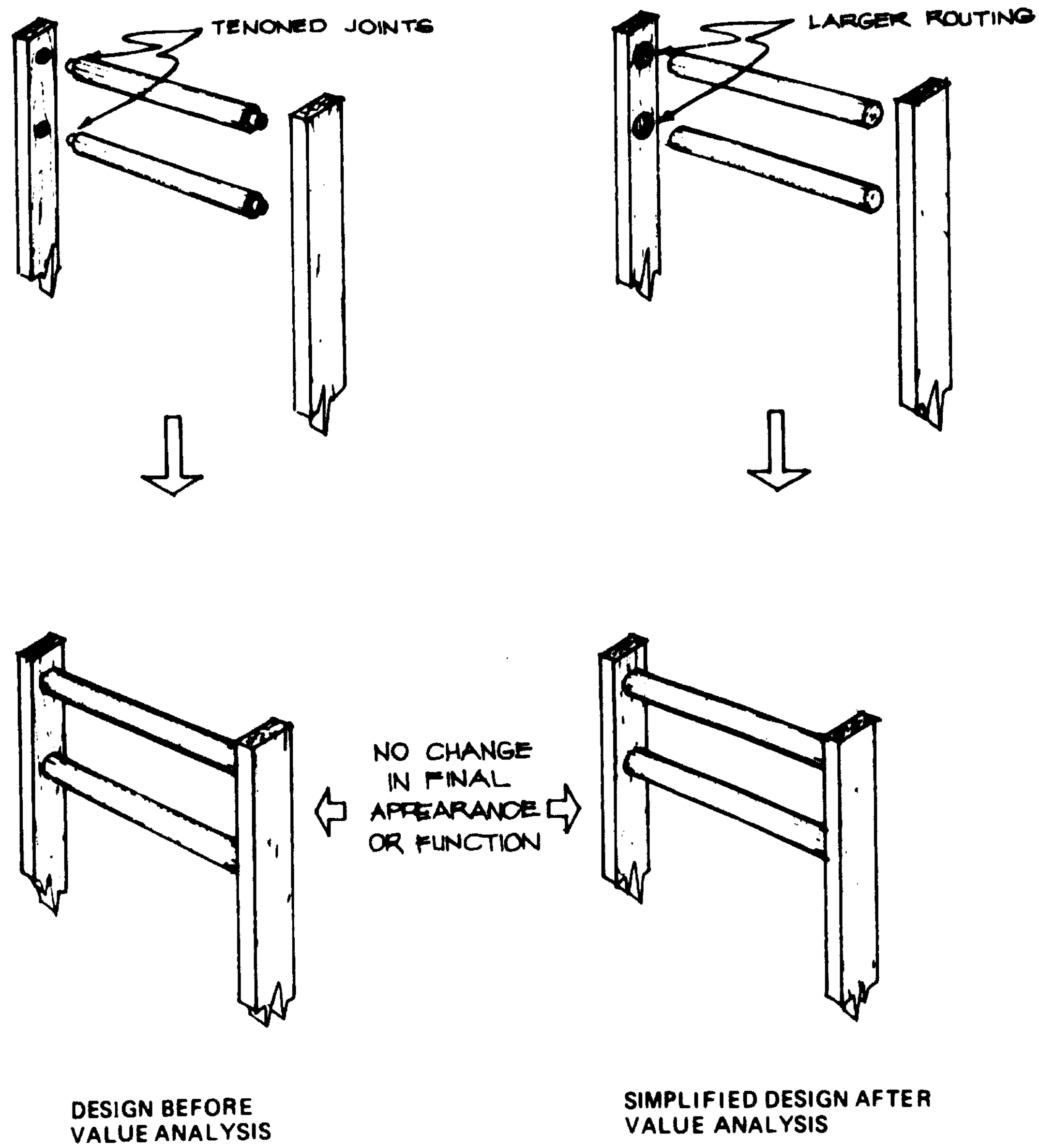


Figure 10. Product simplification by value analysis

C. An actual example of the analytical approach to low-cost automation

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 $14.40
2. Buy a tenoning machine
   Capacity increase 800 per cent
   Total fixed cost for machine $485 per year
   Total variable cost for labour, maintenance and power $1.25 per frame
3. Subcontract the tenoning operation
   Cost (for up to 200 frames per day) $0.18 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 $2.55 per frame, the break-even volume for the machine was 485/(2.55−1.25) = 373 frames per year, well below the anticipated volume. However, the initial cost of the machine ($4,850) 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 cosisted 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 $135, 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 IX, 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, demand continued to increase rapidly. Hence no time was lost in trying to find out how 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 XI, 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 IX, 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 (chapter 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.

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 needs of the furniture and joinery industry for low-cost automation

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 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 IX, 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 IX, section M, is an example.

Assembling

Assembling operations can also be facilitated by LCA. Figure 4 (chapter 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 (figure 11). By combining them, engineers are now able to design sophisticated systems that even include controls.

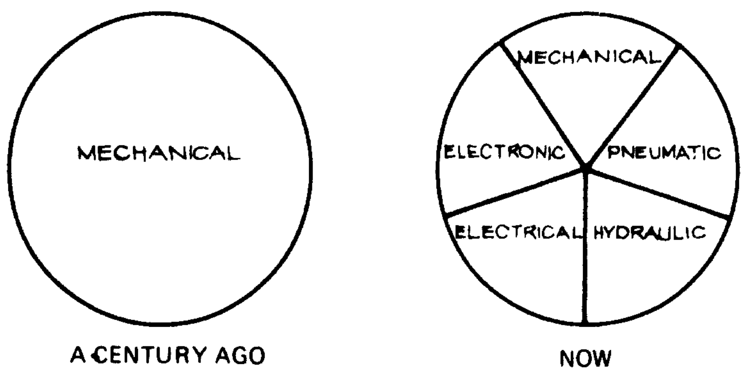


Figure 11. Types of devices available for automation

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 (figure 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.

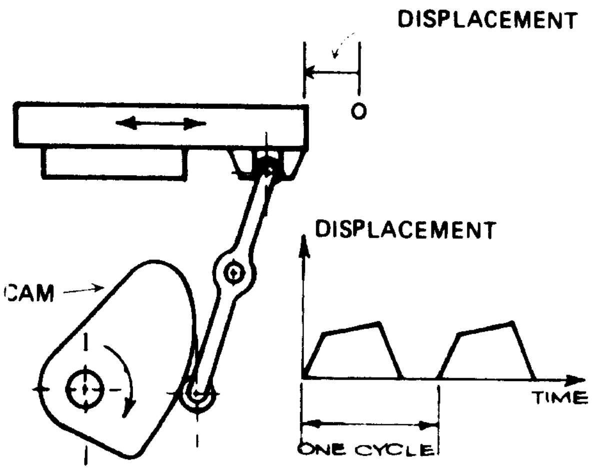


Figure 12. Mechanical cam steering

A construction like the one just described takes over much of the mental and physical work that 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.

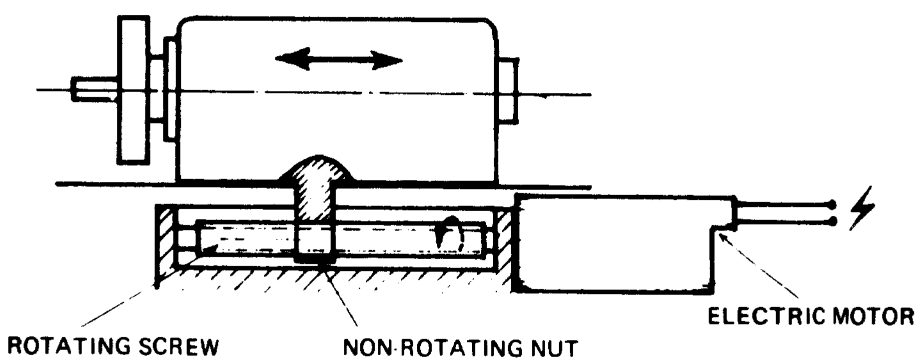


Figure 13. Conversion of rotary to linear movement

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 programme is often fixed and difficult to change;

(c) Replacing the "programme" 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 programme 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 (figure 14), which is normally the cheapest solution, if applicable.

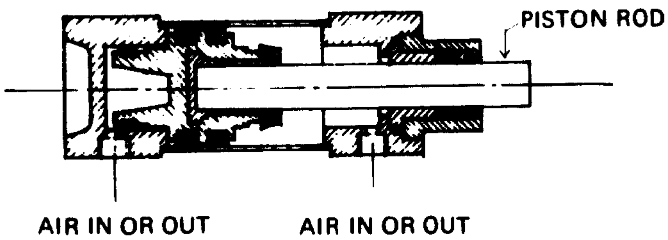


Figure 14. Double-acting air cylinder

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, 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. The arrangement is shown in figure 15.

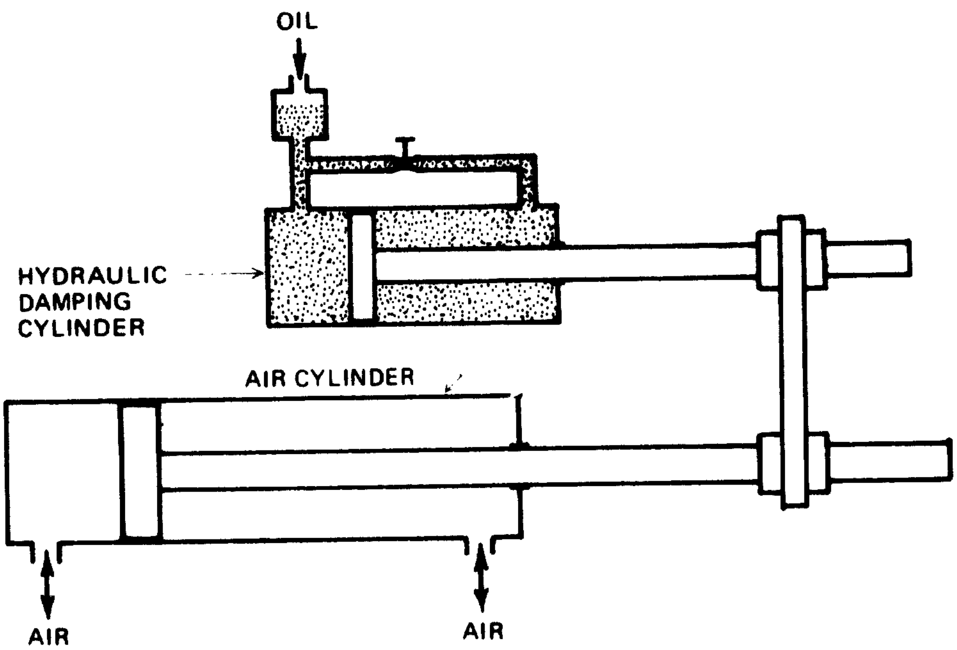


Figure 15. Double-acting air cylinder with parallel hydraulic damping cylinder

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.

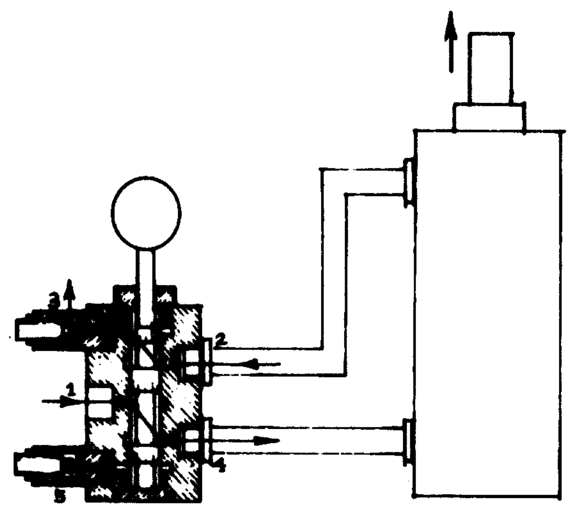


Figure 16. Three-way valve

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.

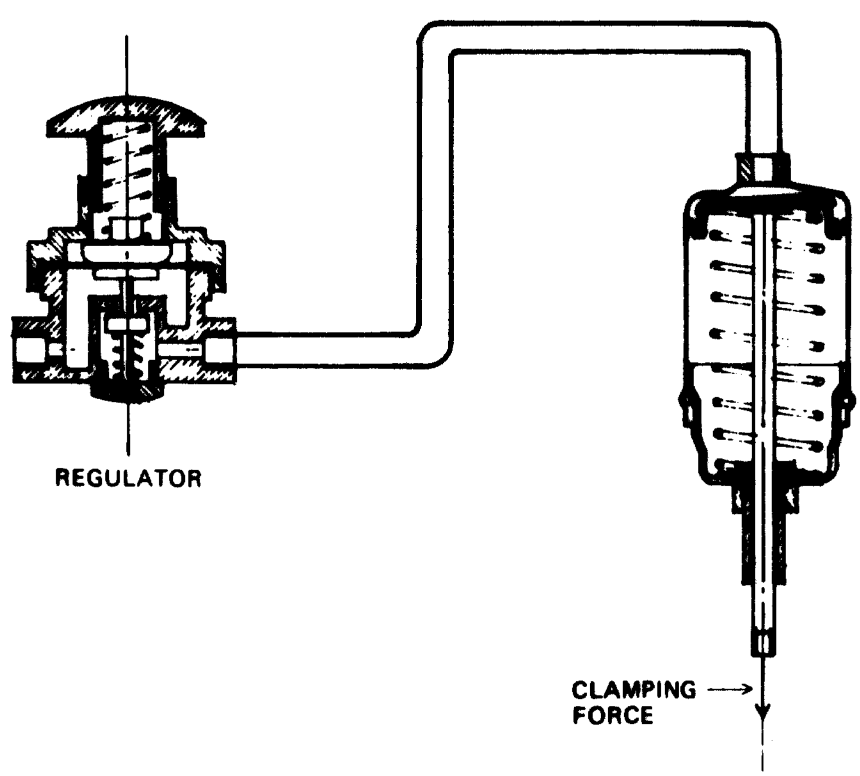


Figure 17. Single-acting thrust cylinder with pressure regulator for control of clamping force

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 aso 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 running intermittently. At an assembling station, for example, a pneumatic nut-runner may be run for only 2 s in a 30-s 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 pressure regulator);

(c) Compared with 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 bar. 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.

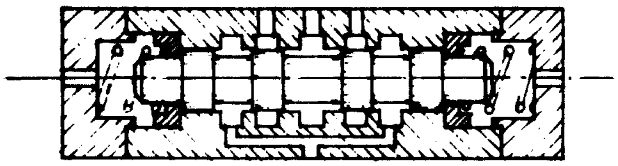
C. Hydraulic devices

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.

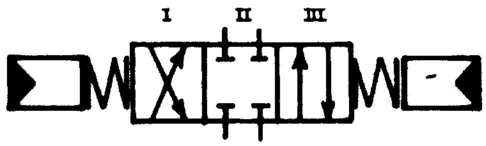
Hydraulic systems require a special pump for supplying each unit with oil in adequate quantity and pressure. That can be a disadvantage of hydraulic systems compared with pneumatic ones, since the latter need only one compressor, no matter how many components there are in the system.

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.



CROSS-SECTIONAL DRAWING



SCHEMATIC SYMBOL

Figure 18. Three-position hydraulic valve

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 (figure 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.

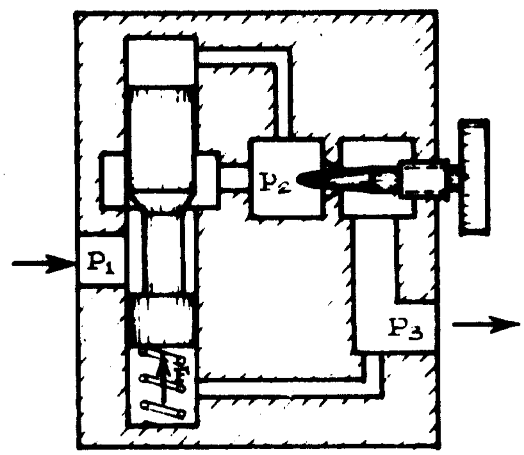


Figure 19. Hydraulic "constant flow" control valve

Another, but more expensive, possibility for speed regulation is to use a pump with variable displacement (figure 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.

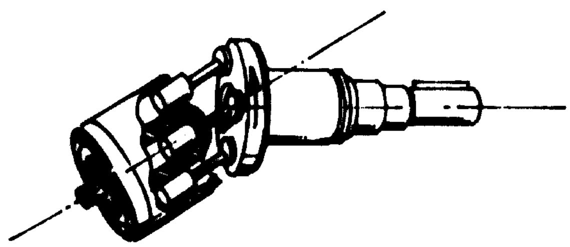


Figure 20. Hydraulic pump with variable displacement

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.

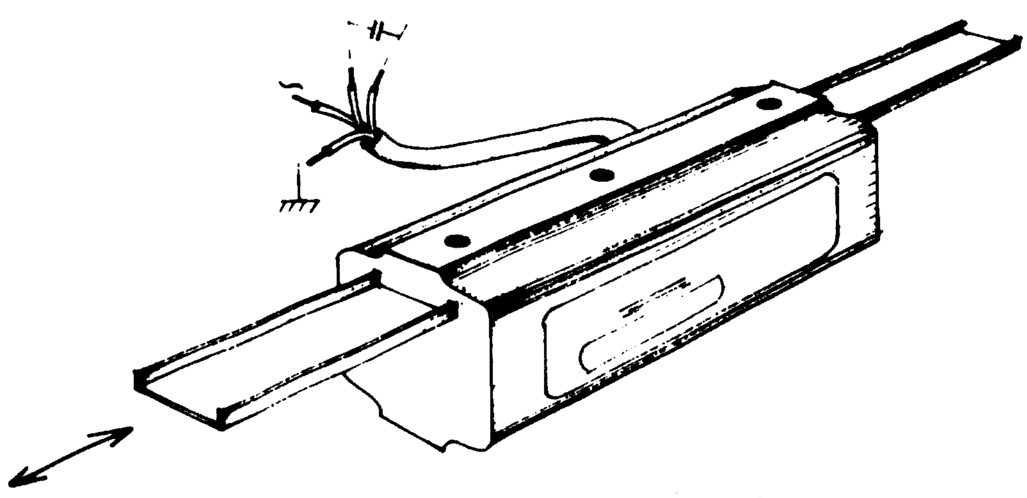


Figure 21. Magnetic coil for short linear movements

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 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 (figure 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.

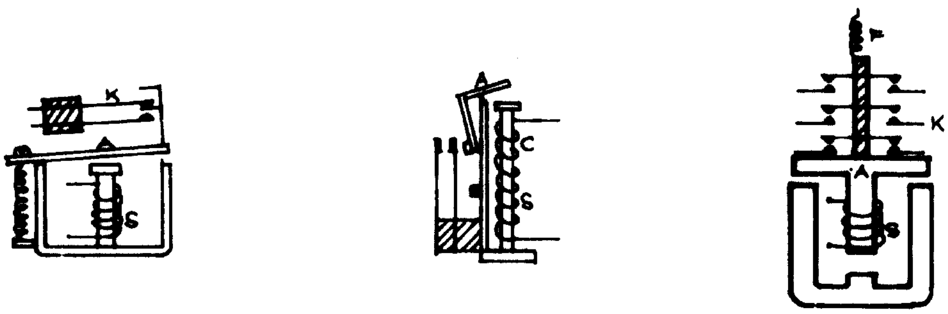


Figure 22. Electric relays

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

Several types of electrical switches and punch card readers are available for programming control systems. The switches, for example, can give signals at fixed 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 i 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 the 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 comined. 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: $PV = \text{const}$.

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,

$$P_iV_i = P_fV_f$$
$$P_f = P_iV_i/V_f = (V_i/V_f)P_i$$
$$= (283/41)P_i = 6.9P_i$$
$$= 6.9 \text{ bar, or } 103 \text{ lbf/in.}^2 \text{ (psi) } (P_i = 1 \text{ bar} = 14.7 \text{ psi})$$

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 $r \approx (P + 14.7)/14.7$; if P is read in bars gauge, $r \approx P + 1$.

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 motor 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 bar. Pressures lower than 5 bar may not be sufficient for some requirements, while pressures higher than 15 bar 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 35-50 per cent because of various mechanical and electrical inefficiencies.

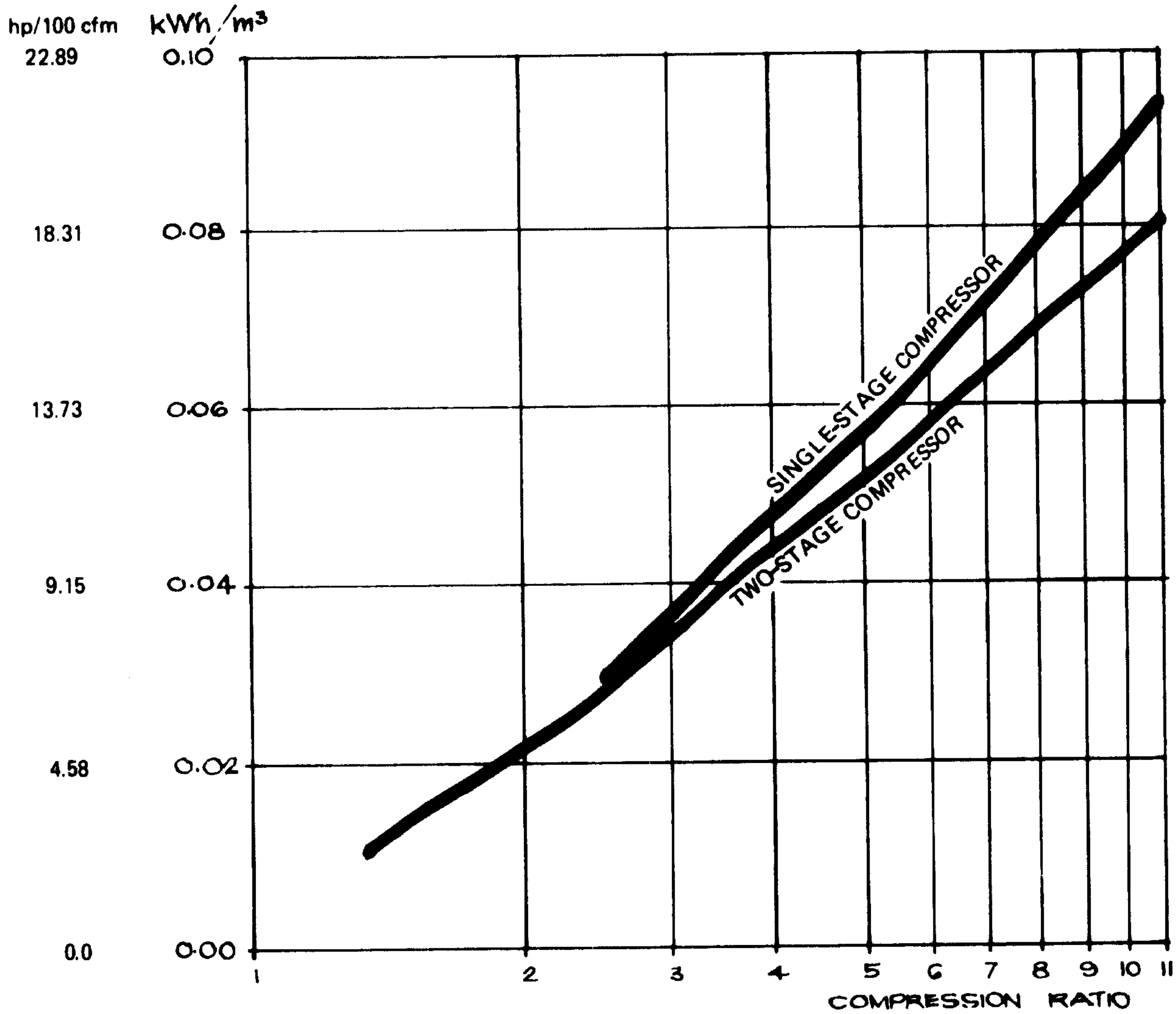


Figure 23. Theoretical specific energy requirements for air compression

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.

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.

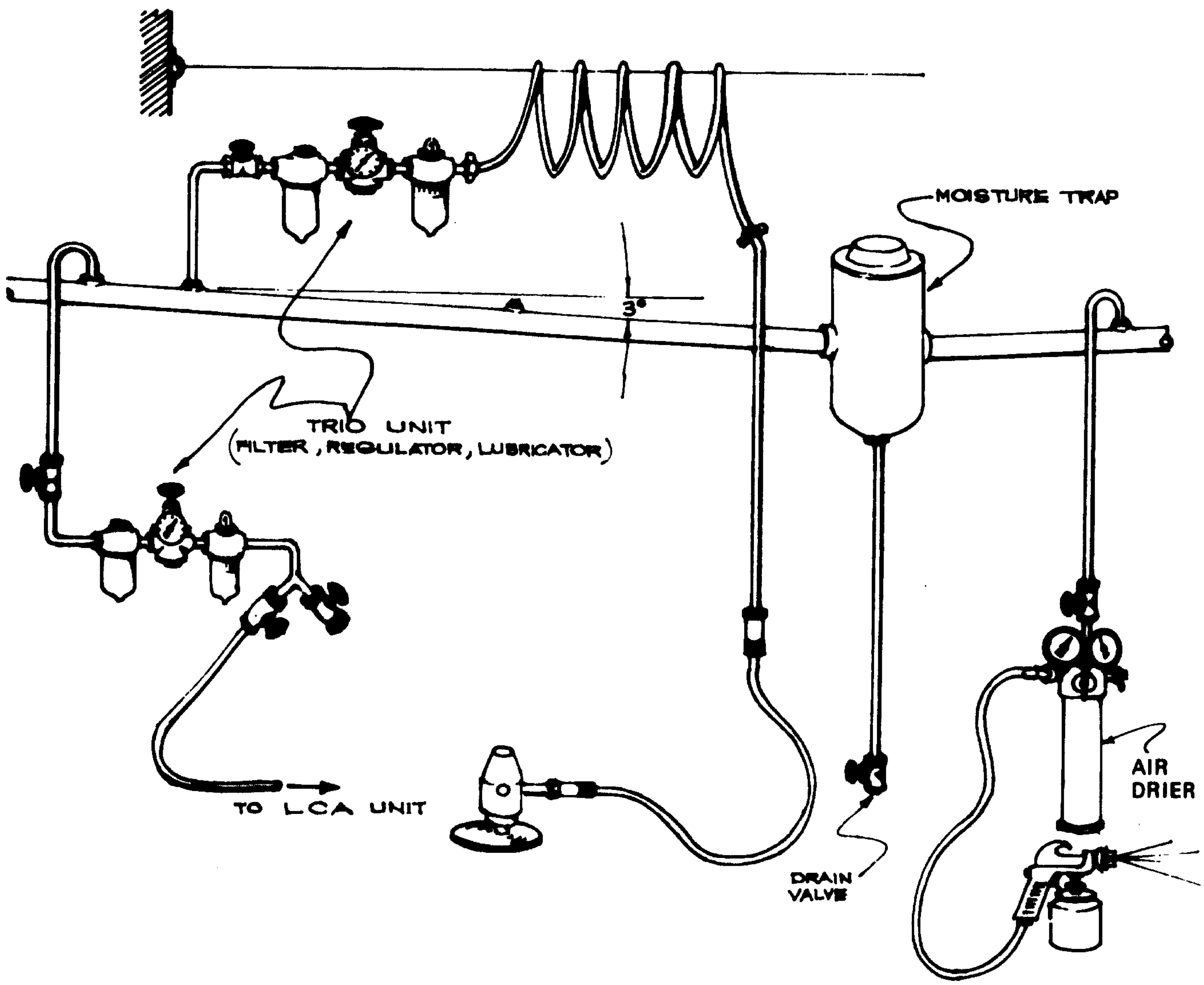


Figure 24. Air-line system

For compressed air up to a pressure of 12 bar, 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 an air-delivery rate of 25 cfm (0.7 m^3/min) can be maintained over a distance of 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 power (second column) to enter the table. For flows not included in the table, assume that the flow/power ratio is 3.5 cfm/hp (0.1 m^3/min per kilowatt). The calculation is only approximate, since the flow/power 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		Compressor power		Run (feet) (metres)							
(cfm)	(m³/min)	(hp)	(kW)	25 (7.6)	50 (15.2)	75 (22.8)	100 (30.5)	150 (45.7)	200 (61)	250 (76.2)	300 (91.5)
5 or less	0.14 or less	1.4	1.0	0.622 (15.8)	→	→	→	→	→	→	→
10	0.28	2.8	2.1	0.622 (15.8)	→	→	0.824 (20.9)	→	→	→	→
15	0.43	4.3	3.2	0.622 (15.8)	0.824 (20.9)	→	→	→	→	→	→
20	0.56	5.6	4.2	0.824 (20.9)	→	→	→	→	→	→	→
25	0.70	7.0	5.2	0.824 (20.9)	→	→	→	→	1.049 (26.6)	→	→
30	0.85	8.5	6.3	0.824 (20.9)	→	→	→	1.049 (26.6)	→	→	→
35	1.0	10.0	7.5	0.824 (20.9)	→	1.049 (26.6)	→	→	→	→	→
40	1.12	11.2	8.4	0.824 (20.9)	1.049 (26.6)	→	→	→	→	→	→
50	1.40	14.0	10.4	1.049 (26.6)	→	→	→	→	→	→	→
70	2.0	20.0	14.9	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 m³/min is desired in a 70-mm pipe, 200 m long. If the initial pressure at the head of the pipe is 7 bar, what will the final pressure at the delivery end be? The intersection of the lines representing 10 m³/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, is read. The delivery pressure is therefore 7.0−0.1 = 6.9 bar. 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:

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

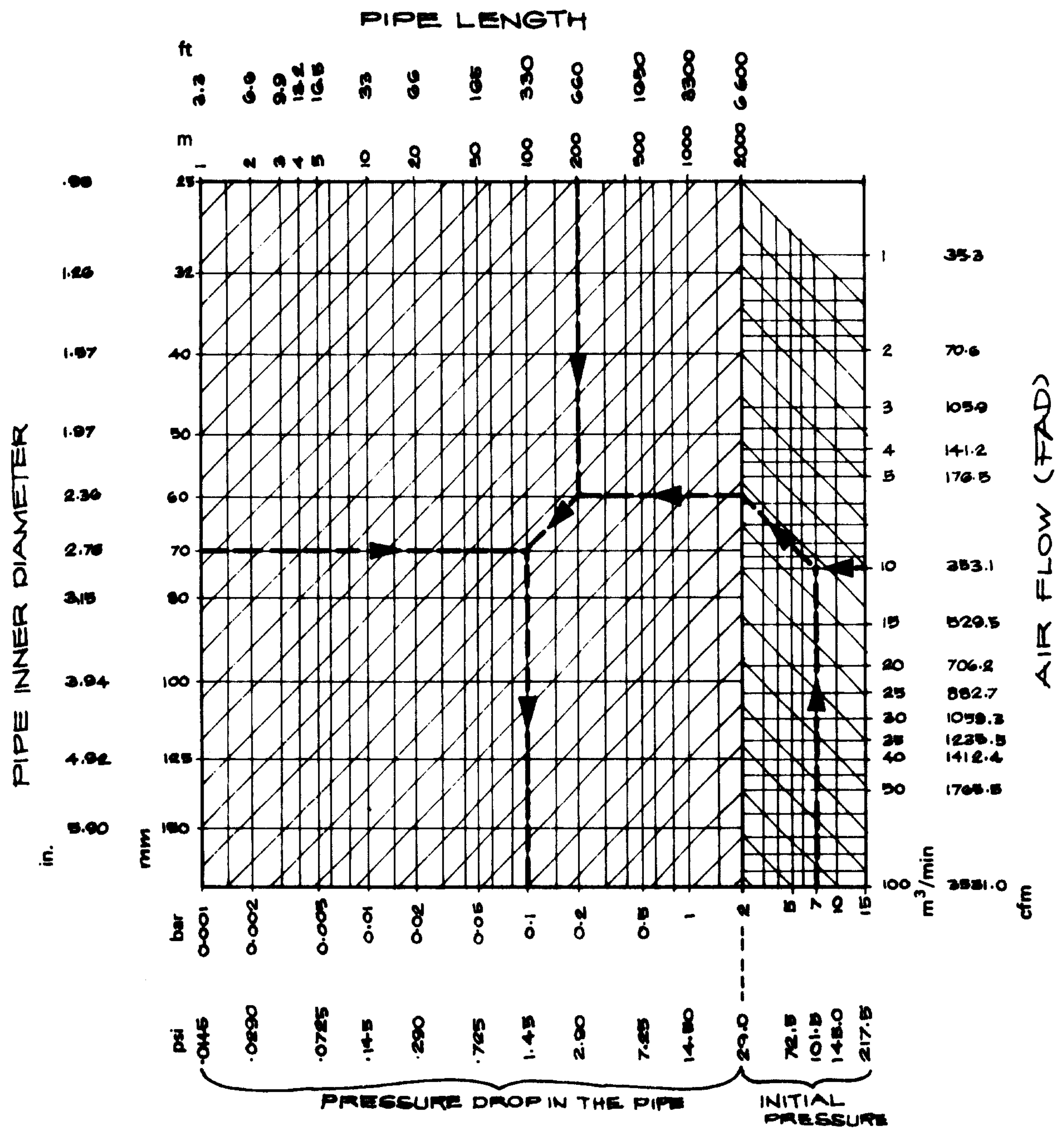


Figure 25. Pressure drop nomogram

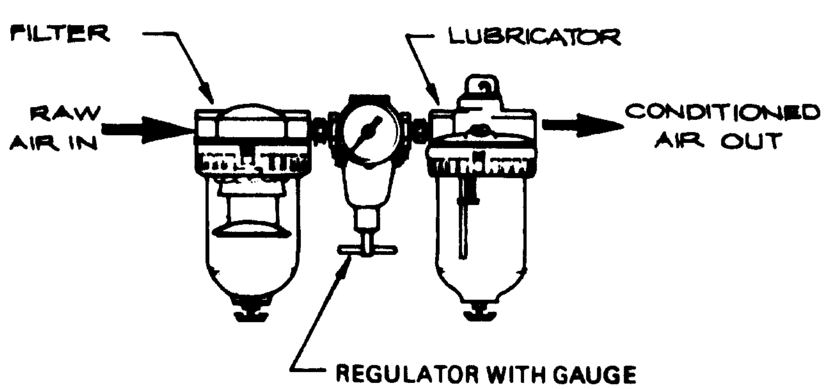


Figure 26. Trio unit: filter, regulator and lubricator

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 ft^3 (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 (figure 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 (figure 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.

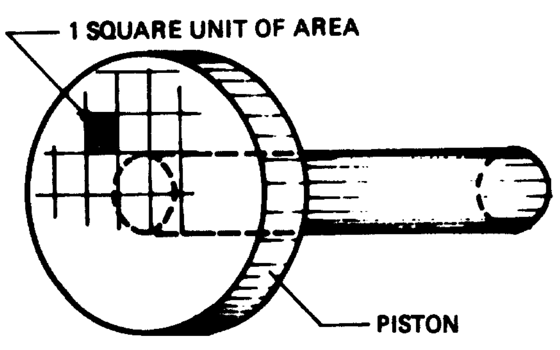


Figure 27. Effective area of piston face

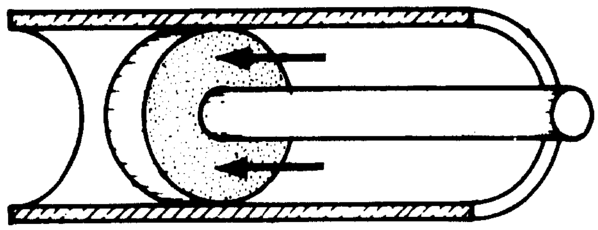


Figure 28. Effective area of rod-end of piston

The compressive and tractive forces of air cylinders with selected bores of 25-200 mm 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 careful 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 (5.45 bar). 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 (figure 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.

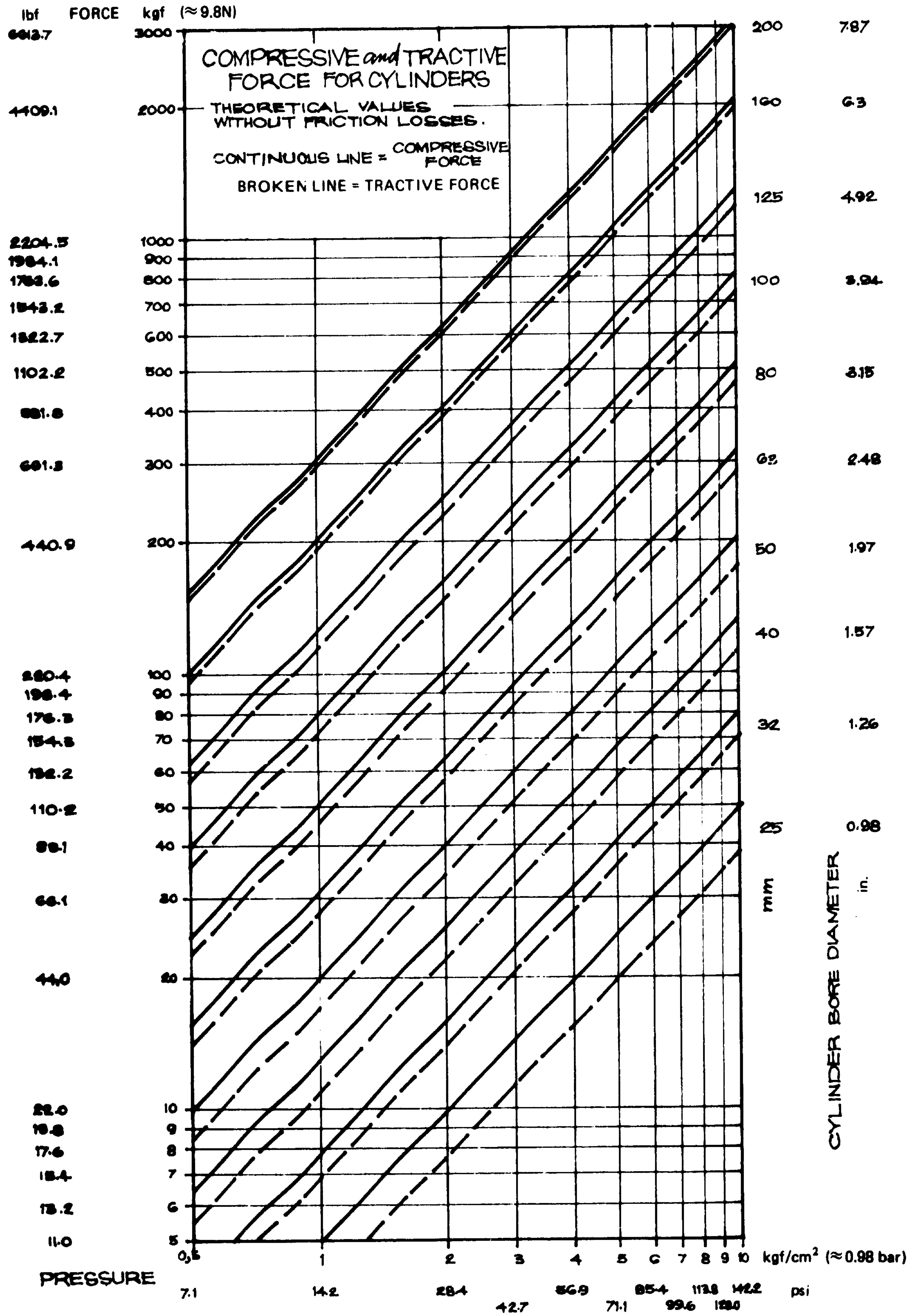


Figure 29. Compressive and tractive force of cylinders

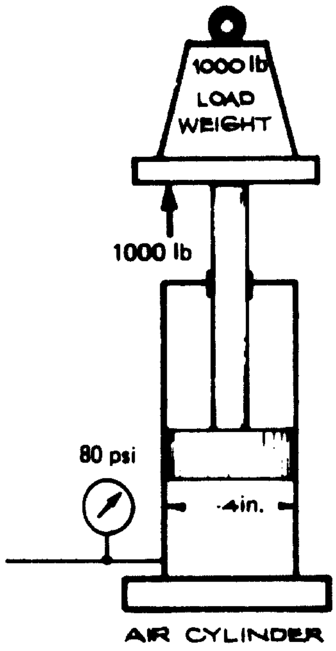


Figure 30. Load-thrust equilibrium of an air cylinder

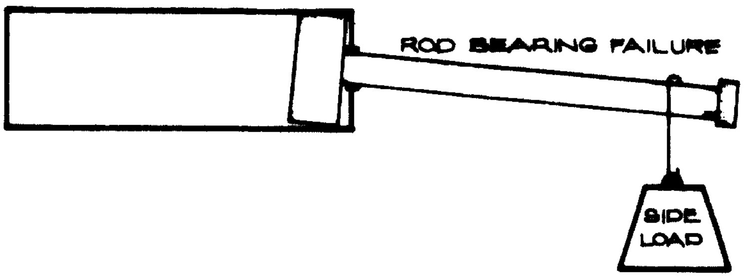


Figure 31. Result of side forces on a piston rod

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 with the rod diameter (see figure 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.

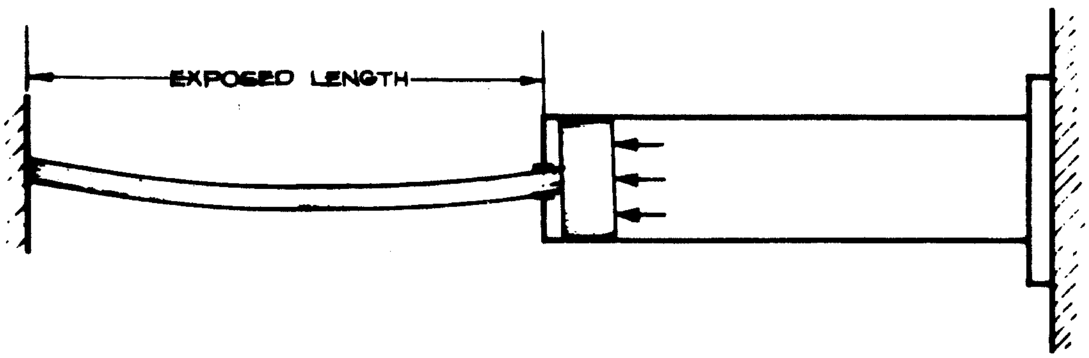


Figure 32. Column failure of piston rod

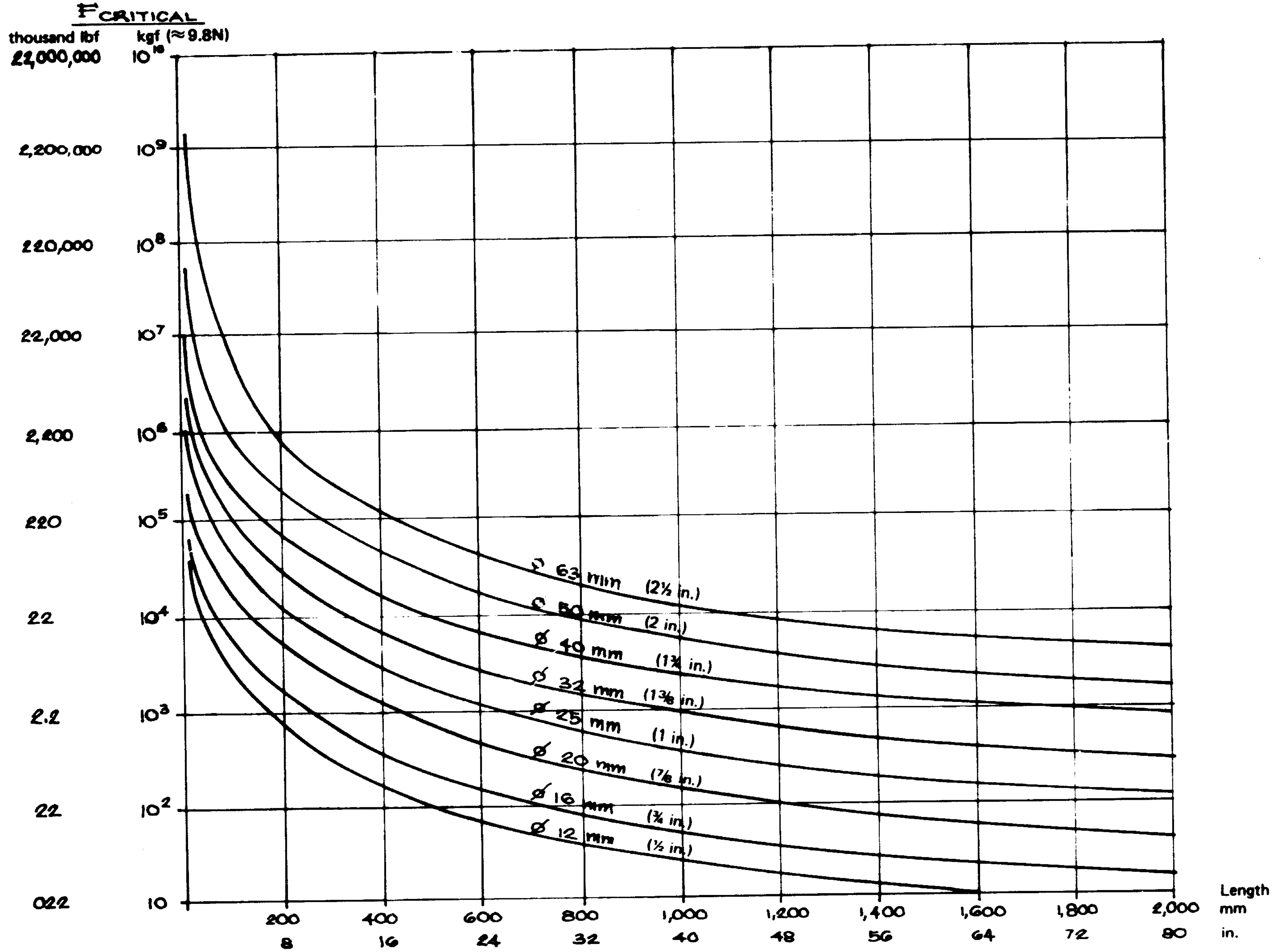


Figure 33. Minimum piston-rod diameter to prevent buckling of rod

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 $in.^3$ (721 cm^3). Find the consumption in terms of free air for a working pressure $P = 60$ psig (4.08 bar gauge).

$$\begin{aligned} \text{Compression ratio } r &= P + 1 = 5.08 \\ \text{Free-air displacement} &= r \times (\text{compressed-air displacement}) \\ &= 5.08 \times 44 \\ &= 224 \text{ in.}^3 \\ &= 0.13 \text{ ft}^3 \ (3663 \text{ cm}^3) \end{aligned}$$

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 with or without a seconadry 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 bar) 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 button, 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, connection 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:

$$\text{Power} = (\text{volume flow rate}) \times (\text{pressure})$$

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 (figure 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.

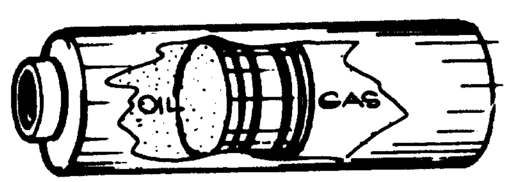


Figure 34. Piston-type accumulator

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 (figure 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.

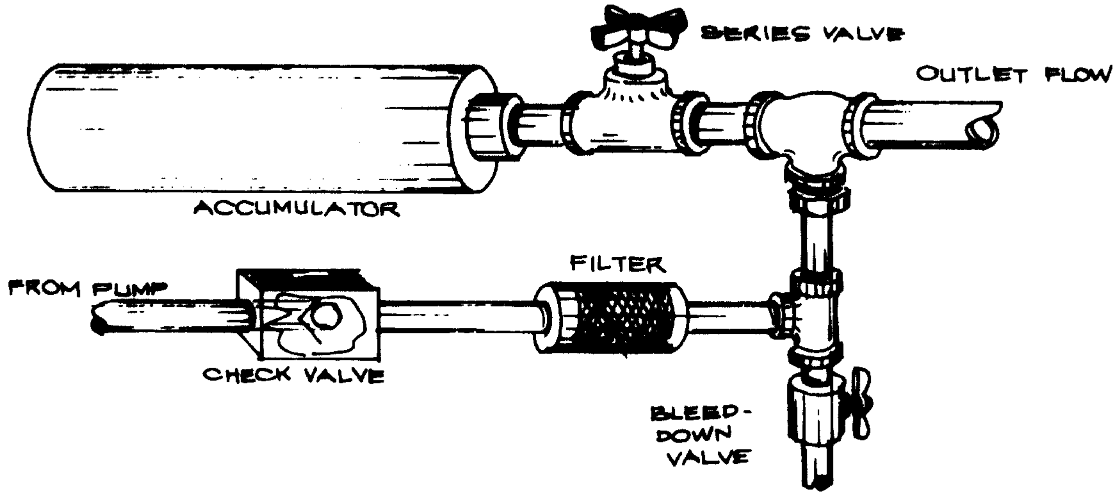


Figure 35. Suggested method of connecting an accumulator

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 in.^{2}. Determine the piston speed. (See figure 36.)

$$10 \text{ gpm} \times 231 \text{ in.}^3/\text{gal} = 2310 \text{ in.}^3/\text{min}$$

$$\text{Piston speed} = \frac{2310 \text{ in.}^3/\text{min}}{9.62 \text{ in.}^2}$$

$$= 240 \text{ in./min}$$

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.

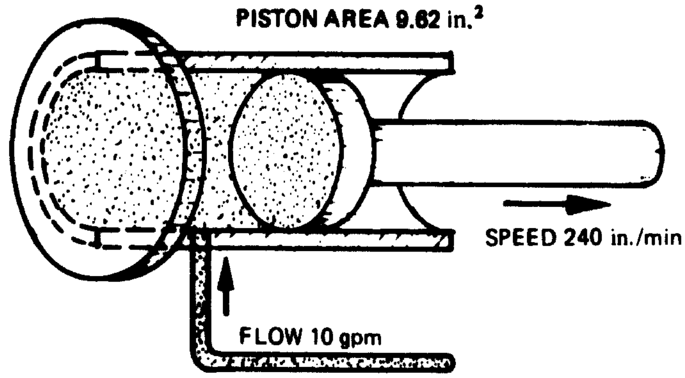


Figure 36. Hydraulic cylinder speed

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/s (0.61-1.22 m/s)
Pressure lines up to 34 bar	10-15 ft/s (3.05-4.57 m/s)
Pressure lines from 34 to 207 bar	15-20 ft/s (4.57-6.10 m/s)
Pressure lines over 207 bar	25 ft/s (7.62 m/s)
Oil lines in air-over-oil system	4 ft/s (1.22 m/s)

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 and 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 button 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 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 connections 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, there are variations in 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 designs possible, some examples are shown in annex 1. 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 the 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 forgotten. 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 had 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 mechnical 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 contacts 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

Environmental conditions
- Normal ambient temperature
- Maximum temperature
- Minimum temperature
- Military specifications
- Standards laboratory specifications
- Moisture
- Humidity
- Dust
- Shock
- Vibration
- Linear acceleration

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

Physical requirements
- Space available
- Size
- Shape
- Mounting
- Termination
- Plug-in
- Enclosure
- Dust cover
- Hermetically sealed
- Sealed

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 transistors switching is faster 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 the 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 connection to the air or hydraulic line. Figure 37 shows these parts of and the standard symbol for a double-acting cylinder without cushioning.

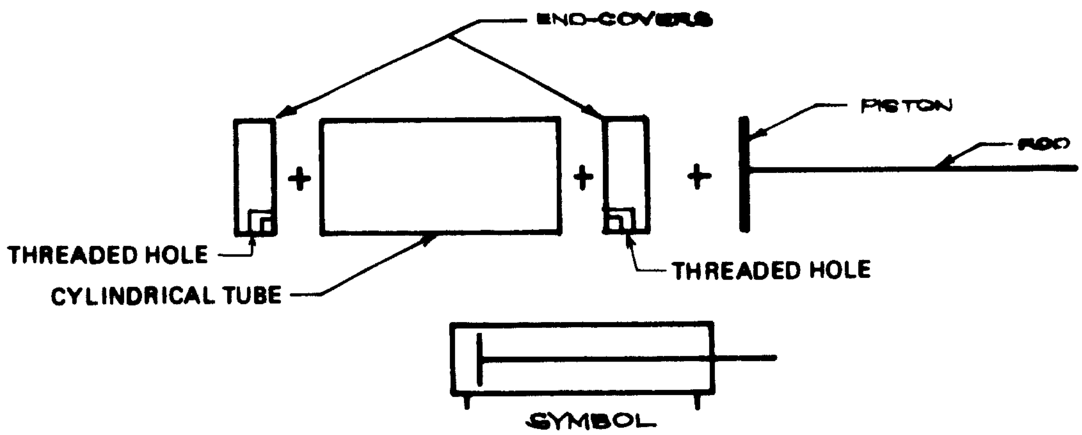


Figure 37. Double-acting cylinder, parts and symbol

A single-acting cylinder (figure 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.

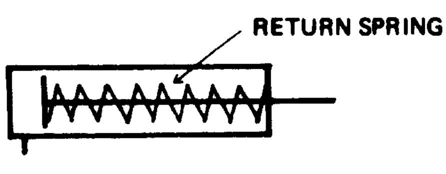


Figure 38. Symbol for a single-acting cylinder

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

a b

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.

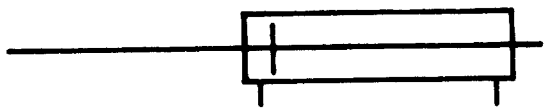


Figure 41. Cylinder with "through-going" piston rod without cushioning

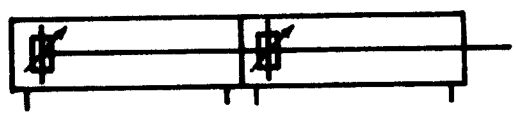


Figure 42. Tandem cylinder with adjustable cushioning in both ends

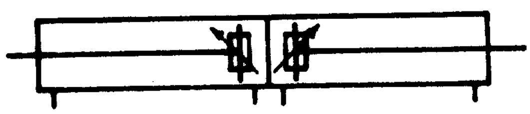


Figure 43. Three-position cylinders (strokes equal)

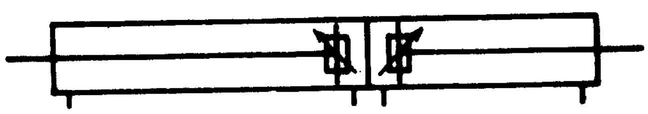


Figure 44. Four-position cylinder (strokes unequal)

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.

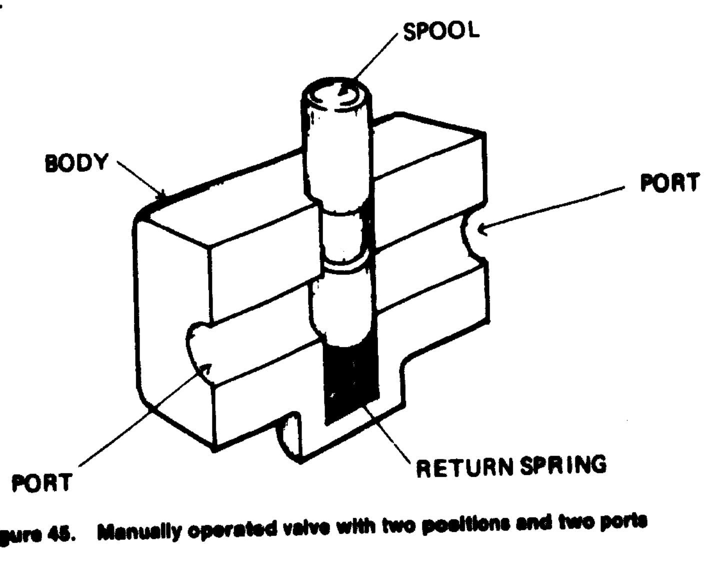


Figure 45. Manually operated valve with two positions and two ports

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.

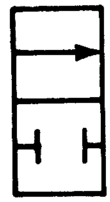


Figure 46. Basic symbol for the two-position, two-port valve in figure 45

The basic symbol is developed further by adding lines representing the tubing connected to the ports (figure 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.

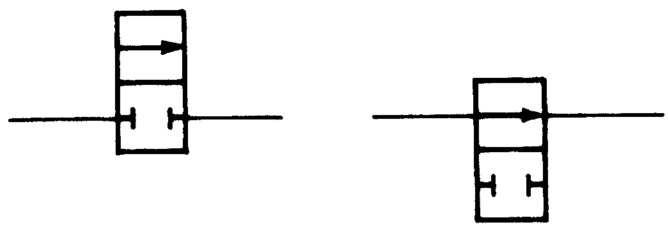


Figure 47. Symbols for two-position, two-port valve in *(a)* closed and *(b)* open states

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.

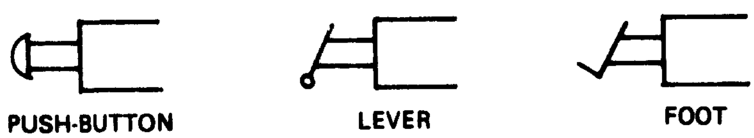


Figure 48. Manual actuators

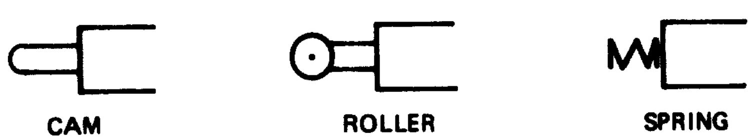


Figure 49. Mechanical actuators

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

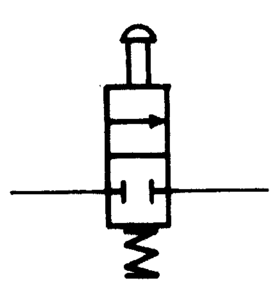


Figure 50. Complete symbol for two-position, two-port valve, showing actuators

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

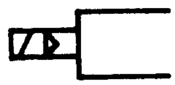


Figure 52. Electrically operated with pilot valve

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.

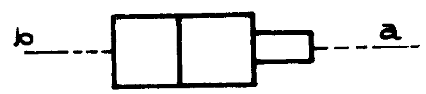


Figure 53. Signal *b* has priority over signal a

The most widely used type of valve in pneumatics is not, however, the one decribed above, but a combination of two of that type, one normally open and the other normally closed (figure 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.

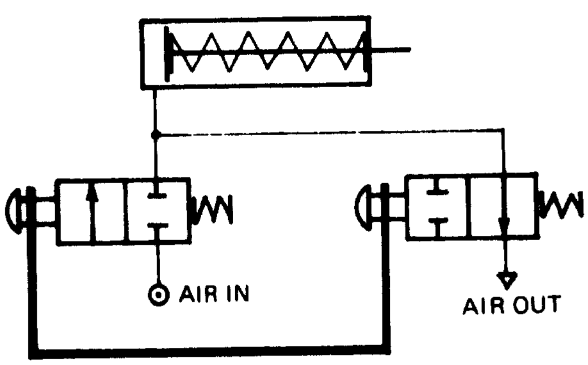


Figure 54. Two two-port valves connected mechanically, one normally open and one normally closed

Figure 54 also shows two new symbols. The circle with centred dot indicates connection 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 (figure 56) or by one five-port valve (figure 57).

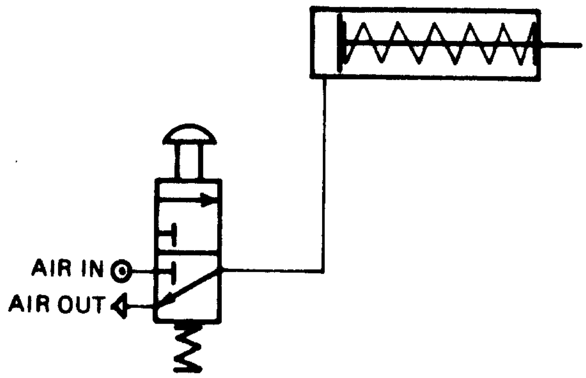


Figure 55. Two-position, three-port valve replacing the two valves of figure 54

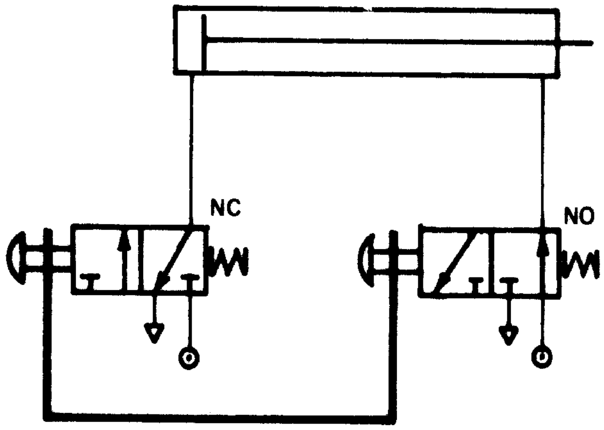


Figure 56. Double-acting cylinder operated by two coupled three-port valves

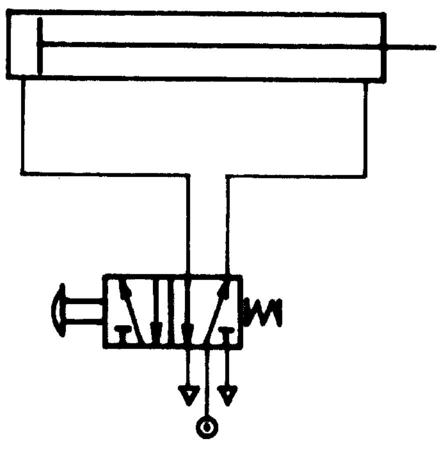


Figure 57. Double-acting cylinder operated by one five-port valve

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-pole 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 (figure 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 (figure 61) permits flow in one direction, stops it in the other. The second (figure 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

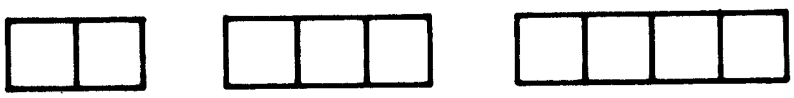


Figure 59. Basic symbols for two-, three-, and four-position valves

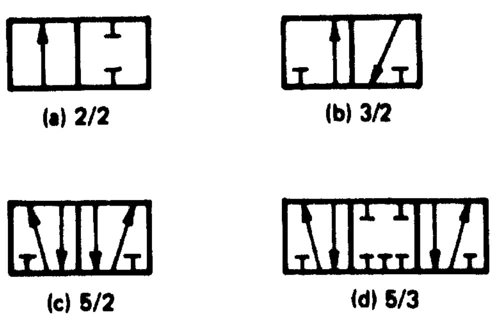


Figure 60. Symbols for and names of various directional control valves

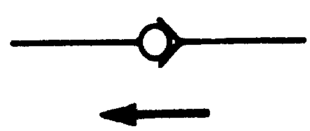


Figure 61. Simplified symbol for a check valve. Flow is possible only in the direction of the arrow

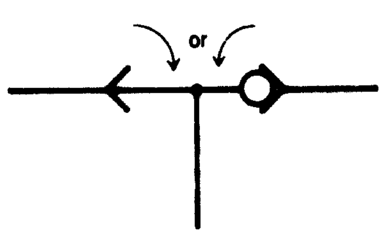


Figure 62. Simplified symbol for a shuttle valve. The arrows show the alternative flow paths

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 figure 65).

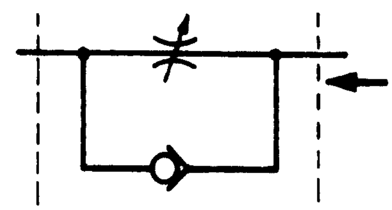


Figure 65. Adjustable flow-control valve with flow in direction of arrow unrestricted; flow in the opposite direction meets the restriction

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

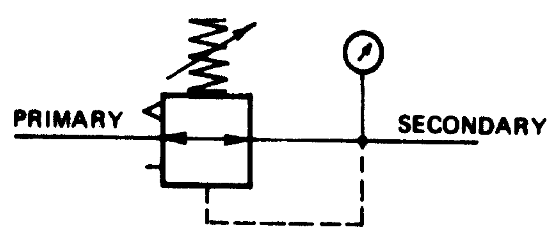


Figure 66. Simplified symbol for a pressure regulator. When the pressure in the secondary line rises above the pressure exerted by the adjustable spring actuator, the valve is actuated and exhausts the excess primary line pressure. When the pressure is too low, the spring actuates the valve to add pressure

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.

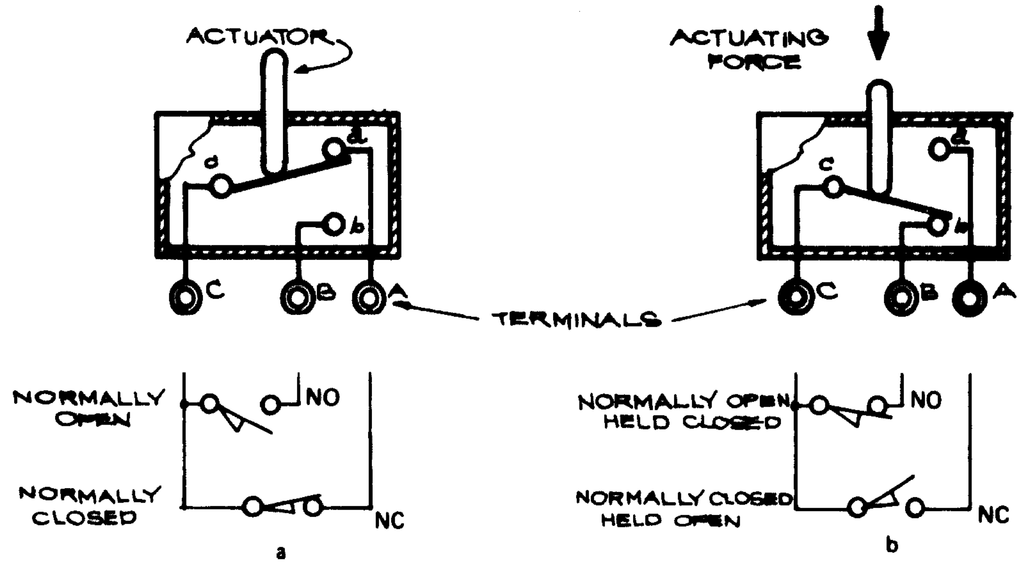


Figure 67. Diagrams and symbols for a typical limit switch in *(a)* unactuated (normal) and *(b)* actuated states

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.

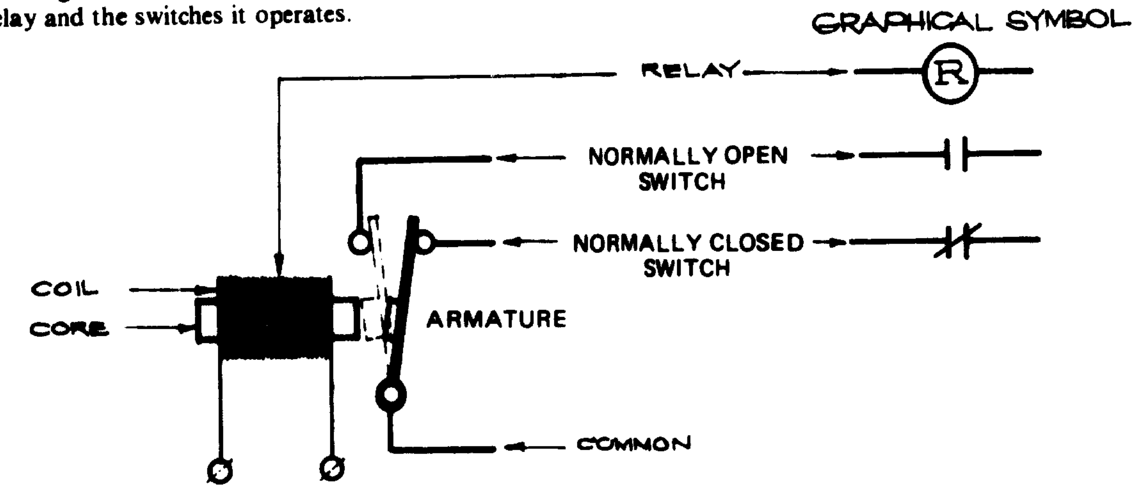


Figure 68. Diagram and symbols for a typical SPDT relay. Position of the relay armature in the actuated state is shown by the broken outline

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;

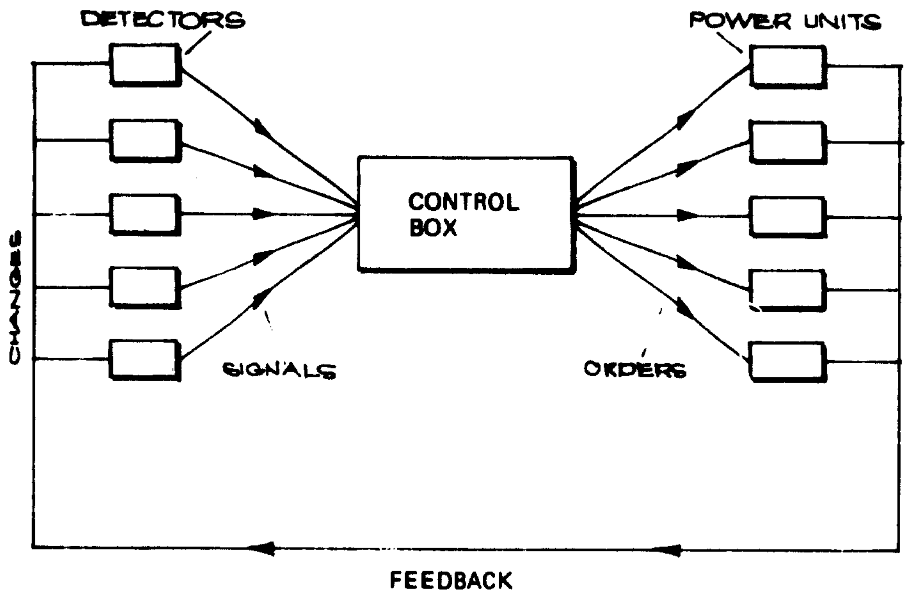


Figure 69. Block diagram of a generalized control system

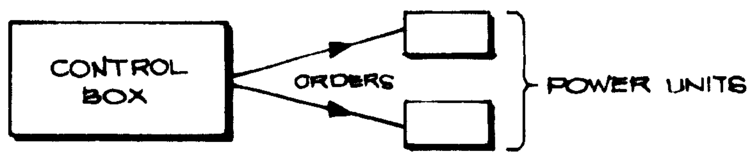


Figure 70. Block diagram of a simple control system without ostensible feedback

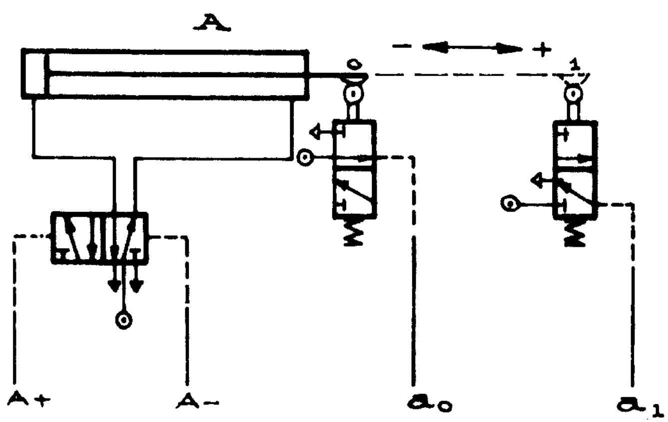


Figure 71. Uncompleted pneumatic (or hydraulic) circuit diagram. See text for explanation

(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.

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− (figure 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.

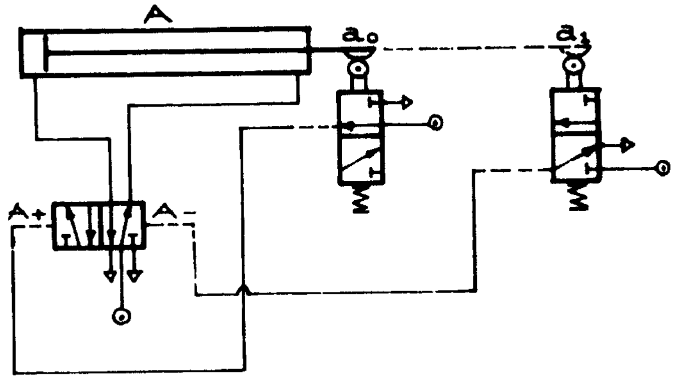


Figure 72. Continuously oscillating cylinder (completion of circuit in figure 71). See text for explanation

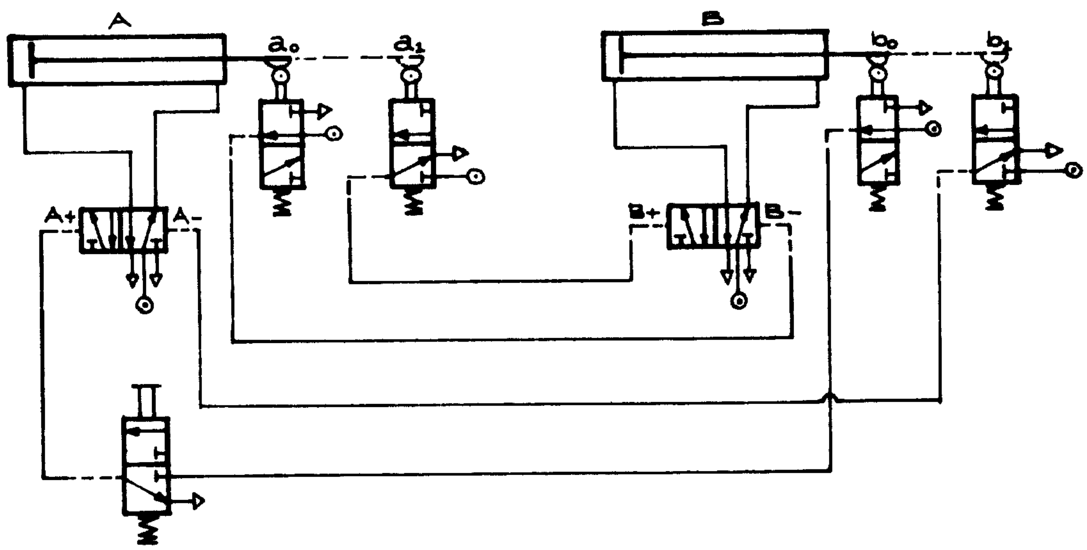


Figure 73. Two-cylinder circuit. When the valve at lower left is actuated, the signal sequence is $b_0A_+a_1B_+b_1A_-a_0B_-$

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 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).

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.

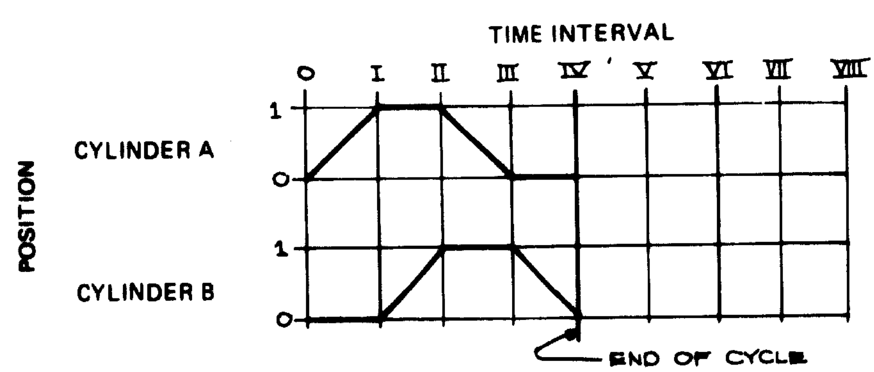


Figure 74. Time-motion diagram for the circuit of figure 73

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.

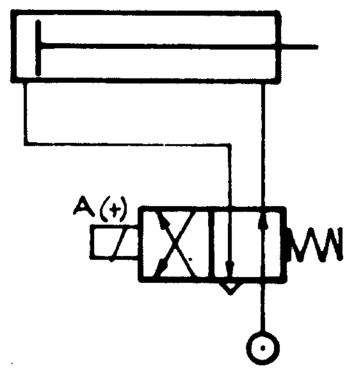


Figure 75. Air cylinder controlled by a solenoid-actuated valve

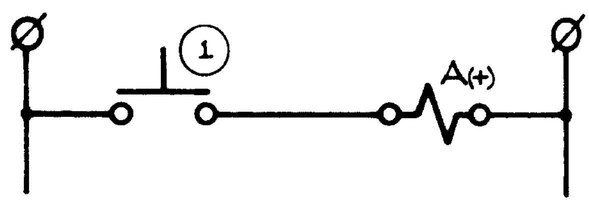


Figure 76. Electrical circuit for controlling the air cylinder of figure 75

Another possibility is the circuit in figure 77, which makes use of relays to carry the soleinoid 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 (figure 79).

The circuit of figure 80 yields an oscillating motion of the cylinder. The oscillation is starting 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.

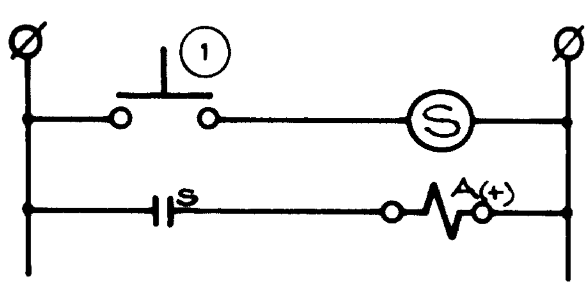


Figure 77. Inclusion of a relay to control solenoid coil current

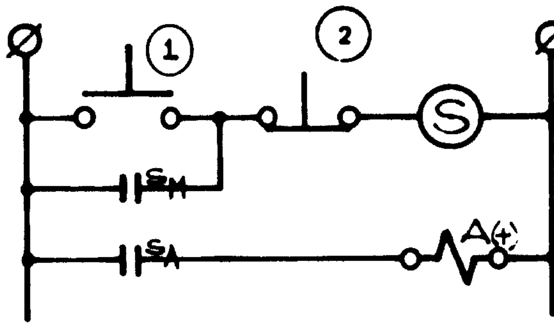


Figure 78. Use of solenoid with "memory" to keep cylinder actuated after push-button is released

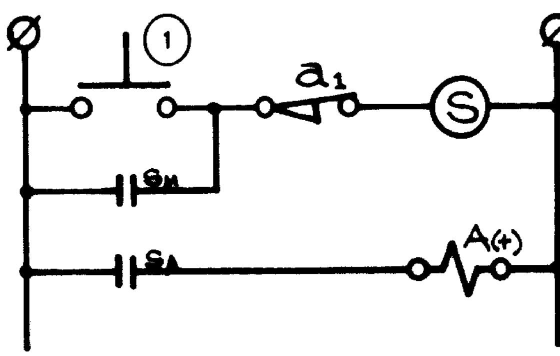


Figure 79. Use of limit switch to destroy memory of relay at a predetermined time

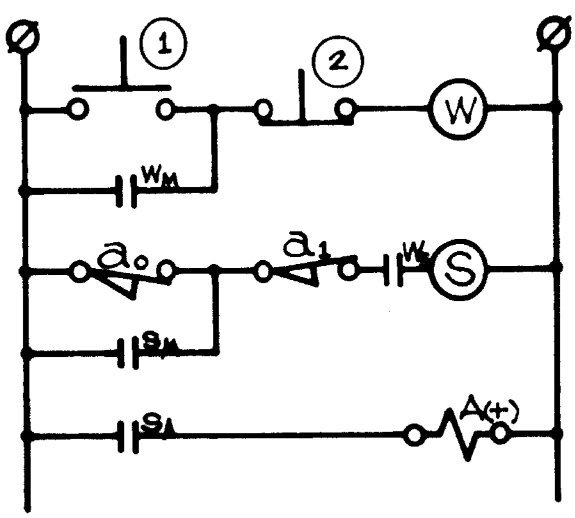


Figure 80. Control circuit for an oscillating cylinder

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 (figure 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.

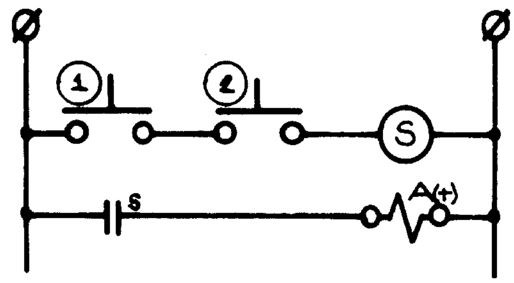


Figure 81. Safety circuit. Cylinder will not operate unless operator pushes switch 1 with one hand and switch 2 with the other

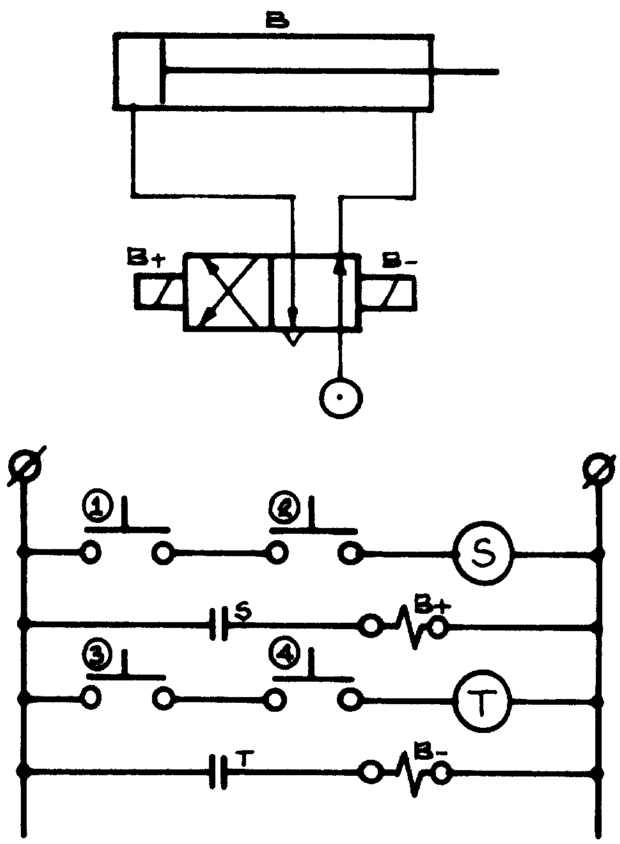


Figure 82. Cylinder press operated by a double solenoid valve and provided with safety switches in both stroke directions

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 soleinoid $B_{(+)}$ are energized simulatenously. 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 soleinoid 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.)

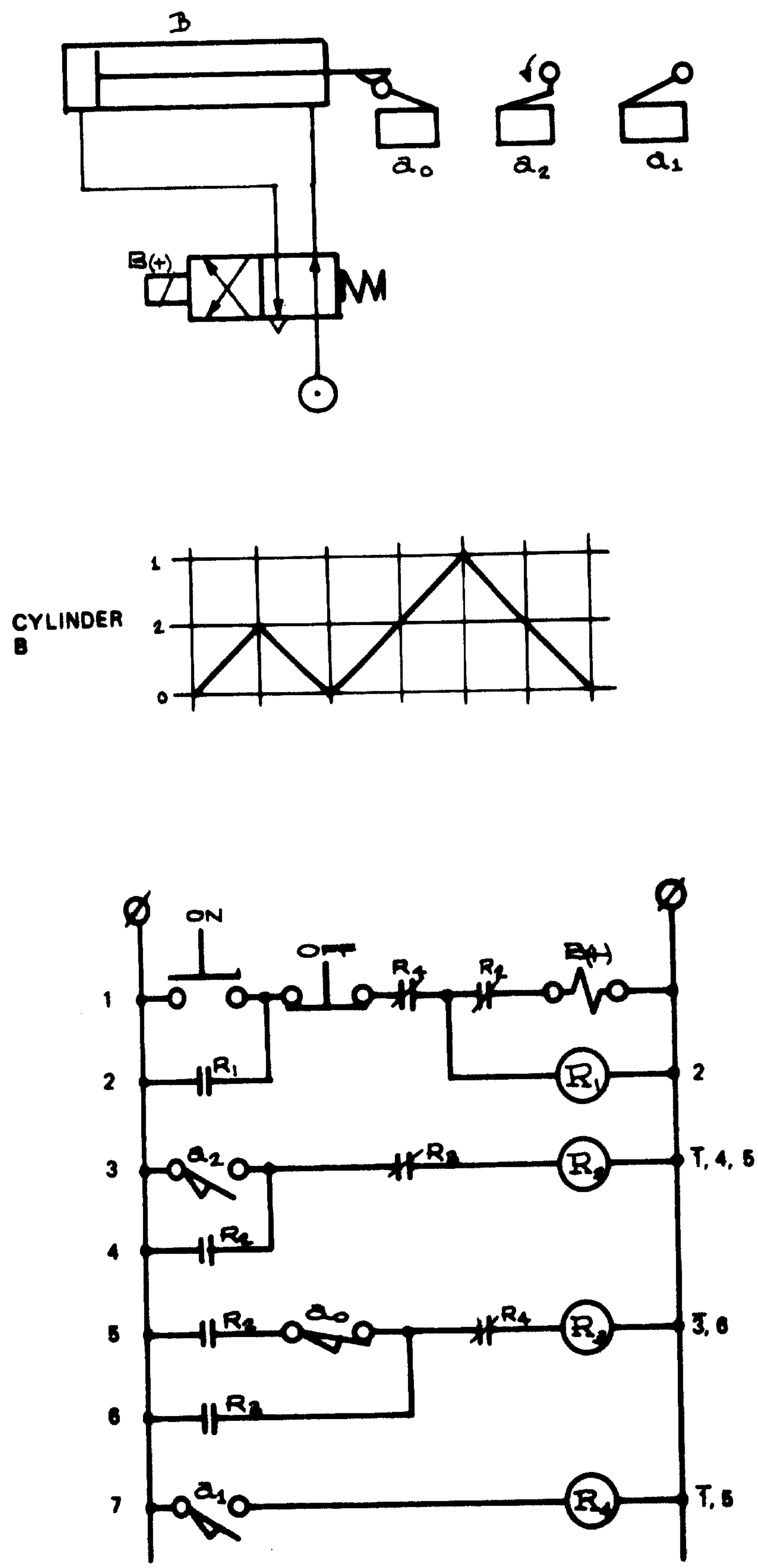


Figure 83. Pneumatic circuit, time-motion diagram and electrical circuit of a cylinder with two successive strokes of different lengths

VII. Low-cost automation systems as applied to the construction of panel-based furniture

A. General process flow in panel-based furniture production

In general, the flow process for panel-based furniture production starts with two major lines:

The preparation of solid-wood components;
The preparation of wood-based panel components.

Figure 84 shows the operations involved in the manufacture of panel-based furniture, using lumber, veneer flitches (or sheets) and wood-based panels as the principal input materials.

Both lumber and veneer inputs should have been sufficiently dried before being processed in the furniture plant. Both solid-wood and panel components are sanded before they are finally assembled to form the complete furniture item. The last operation, of course, is finishing (applying lacquer, polyurethane, epoxy, polyester, pigmented paint and such other coating materials to provide protection in use and enhance the beauty of the wood grain patterns in the furniture).

However, where the panel-based furniture piece is to be transported in "knock-down" (disassembled) condition, the components or sub-assemblies of components are finished before packing and shipping, and they are assembled at the customer's or user's location.

An examination of the general flow process to determine situations for possible LCA application will be made in the following sections.

B. Possible applications of low-cost automation in the preparation of solid-wood components

Trimming to rough length

The basic machine for trimming to rough length is a saw mounted on a horizontally sliding platform above it. Cutting is done by pulling the saw across the board by hand and then pushing it back to its original position after the cut is made. This machine is commonly known as the horizontal radial saw. The boards are fed by hand to the dead-roll conveyors before sawing and are also off-loaded by hand. A very slow operation, it requires at least two lumber handlers and one saw operator.

With the use of LCA the output of this machine can be increased and the number of workers reduced to only one by installing:

(a) A pneumatic cylinder on the sliding platform to move the saw forward and backward;

(b) An electric motor to drive the in-feed conveyor;

(c) A "scissors-lift" on the in-feed and out-feed conveyors, so that the top boards of the lumber pile can be kept at a level that will permit the boards to be pushed (by sliding action) on and off the conveyor by properly placed pneumatic cylinders;

(d) Stoppers with limit switches (or pneumatic valves) to control the forward and edgewise movements of the boards.

Figure 85 illustrates this solution.

Ripping

The basic machine in ripping operations is a single-blade edger saw with a chain type of feeding device. The boards are fed to and off-loaded from the machine by hand. Small workpieces require one worker at each end of the saw. However, bigger and thicker boards require at least two men at each end of the

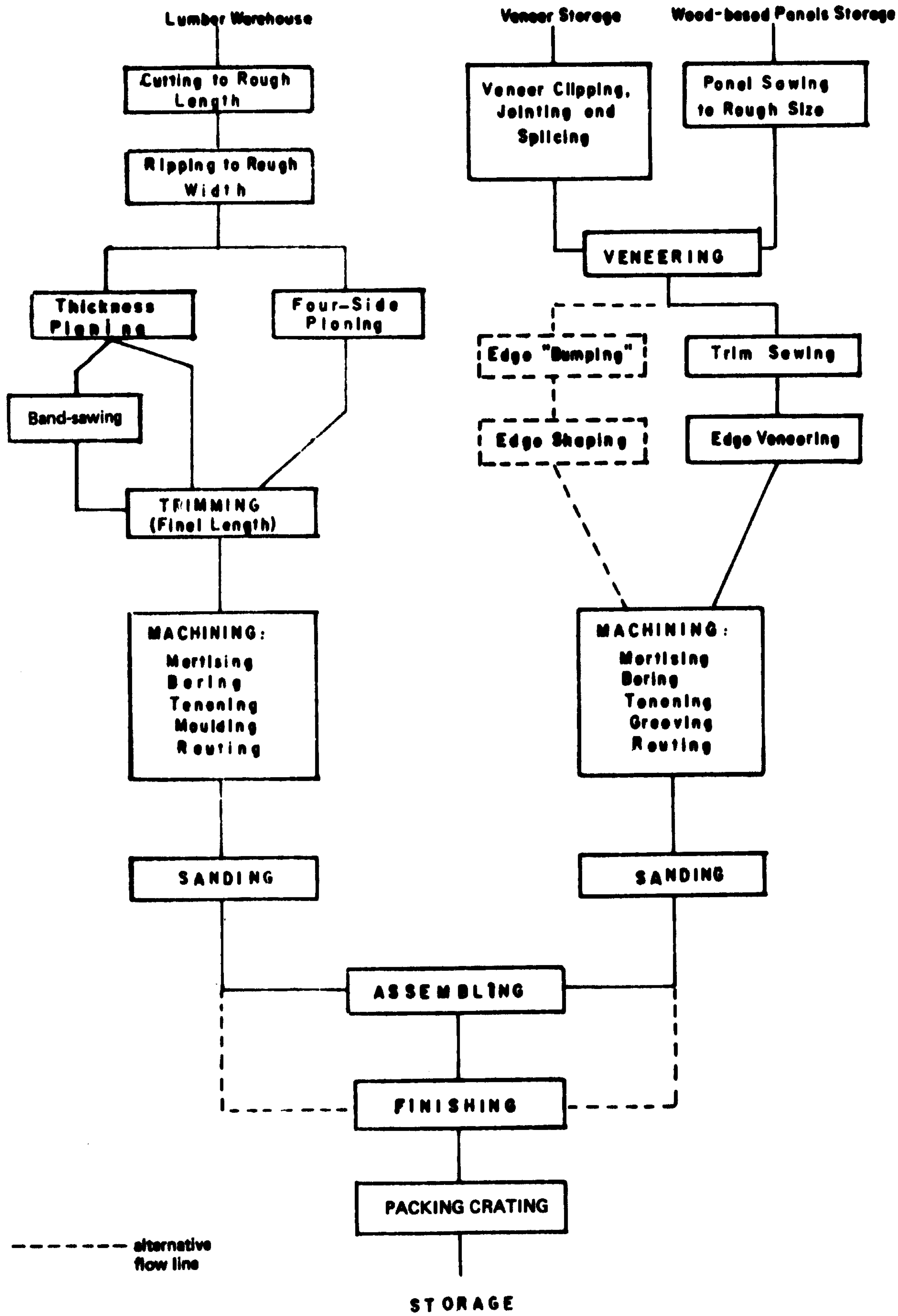


Figure 84. Flow process, panel-based furniture manufacturing

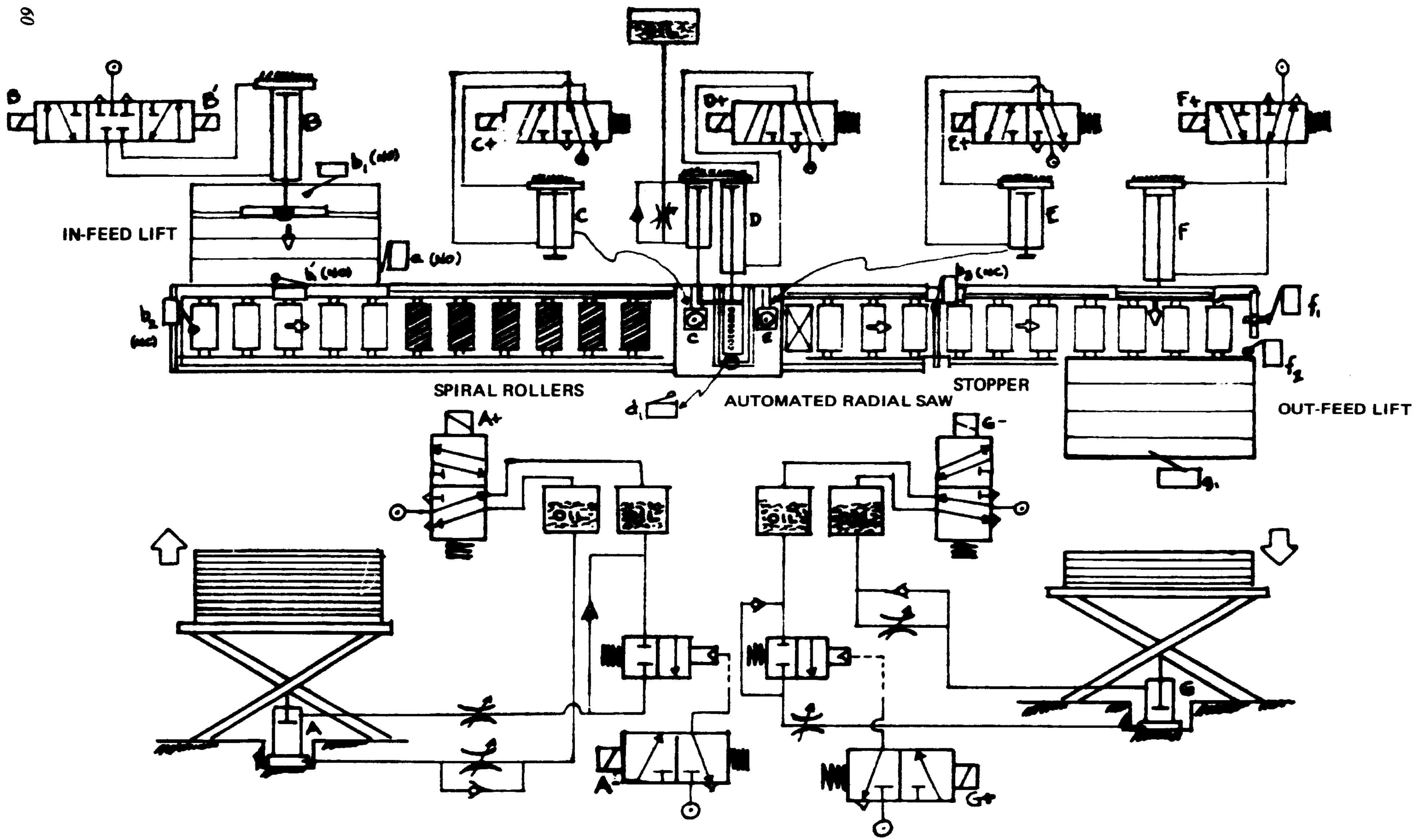


Figure 85. Complete automation of rough trimming operations, solid-wood components

machine. Thus, several pieces of the same width can be cut on the machine only by passing the same board several times through the machine.

In more modern factories, ripping capacity is increased by the use of a multi-rip saw. This machine works in the same manner as the single-blade edger saw, except that several saw blades are mounted on the same shaft. This feature of the machine permits ripping several pieces at one pass on the machine.

Nevertheless, the capacity of the single-blade edger saw can be increased and the number of workers reduced to one by using a "merry-go-round" set-up as shown in figure 86.

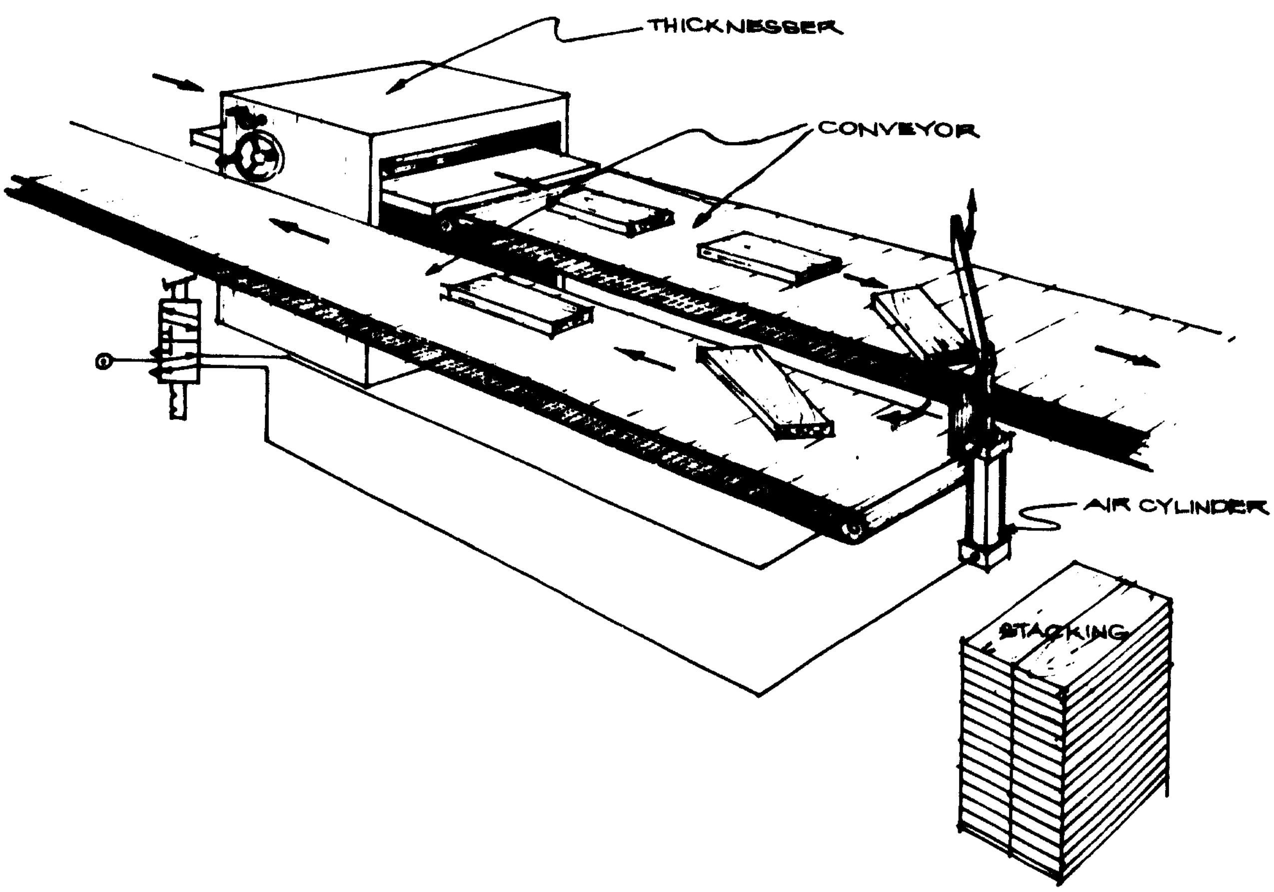


Figure 86. Return conveyor system applicable to edger and thicknesser operations

Band-sawing

Band-sawing is intended to give the workpiece non-linear shapes or non-square surfaces in preparation for further machining operations such as edge shaping, routing and box-planing. The basic machine consists of two pulleys (or band-wheels) mounted one above the other with the band-saw blade mounted on the outer segments of the pulleys. The botton pulley is driven by an electric motor. The upper pulley is mounted on a movable shaft which permits the pulley to move away from or towards the bottom pulley, and thus the proper tension on the band-saw blade can be obtained. The workpiece is hand-fed to the saw blade on a table fixed to the band-saw column supporting the pulleys. The newer models of this machine include a tilting table, while others have both a tilting table and serrated feed rolls driven by an electric motor.

Only a few workpieces per type or shape of cut can be processed on this machine at a time and there are so many shapes to be cut that set-up costs may be greater than any benefits to be gained by automating this operation. However, quality and output can be improved by the use of template jigs. These sawing jigs ensure that all workpieces done on the machine will be of the same shape and size. Use of the jigs will also speed up the operation.

Surface planing

To improve the surface, the workpiece is normally planed. The simplest type of planer has a single cutterhead, in-feed and out-feed rolls, and a table that can be raised (or lowered) manually to obtain the desired thickness of the workpiece

More advanced models of this machine include in their design the following features:

- Top and bottom cutterheads;
- Powered lifting or lowering of the planer table;
- "Anti-kickback" fence and other safety devices;
- Continuously variable feedspeed;
- Other features that reduce the skill required of the operators.

Clearly, application of LCA to this operation is limited to feeding the workpiece to the planer and removing it after planing. When only a single-head planer is available and both surfaces of the workpiece have to be planed, a system similar to that illustrated in figure 86 will help speed up the operation and reduce the number of workers required to one.

Four-side planing

Four-side planing is similar to surface planing except that the planing machine in this case is equipped with an additional two vertical cutterblocks to permit surfacing of all four faces of the workpiece simultaneously. From the viewpoint of LCA application, the output of this machine can be improved only by using feeding and off-loading devices.

Trim sawing to final length

This operation is essentially the same as the first trimming operation. However, higher precision in cutting and more careful handling of the workpiece are required. Workpieces with large cross-sections are trimmed to final length by the radial saw, while those with small cross-sections may be cut on the tilting arbor saw (or table saw) with the aid of a trimming jig to permit cutting of several workpieces in one pass across the saw.

The forward-and-backward movement of the radial saw may be automated as discussed in the subsection "Trimming to rough length" of this chapter. The feeding and off-loading system, however, would have to be revised to ensure greater precision in cutting and more careful handling to prevent damage to the planed surfaces of the workpieces.

When a tilting arbor saw is used, automatic feeding of individual pieces may not be successful because the workpieces are so small. However, a significant increase in output may be attained in this operation by the use of trimming jigs (figure 87). Where the workpiece is wide enough, a rubber roller feeding device can be used to increase the output from this operation.

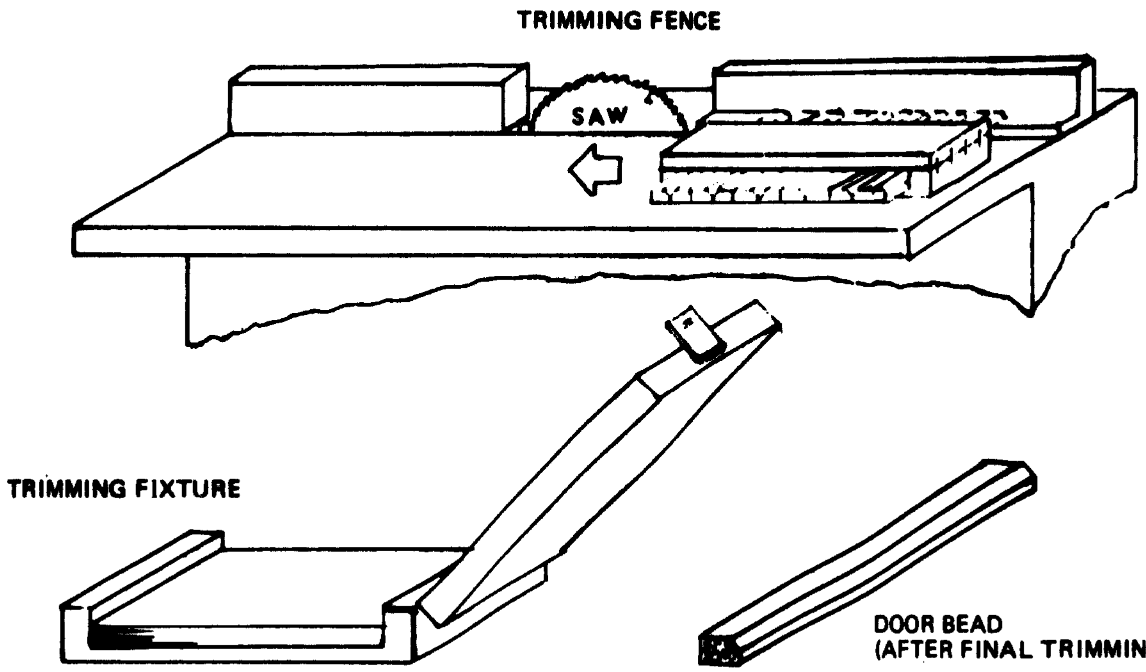


Figure 87. Trimming fixture for wooden components with small cross-sections

Mortising

The machines that make mortices on solid-wood parts for furniture joints are slat, chain, hollow-chisel and oscillating mortisers. All these machines are hand-fed and thus have low outputs. However, LCA may be applied to any of these machines to attain higher output levels by increasing the feed speed. If more than one mortise is required on the same workpiece, an automated work-advancing device may also be installed. Figures 88 and 89 illustrate the automation system for a chain mortiser suggested by M. Koch and F. Lastuvke (see bibliography). A system that has attained an output of 1,000 slots per hour, it has the following parts:

Machine pedestal mortising guide;
Chain mortising head with pneumatic feed device;
Transport carriage and intermittent feed unit;
Workpiece clamp;
Carriage stop;
Control console with pneumatic control system for external sensors and cylinders.

Similar arrangements can be designed for automating other types of mortisers, provided, of course, that the volume of work justifies such a move.

Dowel hole drilling

The use of dowels in joining components of panel-based furniture has greatly simplified the assembly of the panel components. Costs are reduced whenever dowels replace metal fittings in joining one panel to another, since wooden dowels cost much less than metal fittings.

Dowel holes are usually drilled with precise spacing to achieve perfect fitting between the panel components to be joined. Furthermore, a piece of panel-based furniture usually requires many dowels, but the old, hand-fed method cannot be used when many dowel holes have to be drilled. Figures 90 and 91 illustrate the automated dowel hole-drilling system suggested by the authors of this manual.

Boring

Holes in panel-based furniture production are usually bored by a drill press or a router, whichever is better for the required situation. Pilot holes for wood screws on the solid-wood components of panel-based furniture can be drilled by the same device used for drilling dowel holes. In this case, however, the depth of the hole is controlled by changing the position of the limit switch, as in figure 90. For drilling holes on small wooden pieces, such as drawer fronts, the set-up illustrated in figures 92 and 93 is recommended.

Where multiple holes of different directions are required on the same piece of solid-wood component of the furniture, use of an indexing table is more efficient, for the workpiece is not moved off its clamped position until all the required holes have been drilled. Figures 94, 95 and 96 illustrate such a set-up.

It should be noted that in all these set-ups the drill is usually fixed, while the workpiece is made to move to locate another hole. The reverse situation, moving the drill heads on the fixed workpiece, would be cumbersome.

Tenoning

Solid-wood components are tenoned to make corner-lock, tongue and groove and stub-tenon joints.

Tenoning is usually done on a vertical-spindle moulder (shaper) with special attachments, and on a single-end or a double-end tenoner. Tenoners are preferable for high-volume production, since they are equipped with several cutting heads and saws. A double-end tenoner ensures a workpiece that is more exactly square, whether solid-wood or panel component. Such a tenoner is also capable of peforming other more complicated and precise machining jobs on the workpiece.

LCA application to a vertical spindle moulder (shaper) for processing solid-wood components of panel-based furniture is limited to feeding and off-loading the workpiece. The same situation is true for tenoners. However, additional cutting heads may be installed on the tenoner to obtain fewer machine set-ups for other milling jobs on the workpiece. Tenoners are also easier to link with other machines by means of transfer conveyors.

Moulding

Grooves, rabbets, roundings and other profiles, tenons and slits, and moulding with templates are usually done on a vertical-spindle moulder. However, the output of a vertical-spindle moulder can be increased considerably, its work quality improved and its operations made safer if a feeding device is used on the machine.

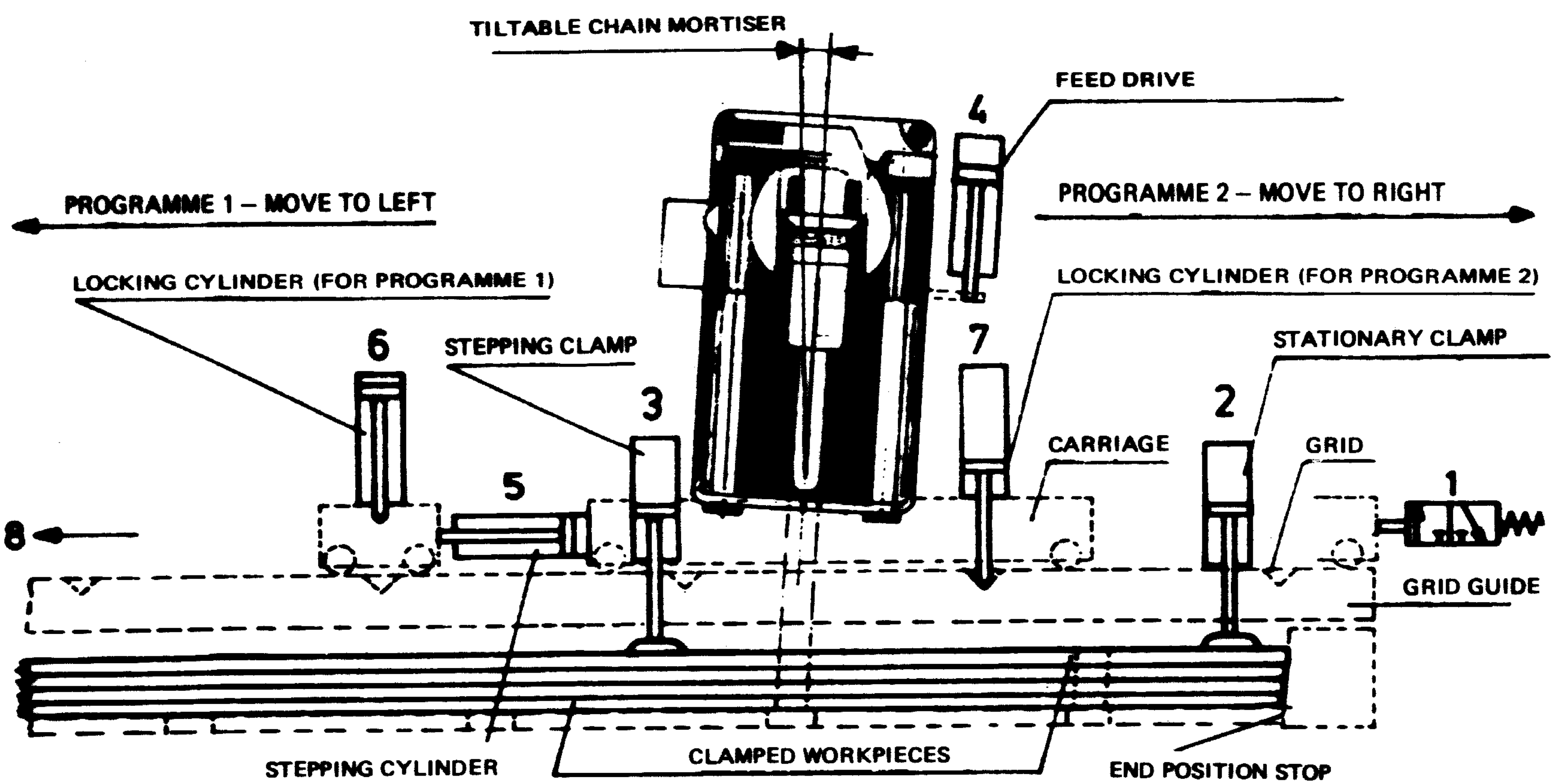


Figure 88. LCA device applied to a chain mortiser
(Numbered items refer to the time-motion diagram in figure 89)

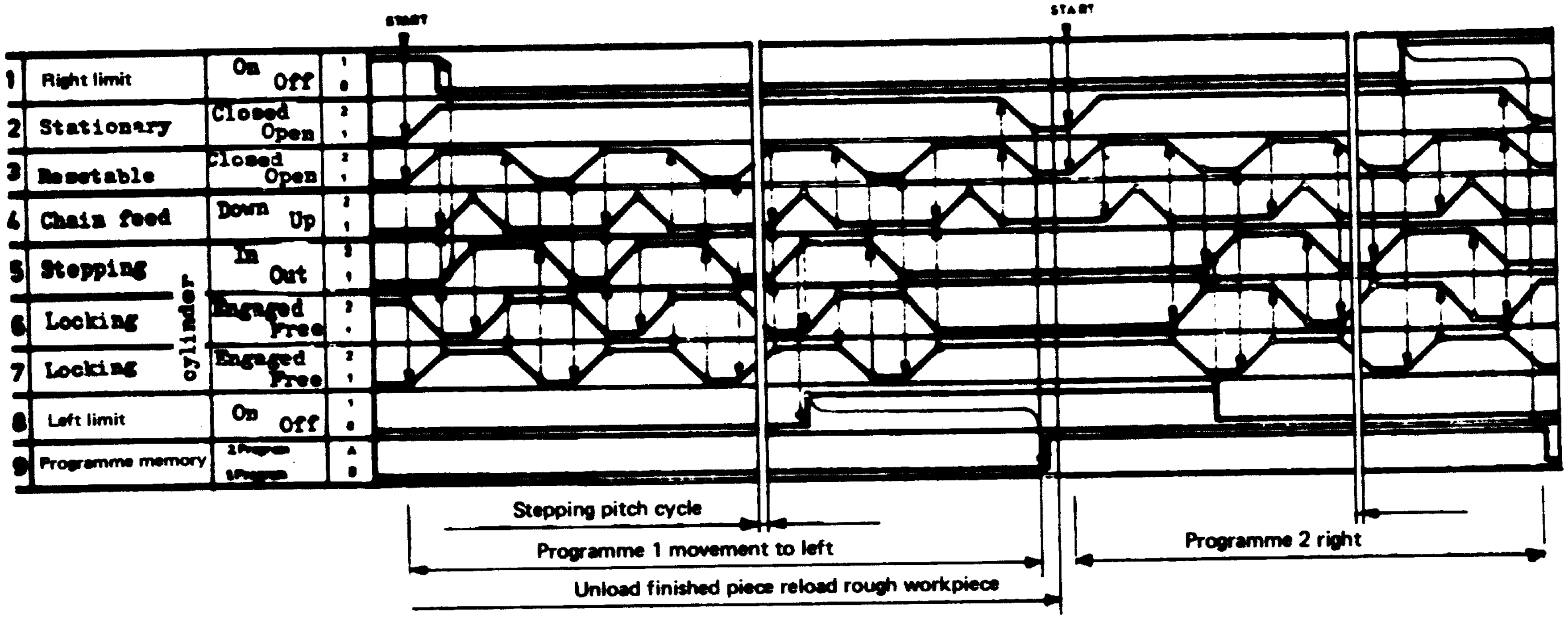


Figure 89. Time-motion diagram for chain mortiser with LCA device

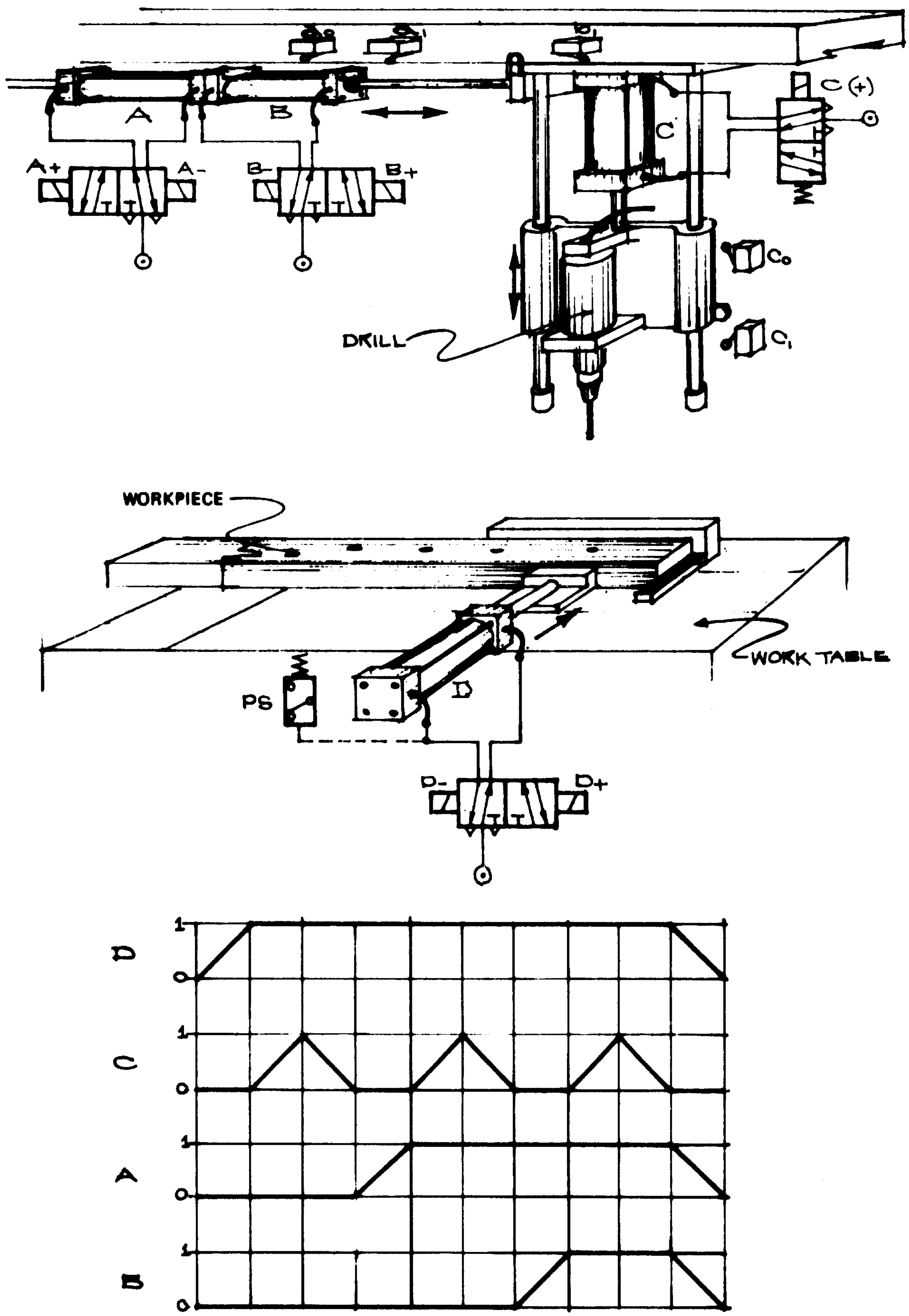


Figure 90. Dowel hole drilling aided by LCA device and corresponding time-motion diagram

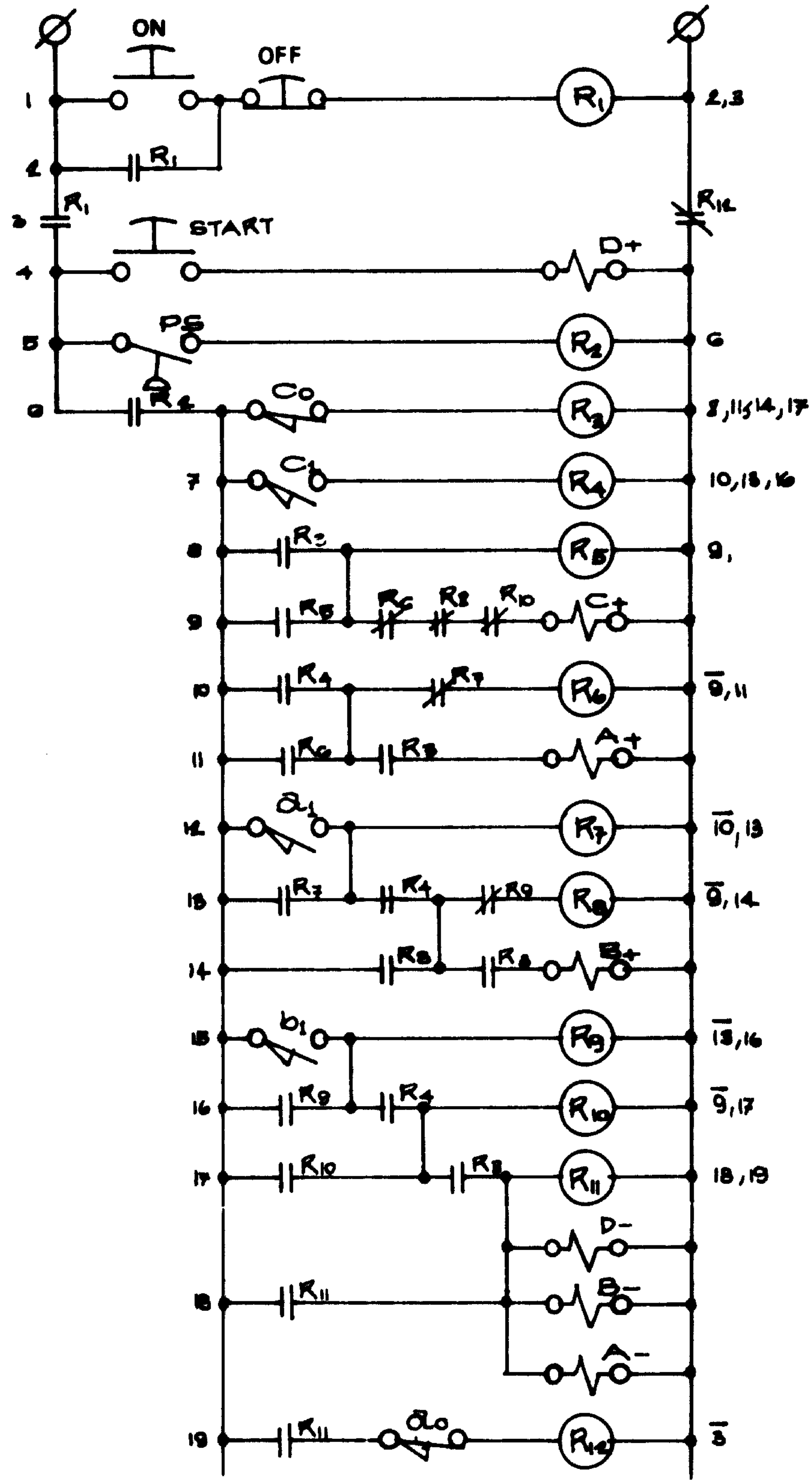


Figure 91. Electrical circuit diagram for dowel drilling with LCA device

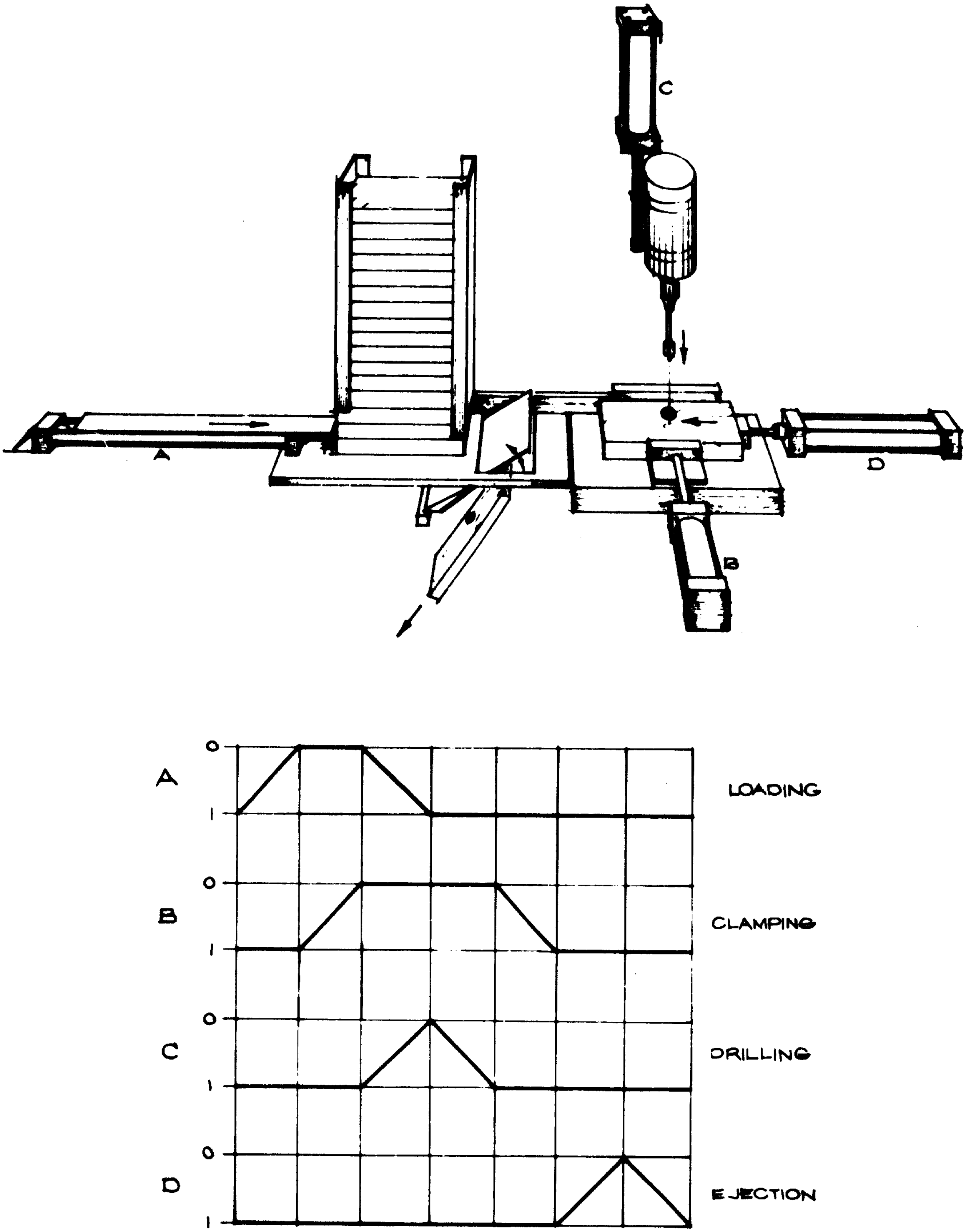


Figure 92. Automatic drilling with automatic feed and ejection system

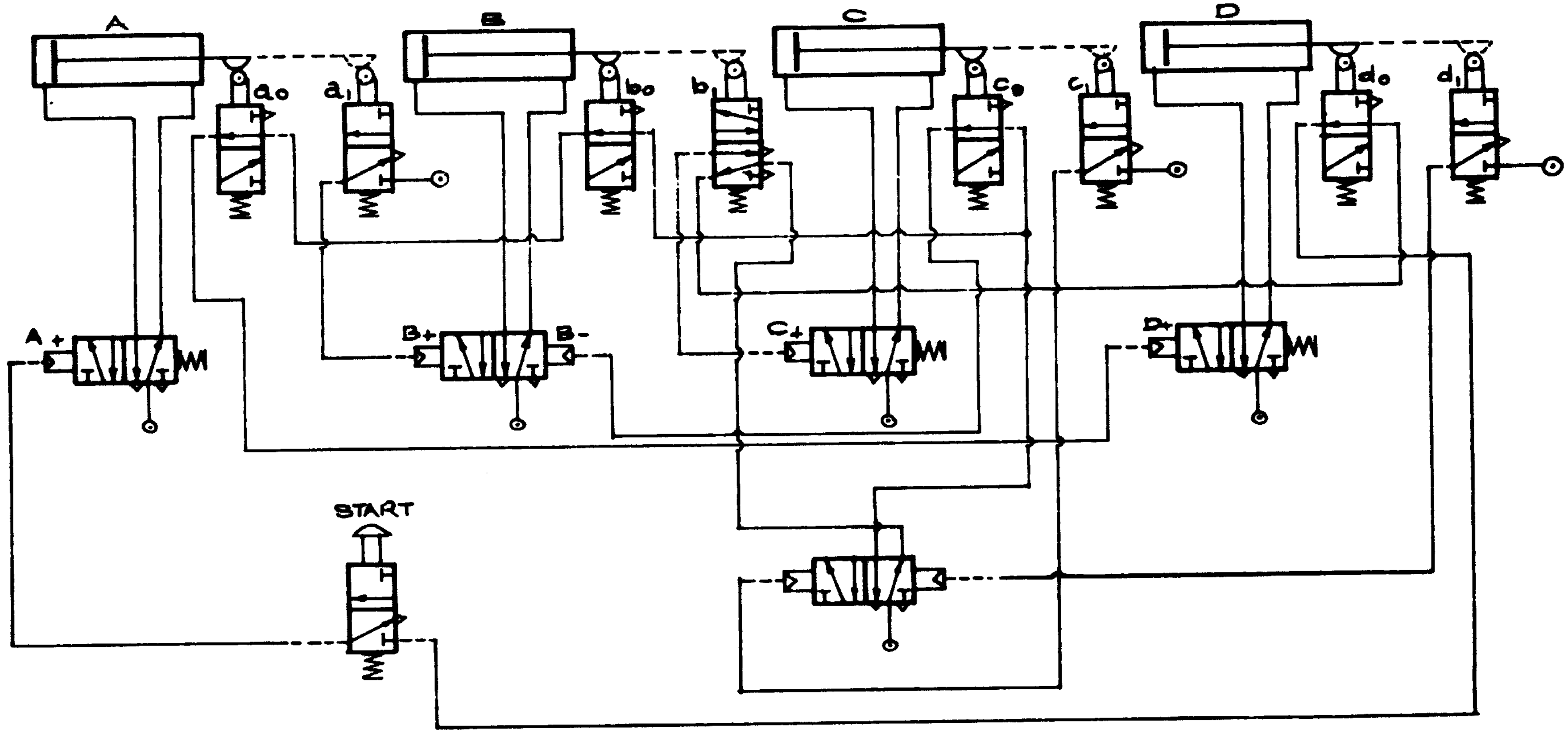


Figure 93. Pneumatic circuit diagram for automatic drilling with feed and ejection system

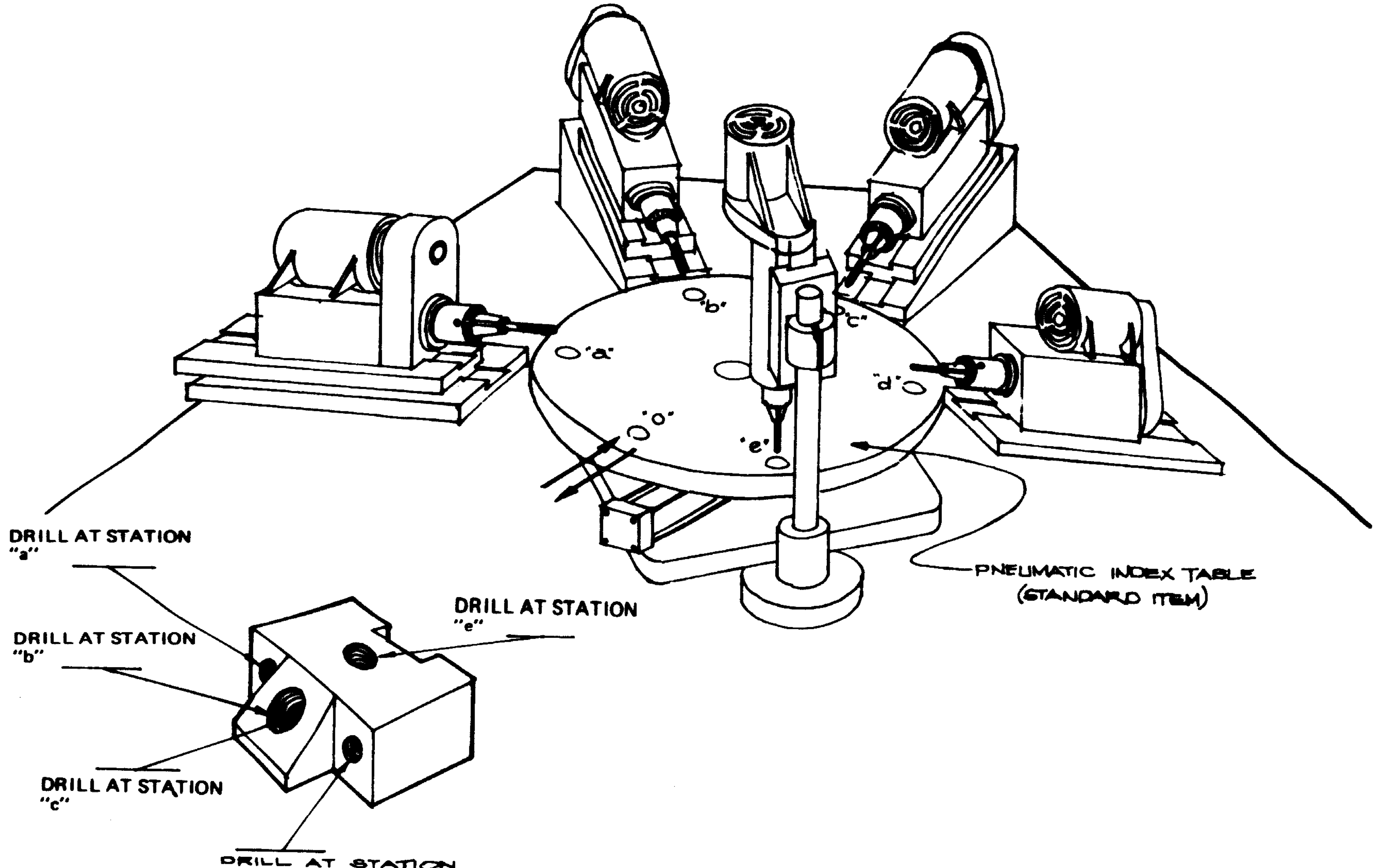


Figure 94. Indexing table: pictorial diagram

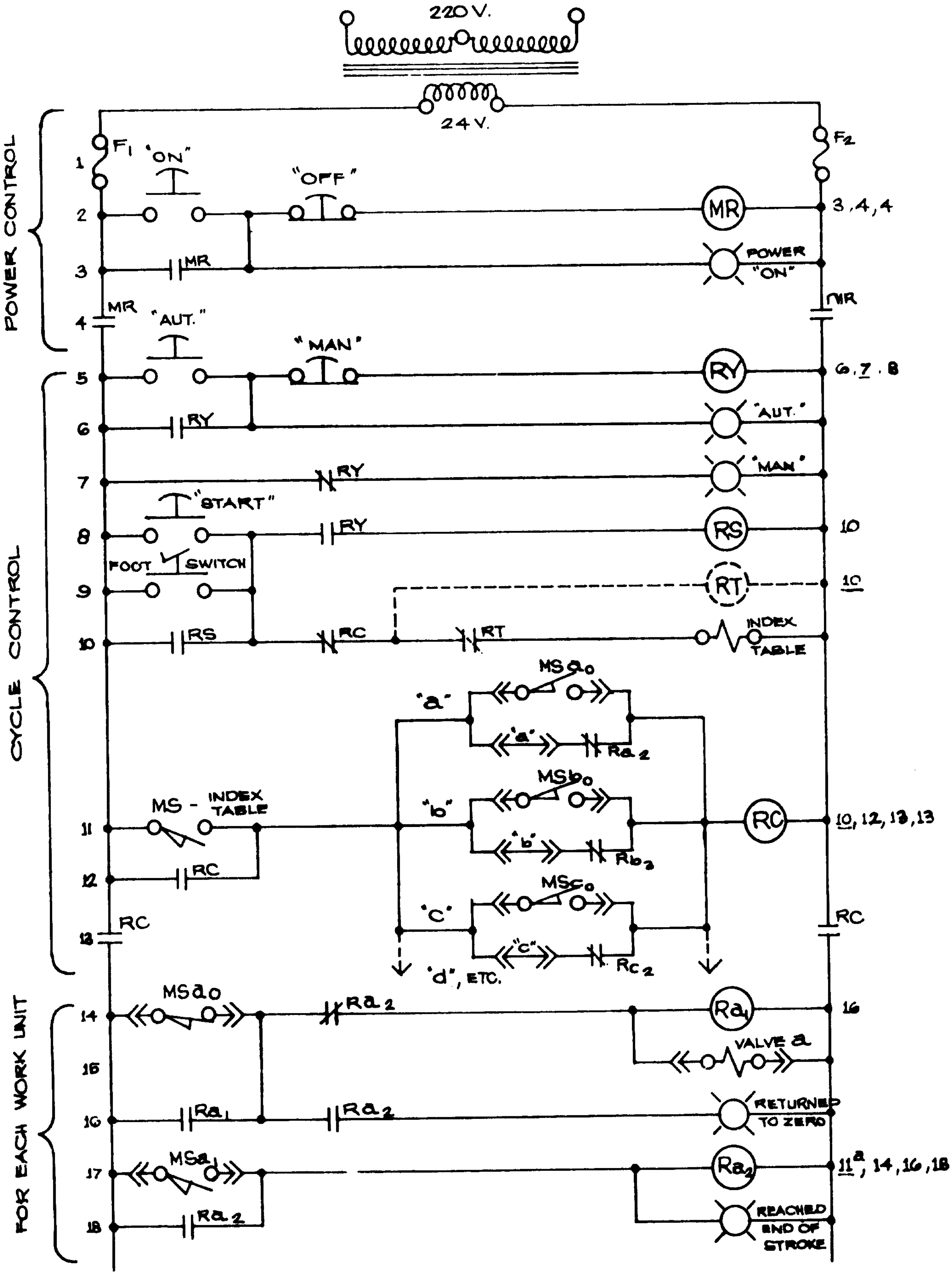


Figure 95. Indexing table: electrical circuit

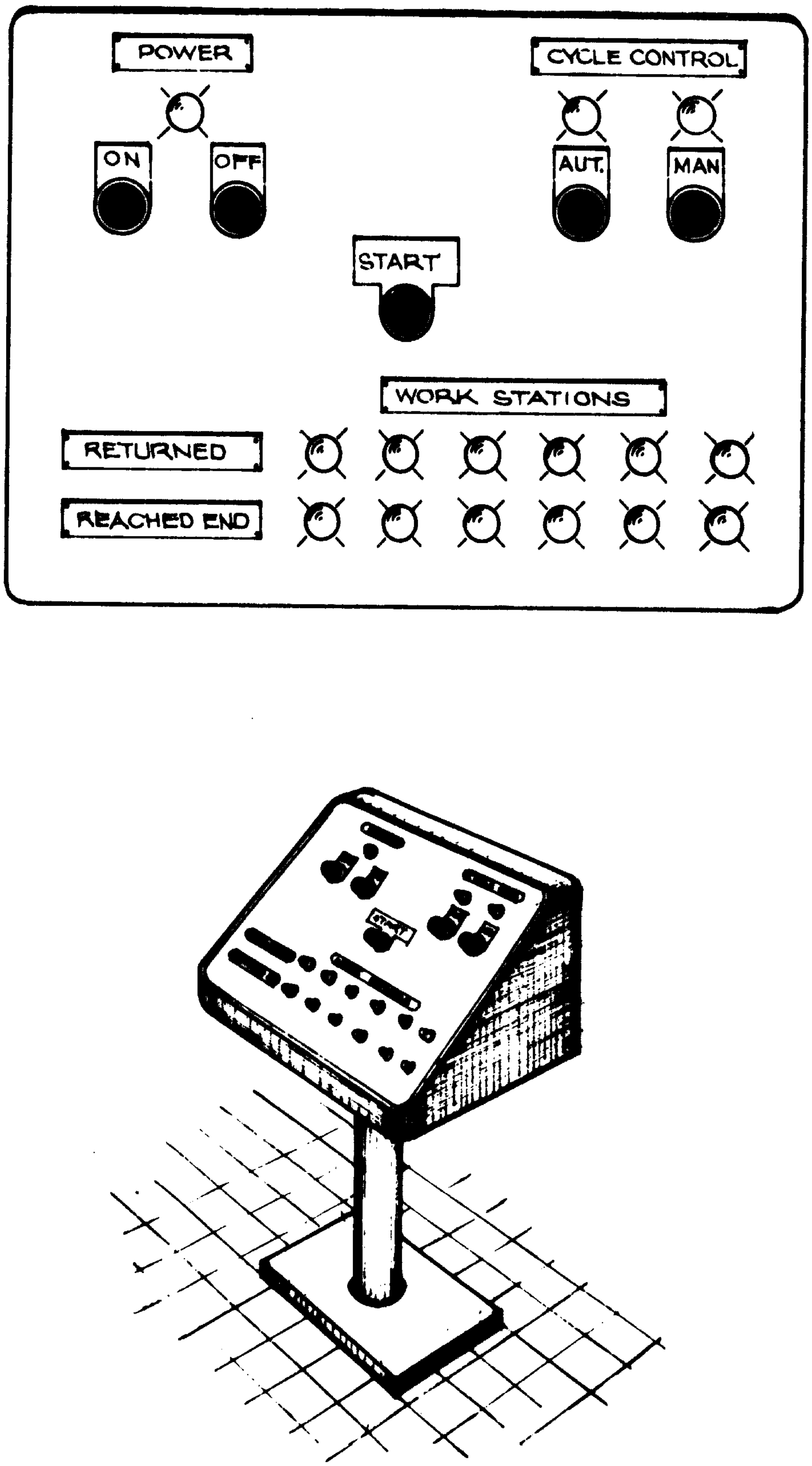


Figure 96. Indexing table: control console

Routing

Routing work is best done on a high-speed, heavy duty router with 15,000 rev/min and higher cutting speeds. The higher the cutting speed the better will be the quality of cut. The heavy-duty router has a fixed head and a movable table. The table is moved up and down by mechanical linkage controlled by a foot pedal. More advanced router models feature tilting heads and/or tilting tables. However, their outputs do not vary much from the fixed-head type of heavy-duty router, since the routing speed is still controlled by the rate at which the operator can load, move the workpiece against the router bit, and unload the routing jig or template. Output volume, however, can be increased by the use of good clamping devices and routing templates, moved by pneumatic LCA devices.

Small furniture factories make more use of the portable router. Here, the router is moved over or around the workpiece to do the routing job. As in any type of purely manual operation, output is low and quality of work is poor. To obtain a higher output and better-quality work with a portable router, a device may be set up to fix the router head in position and move the workpiece against the router bit. Movement of the workpiece is facilitated by the use of a routing jig or template fixture.

Routing set-ups in which the workpiece is moved around a fixed routing head lead to possible automation, as discussed later in this manual.

Sanding

The surfaces of solid-wood components are prepared for coatings of finish on a wide range of sanding machines. The following types are used by small and medium-size furniture plants:

- Narrow-belt sanders:
  - Single- or double-belt stroke sander;
  - Levelling sander (horizontal belt sander);
  - Universal oscillating belt sander;
  - Vertical-belt sander for sanding the edges and sides of drawers;
- Profile sanders, which use cloth-backed sanding belts and are especially effective for sanding surfaces with profiles or contours;
- Wide-belt sanders:
  - Single-belt;
  - Double-belt;
  - More than two belts.

Except for the wide-belt sander, which has its own mechanism for controlling the pressure of the sanding belt against the wooden surface being sanded, all the other sanders mentioned above depend on human judgement and skill to obtain the correct pressure. This, of course, leads to variation in the quality and output of the sanded work-pieces.

Although it is hardly possible to design devices that will prevent sanding errors due to human factors, in certain situations the configuration of the workpiece and the sanding quality desired permit the use of a simple LCA device.

The wide-belt sander also has its own feed mechanism, a belt conveyor. The opening between the feed conveyor belt and the sanding-belt surface is adjustable. Thus, the machine is suitable for sanding both solid-wood and panel components. It is easily linked to other production machines. Obviously, the machine output greatly depends on how fast the worker can set the workpieces on the feed conveyor belt of the machine.

C. Possible applications of low-cost automation in the preparation of panel components

Veneer preparation

The primary objective of preparing veneer for panel components is to produce veneer sheets (faces, backs, cross veneers and edging strips) of specified size, shape and desirable grain pattern. The three principal operations involved are clipping, jointing and splicing; and the principal pieces of equipment required are veneer clippers, jointers and splicers.

Face veneers usually come from high-priced timber species and thus must be processed with the utmost care to keep wastage to a minimum. Face and back veneers are usually 0.7 mm thick, while cross veneers may vary from 1.5 to 3 mm in thickness. Cross veneers are normally cut to have their grain patterns perpendicular to those of the face and back veneers.

To ensure perfect adhesion of the veneers to the core board, the veneer components are cut 5 mm-10 mm wider or longer than the core board. The core boards are cut with up to 15 mm (maximum) excess over the final dimensions whenever the edges have to have contours or profiles.

Face veneers usually are sliced veneers; back veneers are either sliced or peeled veneer, while cross veneers are always peeled veneers. Edge strips usually come from the same veneer sheets as face veneers.

Veneer clipping

Veneer sheets made from a set of veneer flitches have very irregular edges and must be cut across and along the grain to obtain rectangular sheets. A hand-fed, pneumatic-actuated, foot-operated veneer clipper is the machine most commonly used for this purpose. Clipping accuracy on this machine depends solely on the ability of the clipper operator to position the veneer sheet under the clipper knife properly, actuate the knife, withdraw the veneer after clipping an edge and reposition the sheet for successive cuts. Thus, automation of the cutting cycle of this type of machine is hardly possible without interfering with the accuracy of the cut. Mechanization of picking up the uncut veneer sheet from the veneer pile and piling the cut veneer sheets on another pallet (or container) is also a hard problem to solve. Even in some highly industrialized countries veneers are still clipped manually.

However, safety considerations require that the chances of the operator's cutting his hands or fingers during the veneer cutting cycle be minimal. A safety device as shown in figure 97 will help minimize accidents during clipping. The device cuts off the supply of air to the foot-operated valve whenever the safety shield is lifted accidentally (or intentionally) off the contact valve, thus making it impossible for the clipper knife to be actuated.

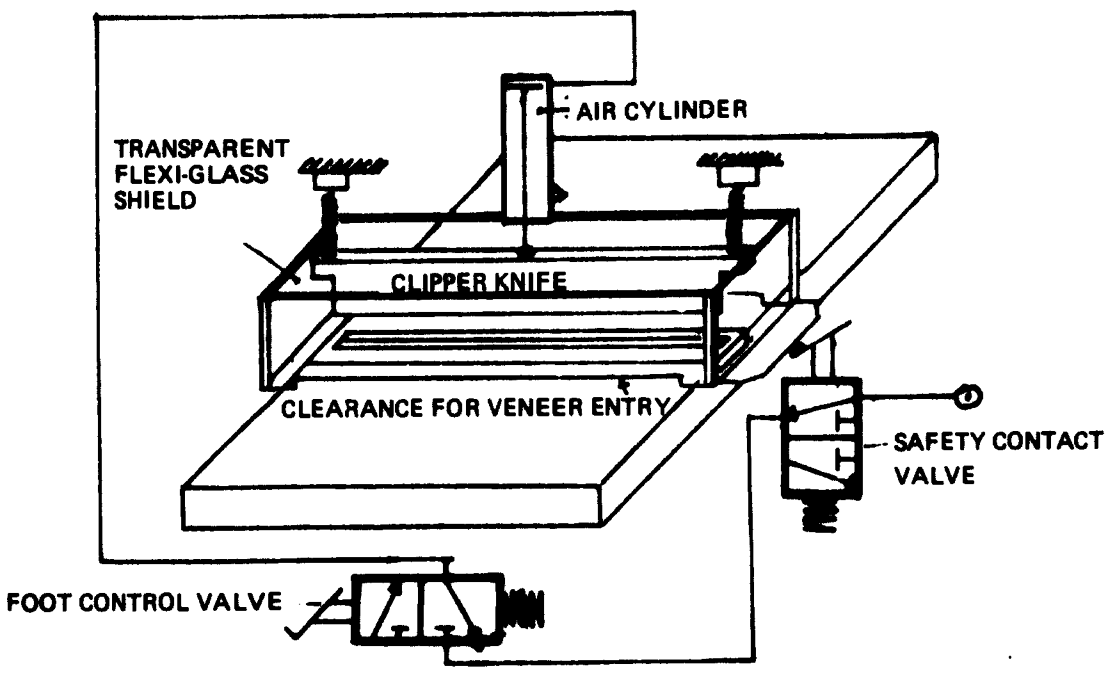


Figure 97. Veneer clipper safety device

Veneer jointing

In small and medium-size plants the veneer clipper is commonly used for veneer jointing. Some of these plants use the regular hydraulic-operated "guillotine" for jointing cross veneer and back veneers. The machine makes possible jointing of several sheets simultaneously. Other more advanced plants use a combination cutterblock jointer and splicer. All these machines are hand-fed. The automation of the machines as installed is therefore hardly possible. Safety devices, however, can be installed in the machines to prevent accidents.

Veneer splicing

The basic veneer-splicing machines usually found in small and medium-size furniture plants are very similar to, if not identical with, those found in the dry-veneer-processing sections of plywood plants. One splicer model uses a belt conveyor to transport the veneer sheets (with glued jointed edges) to be pressed on a metal platen by a heated calender, which cures the glue on the veneer splicing joints. The result is a continuous veneer sheet that is then clipped to the desired sizes by a standard veneer clipper. Another model lays a thread of adhesive material zig-zag across the joint to be spliced or applies spots of thermo-plastic adhesive material over the jointed edges at predetermined spacings. Other models use splicing tape, which is sanded off later, after the furniture panel component is completely assembled.

The splicer model using glue thread is highly recommended for splicing face and bottom veneers, whereas the model using a heated calender is preferable for splicing cross veneers. Again, the design of the splicers using adhesive thread or tape or laying spots on the splicing joints is such that purely manual feeding and off-loading of the machine are necessary. The model that produces a continuous sheet provides a good opportunity for mechanized feeding and linking to joint operations.

The combination veneer jointing and splicing machine is considered the best for medium-size furniture plants.

However, more recent developments in veneer-splicing technology have produced splicing machines with a cutterblock jointer that cuts the veneer edge ahead of the head that lays zig-zag adhesive string to produce a continuous sheet of face or bottom veneer. This type of splicer is recommended for high-volume production. Further automation of the machine by the use of LCA is hardly possible in this case.

Preparation of core boards from wood-based panels

The basic machine for cutting wood-based panels into smaller boards to be used as a core material for furniture panel components is the table saw with a sliding table extension. In some instances the table saw is equipped with a tilting arbor to permit bevelled cuts on the board's edges. The panel is hand-fed into the saw blade and the sliding table extension facilitates cutting long, straight edges.

Among the more advanced models of panel saws are the following:

(a) Vertical frame panel saw, where the panel is placed in an upright position on the frame, then held by clamping devices, while the saw is moved across the board to obtain the desired widths (or lengths) by a mobile platform that is moved up and down the length (or width) of the board;

(b) Gantry panel saw, where the panel (or panels) are horizontally laid on the machine bed, held by a strategically located clamping device. The gantry device holds several sawing units, one of which cuts across the board as the gantry is moved from one end to the other end of the panel. Each saw unit is activated at the precise cutting location by limit switches that stop movement of the gantry, start the saw motor and activate the device that moves the saw unit along the panel's surface.

In some factories, a single-blade edger saw, with chain feed and wide bed, is used to cut wood-based panels into small boards. This method requires passing the panel several times through the machine to cut the desired board sizes. This is possible only if the proper type of cross-cutting saw blade is used to cut the panels. Again, the LCA conveying system to return the boards to the saw as shown in figure 86 is applicable.

Panel lamination (veneering)

The veneer sheets are laid on the core board with urea type adhesive and are hot-pressed (100°-120°C) on a multi-opening hydraulic press. In small and medium-size furniture plants, the hot presses are commonly loaded and unloaded by hand. This results in a low output. In some medium-size plants equipped with 15-20 daylight hot presses for loading and unloading an elevator that carries two workers and the panels is used. Loading and unloading are both done on the same side of the hot press in the following manner:

(a) The elevator is lifted to the highest platen level and unloading starts from the top platen;

(b) The elevator is gradually lowered to the level of each lower platen to unload the panels;

(c) The pile of hot-pressed panels is unloaded off the elevator at its lowest (normal) position and a pile of laid-up panels is pushed onto the elevator;

(d) Loading starts at the lowest platen and proceeds upward until the top platen is loaded;

(e) The elevator is lowered to its normal position after completion of the loading trip.

However, if the pressing cycle is shorter than the time it takes the elevator to travel from top to bottom platen, the elevator stays at the topmost platen level and waits for the platens to open, and the unloading phase proceeds as described above.

In more modern panel-based furniture plants, hot pressing is done on a short cycle, single-opening hot-press. The boards are glued and the panels assembled on the in-feed end of the hot-press. Unloading and loading are done rapidly through a system of conveyors and mechanical linkages. This type of hot-press is easily linked to other machines by conveyors. Furthermore, it can be used in laminating core boards with sheets of synthetic material (PVC etc.). In this case, the synthetic material, wound on a reel, is fed into the press by rollers and cut to the desired length by a specially designed slitter knife that travels across the width of the board at the out-feed end of the hot-press.

It follows from the foregoing discussion that application of the LCA to the hot-pressing operation itself may mean that radical changes must be made in the press design itself, which small and medium-size furniture plants are usually not equipped to do. However, knowledge of the principles of LCA will help ensure proper maintenance of the hot-press, since the hydraulic system and timing controls of the hot-press are designed under concepts similar to those of LCA.

Panel edge preparation

Panel edges must be prepared before edge veneering or edge shaping. A veneer trim saw is used whenever the edges are to be veneered. In some panel constructions, however, a vertical spindle moulder is used to remove the excess veneer from the panel edges. This technique is used when a solid-wood edge-band is glued to the core board, and a profile has to be cut on the edge-bands. This technique is successful only when the panel corners are rounded. Veneer edging permits sharp, square corners on panels.

The table saw with sliding table extension is commonly used for veneer trim sawing in small and medium-size furniture plants. This type of saw, when equipped with a tilting arbor, will facilitate cutting of canted edges on the boards, provided that the panels are not too large. Automation of this particular operation may be done as illustrated in figure 98.

If the edges of the panel are to be profiled, an LCA system as illustrated in figure 99 will help speed-up the job and improve the quality of work for panels with rounded corners. However, an LCA system similar to the set-up in figure 98 will be more effective when the panels have square corners.

Edge veneering

Veneer strips are glued to the edges of the panel with the aid of clamps and holding fixtures. In most situations, the glue is allowed to set and cure while the veneer strips are still clamped to the panel edges—a very slow process.

Glue setting and curing may be hastened by adequate heating. Figure 100 shows how this can be done with the aid of LCA components, an electric arc-welding machine and a length of ordinary fire-hose. The amount of heat generated on the copper strips is regulated by adjusting the current delivered by the welding machine.

The desired pressure on the veneer strip is attained by controlling the amount of air delivered to the fire-hose through an adjustable pressure switch. The length of pressing time is controlled by the timer connected to the welding machine.

The next step after gluing the veneer strips to the board edges is to level the veneer edge to the surface of the panel and make a slight chamfer of the edge strip to break the sharp edges. In small and medium-size plants this operation is commonly done with the use of a shaper (vertical spindle moulder). In more modern plants the edge veneer gluing, levelling and chamfering operations are done successively on one machine, the edge banding machine. Single-edge and double-edge banding machines are currently available on the market.

Machining

Machining operations on panel components are similar to those for solid-wood components, except that the machines required for machining panel components need bigger work-tables or platforms. Hence, the ideas of automation discussed in connection with machining operations for solid-wood components are also applicable to machining operations for panel components.

Making cut-outs on panel components is usually done by hand on a heavy duty router. It is a slow operation, particularly when the panels are thicker than 19 mm. Moreover, the quality of the routing job varies from one panel to another when the worker becomes tired. This situation could be improved through the use of LCA systems. Figure 101 shows how this may be done, with simple LCA devices. When the router work load for making cut-outs on panels is large, it may be justifiable to automate the router specifically for making cut-outs, as in the case of the second illustrative example in this paper. The original steel-bed work-table of the heavy duty router is replaced by a steel frame that holds the pneumatic cylinders, valves and limit switches that control the movement of the panel under the router bit. The basic panel movements are left to right and forward and backward of the router bit. Other cut-out shapes can be routed by adjusting the design of the LCA system to fit the desired shape.

Caution: This type of cut-out routing will always give rounded corners on the cut-out. The acuteness of the rounded corners depends on the size of the router bit used.

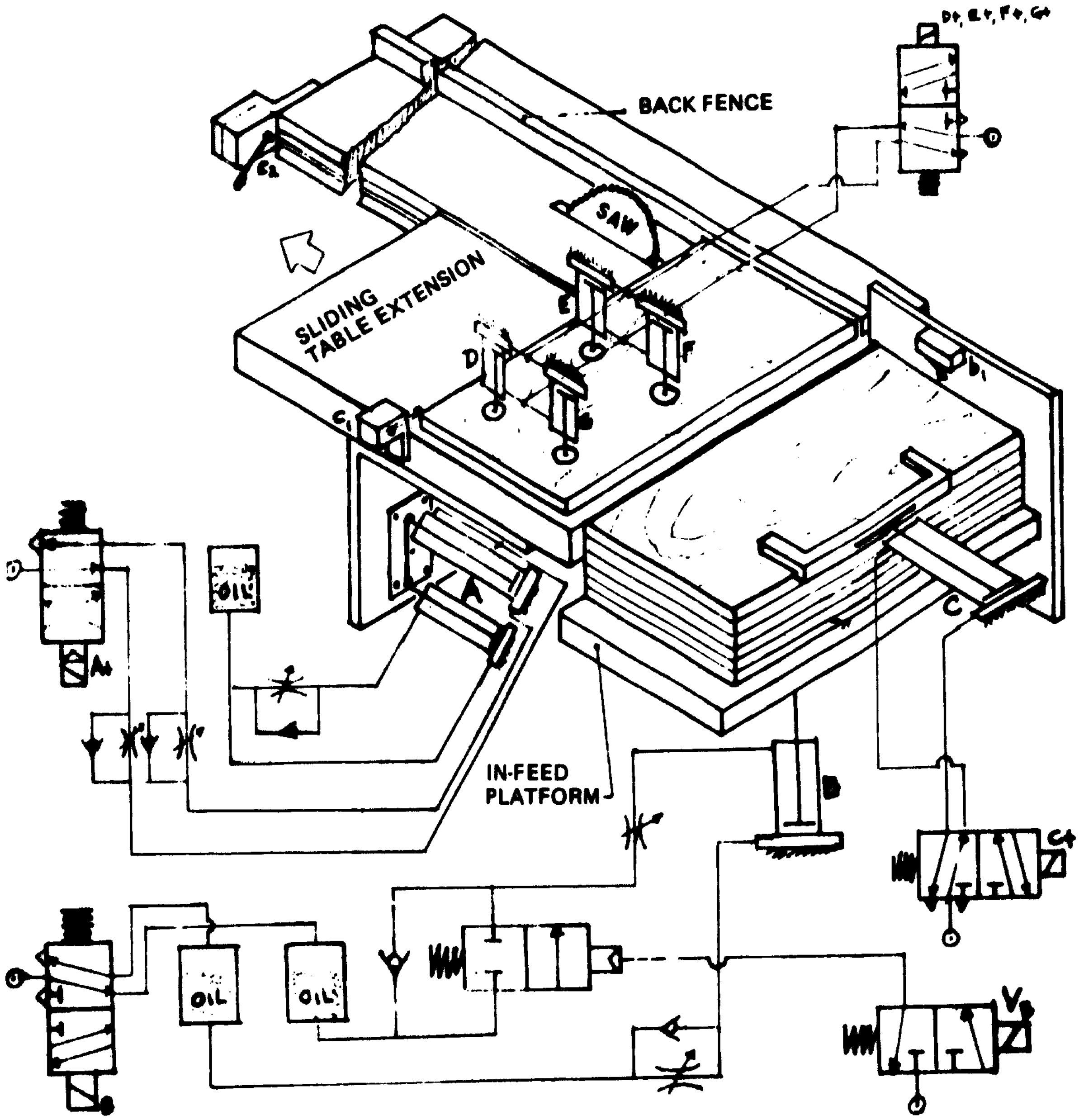


Figure 98. LCA applied to panel edge trim sawing on saw with extension table

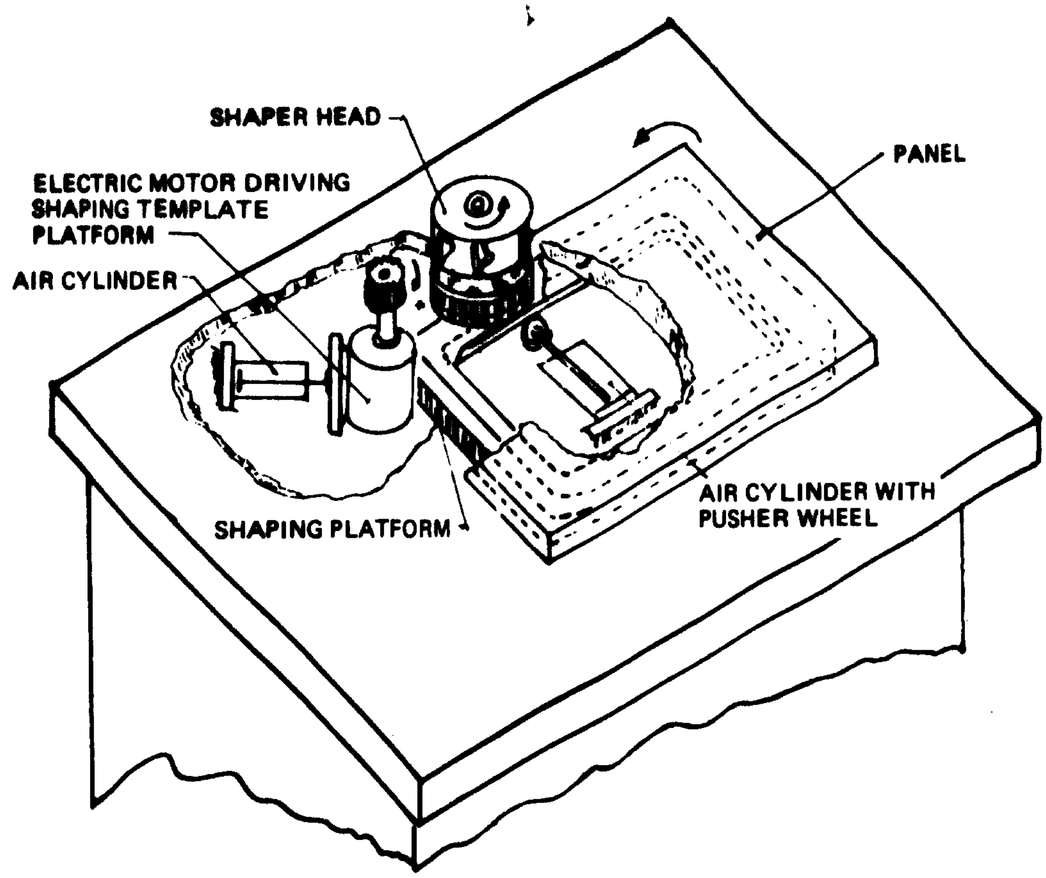


Figure 99. Edge shaping on vertical spindle moulder with LCA system

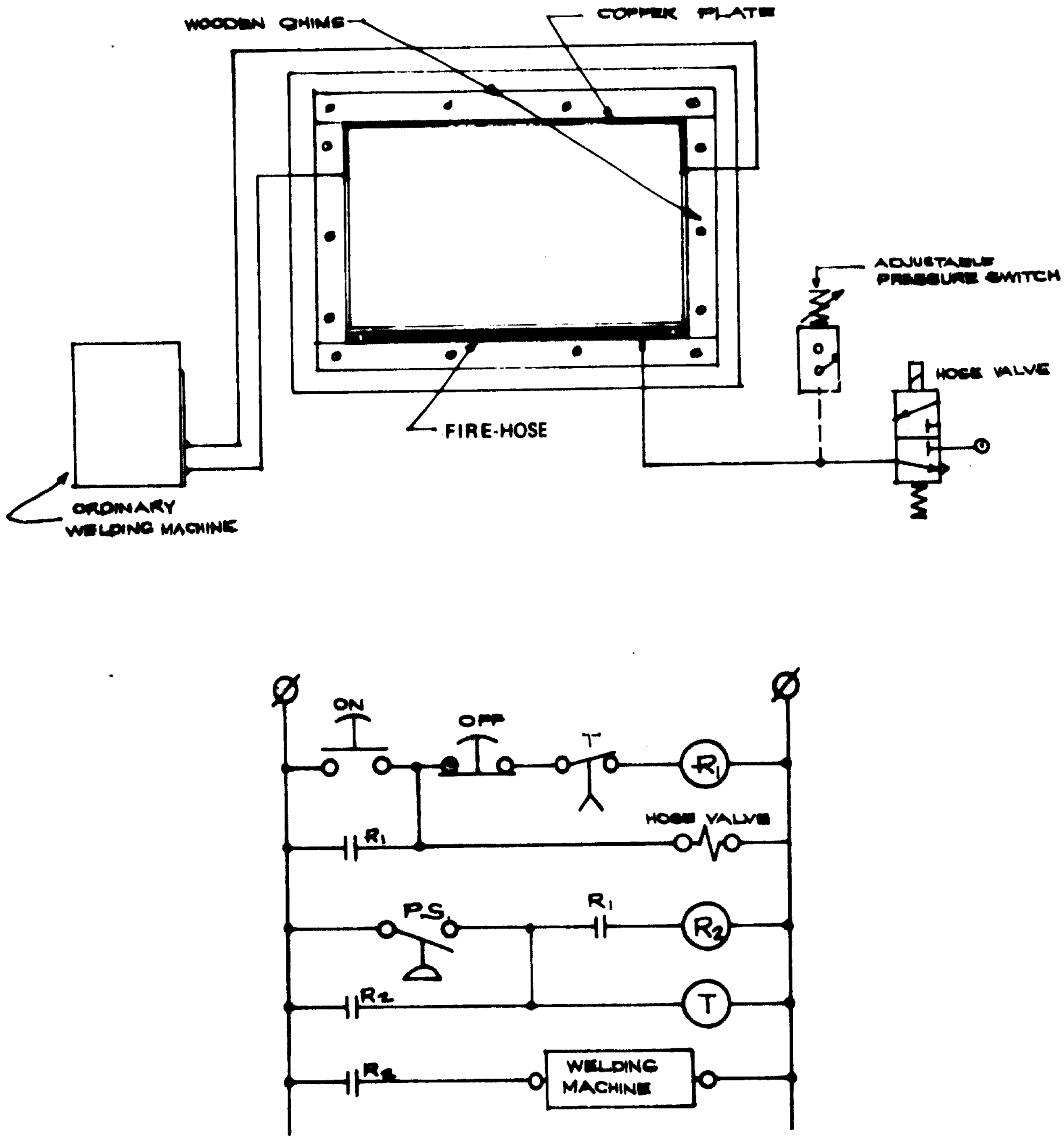


Figure 109. Edge veneer gluing with LCA device

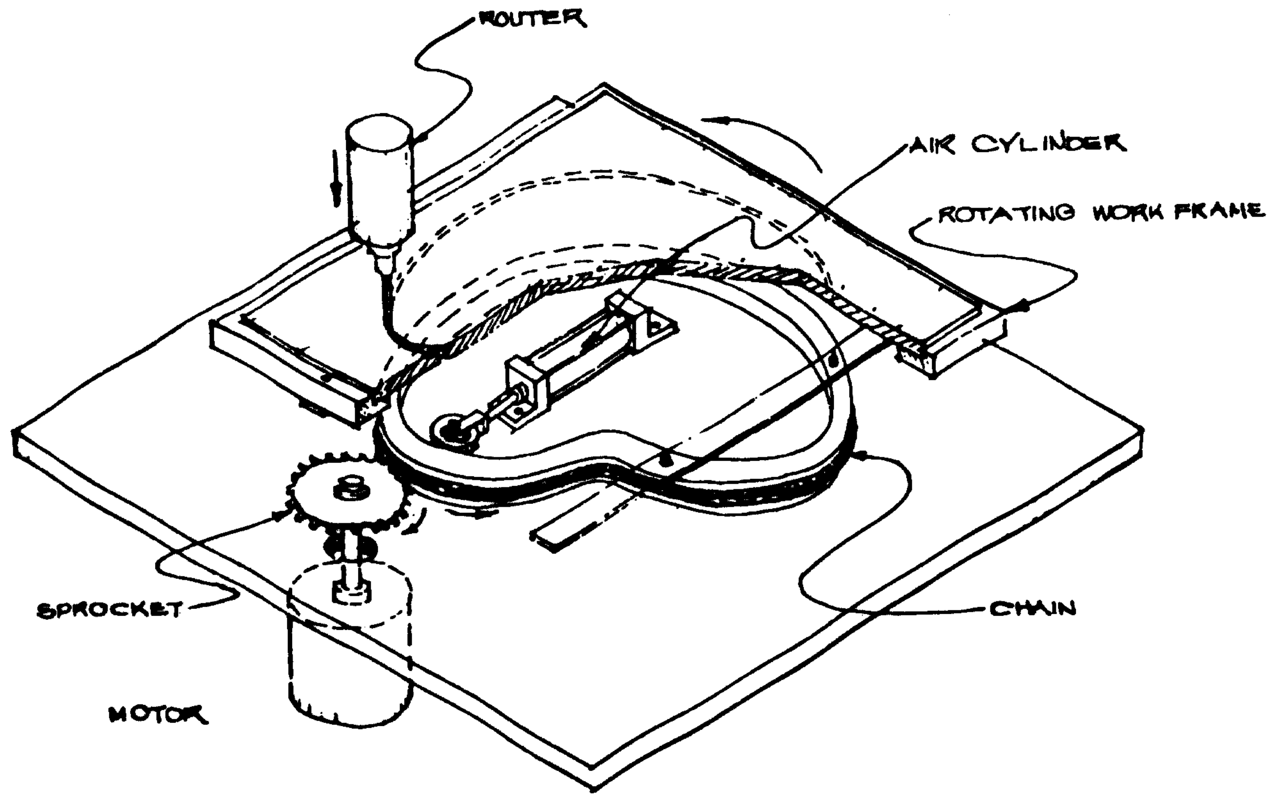


Figure 101. Routing cut-outs on panels aided by an LCA device

Sanding

Small and medium-size panel-based furniture plants commonly use narrow-belt sanders (single- or double-stroke sanders) for sanding panel components. As discussed in a previous section, this operation is rather slow and requires the worker to be highly skilled. Incidence of veneer sand-through on the panel edges is high.

More modern plants use wide-belt sanders, usually double-belt models, while other plants use drum sanders with drum oscillating mechanisms. These modern sanding machines have their own feed mechanism and can be easily linked to other operations in the plant.

The edges of panel components in small and medium-size plants are usually sanded on a universal sanding machine with an oscillating mechanism for the sanding belt. Some models of this type of sander have tables that can be inclined to permit sanding of panels with canted (sloping) edges. The panel surface to be sanded is pushed by hand against the moving sanding belt. Again, a certain degree of skill is required of the worker to reduce sanding rejects to a minimum. Automation of this operation is hardly possible without interfering with the working mechanism and design of the machine.

Panels with profiled edges are edge-sanded on a "contour sander" using a narrow cloth-backed sanding belt. The key to success in this operation is having the proper shaped pad at the back of the sanding belt; it should mate properly with the profile of the panel edge.

D. Possible applications of low-cost automation in assembling operations in panel-based furniture manufacturing

The basic tools and implements, among others, used in assembling panel-based furniture are screw drivers, C-clamps and bar clamps, toggle clamps, stapling tools, glue applicators, assembly jigs and fixtures and frame and carcass clamps.

The key to efficient and rapid assembling operations is the use of suitable jigs and fixtures equipped with clamps or other devices to hold workpieces. Separate jigs and fixtures are needed for the sub-assembly of drawers, special shelvings and cabinet partitions; appliqués on doors and drawer fronts, automatic mechanisms for locking drawers. Modular assembly jigs and fixtures can be designed and fabricated for the assembly of the panel-based furniture carcass, sidings, top, back and bottom. This method leaves the front open for easy access to the inside areas of the cabinet. In some cases, the top panel is the last to be assembled, particularly in furniture where the top panel edges protrude over the sides and front, such as in night tables or dressers. In other instances, however, the back panel is the last to be assembled, as in stereo speaker units or the console type of radio-phonograph cabinets.

Drawer assembly

Whether the panel-based furniture item is shipped in the assembled or in the knock-down state, drawers are always assembled before finishing. Modern furniture design calls for drawer fronts flush with the cabinet front surface, unlike the old cabinet designs where drawer fronts are provided with lips that overlap the front face of the drawer frames, covering the clearances between the drawer and the drawer frame. Thus, the drawers should be assembled as squarely as possible to attain the desired fit with the drawer frame. This constraint imposes strict adherence to machining tolerances of drawer and drawer frame components, so that perfect squareness is attained when assembling drawers. Perfect squareness in assembling drawers is better attained through the use of metal assembling jigs and pneumatic-actuated clamps, which will hold the components firmly in place until the adhesive applied to the joints has set or until fasteners have been put in place to fix the drawer components in a squarely assembled form. Figure 102 illustrates such an assembly jig.

Glue application

Too much glue or too little glue in assembling gives poor results. Excess glue leads to glue squeeze-outs and a messy job. Glue-starved joints are weak, since there is not enough adhesion to make the joint strong. Hence, for precise glue application requirements, a device operated by LCA components similar to the system illustrated in figure 103 may help workers to do a satisfactory gluing job. The amount of glue deposited on the wooden piece is controlled by the size of the nozzles and the speed by which the wooden piece is pushed under the glue nozzles.

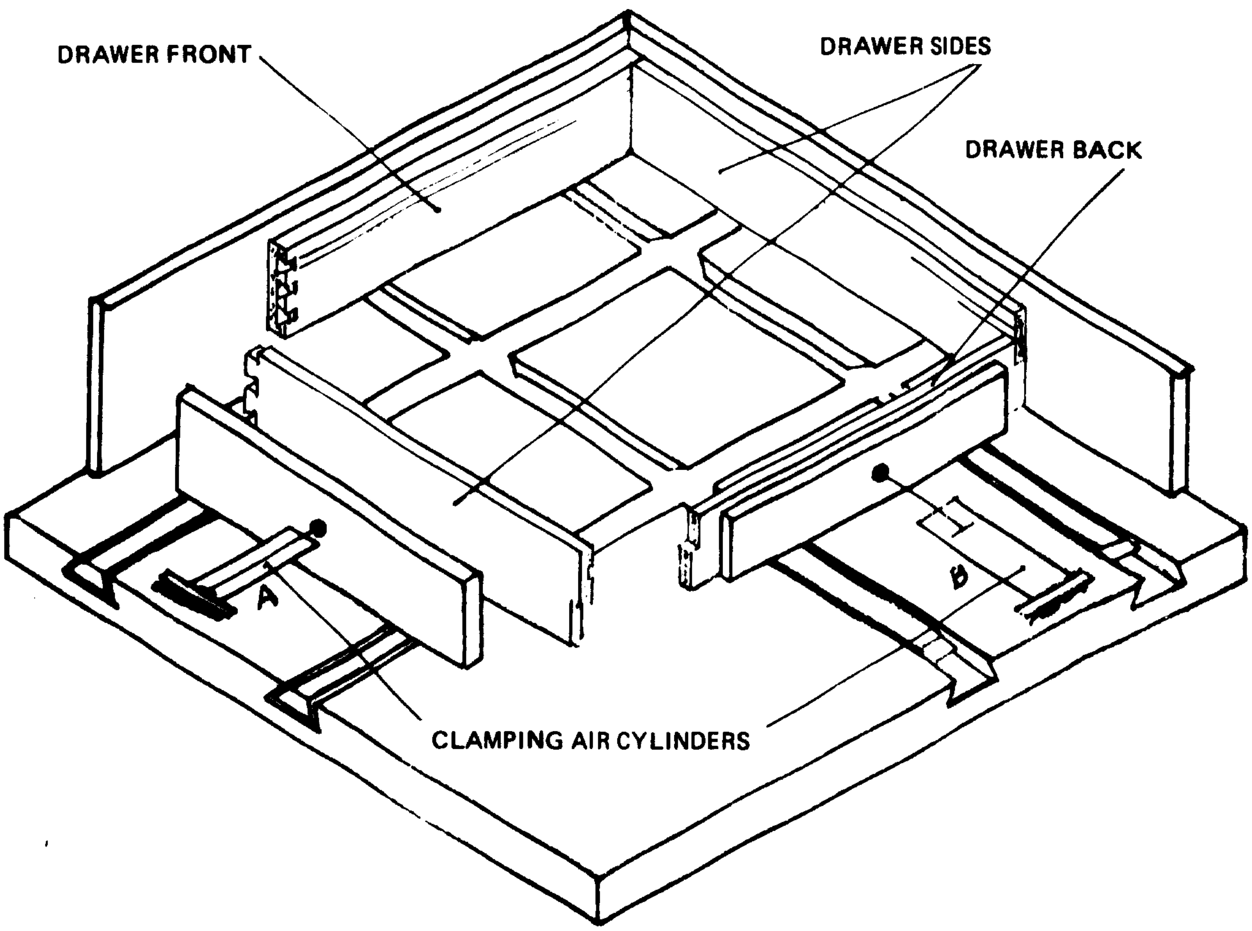


Figure 102. Drawer assembly jig

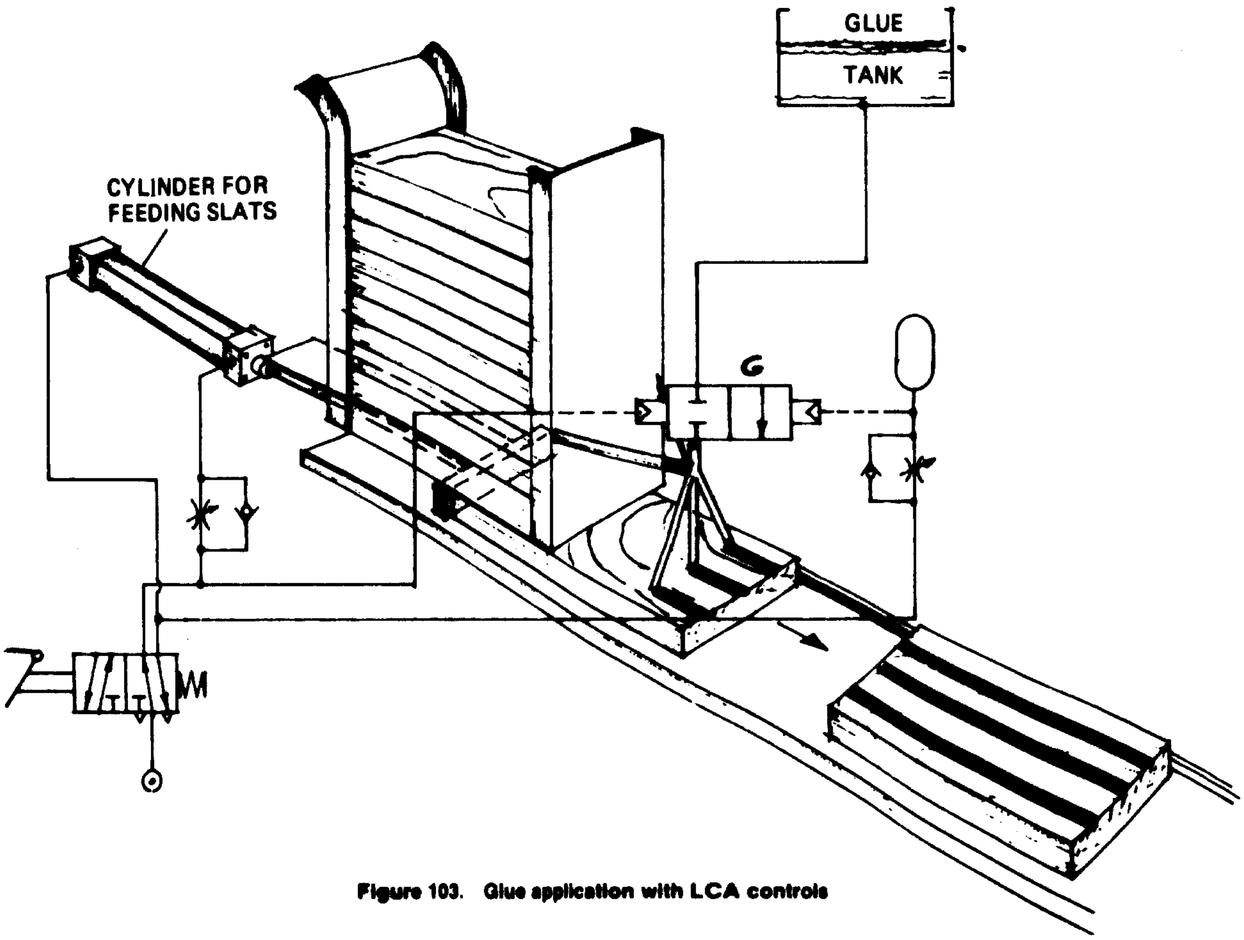


Figure 103. Glue application with LCA controls

Screw-driving tools

With proper size pilot holes, wood screws can be used to attach hardware and other fittings to panel-based components of the furniture. The danger, though, arises from turning the screw more than what the wood substrate can take, thus destroying the holding power of the screw threads to the wood-based panel. Such screw "over-driving" frequently occurs when mechanical screwdrivers are used. The use of pneumatic screwdrivers equipped with an adjustable clutch device will help reduce rejects due to "over-driving" wood screws. The clutch device can be set to match the screw-driving limits determined for each type of panel-substrate and screw size.

Modular assembling jigs and fixtures

Modern panel-based furniture items are basically rectangular or square. This feature makes it possible to devise modular assembly jigs for joining the carcass of the panel-based component and also for joining the panel to the carcass. Figure 104 shows P. Paavola's suggestions for such an assembling jig that permits assembly of two cabinets at a time. The jig uses a fire-hose with air pumped into it to clamp the components in place while the assembling goes on.

For assembling cabinet doors, the device shown in figure 105 also makes use of a fire-hose and a pneumatic cylinder with appropriate control valves to attain the desired pressure on the parts being put together.

E. Possible application of low-cost automation in finishing operations in panel-based furniture manufacturing

The basic steps in applying clear finishes to wooden furniture may be summarized as follows:

- Sap staining or full surface staining;
- Filling;
- Sealing;
- Scuff sanding (if necessary);
- Applying top coat;
- Polishing (buffing), if necessary.

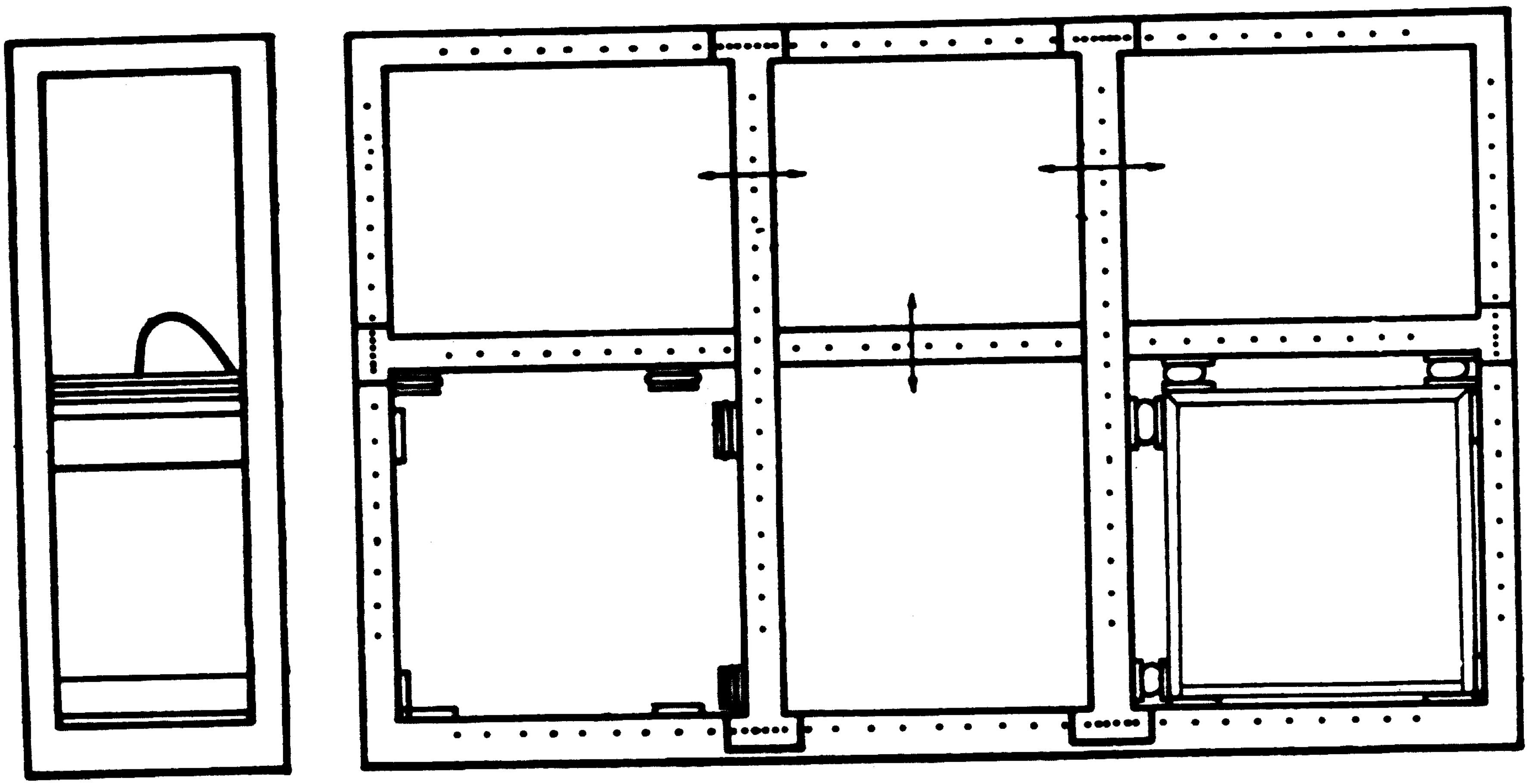


Figure 104. Panel-based cabinet assembling fixture

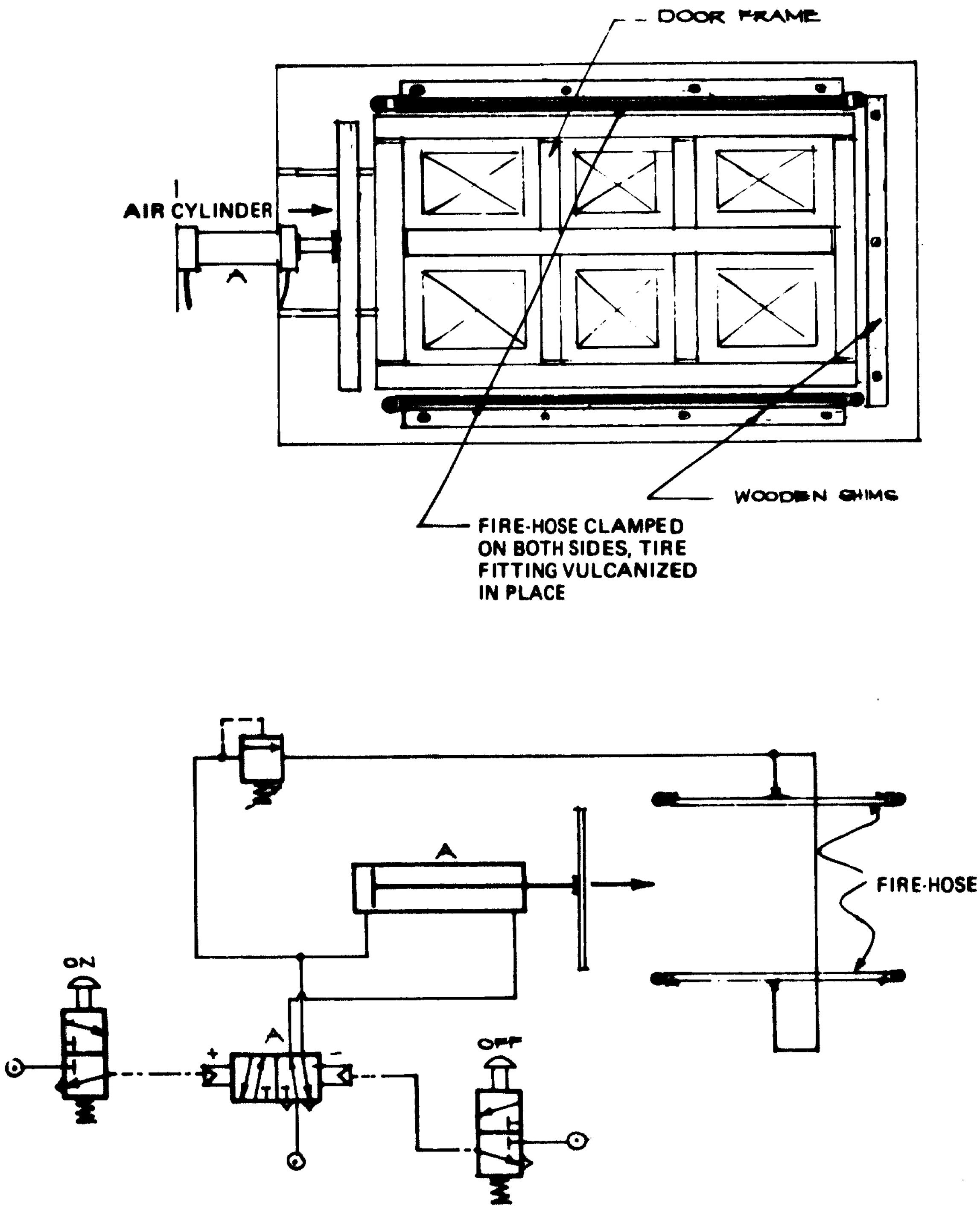


Figure 105. Cabinet door assembling jig

Staining

Staining is normally done by spraying, using conventional air-spray guns. The primary objective in sap staining is to deepen the shade of sapwood areas on the face veneer and make it match the other areas of the panel face. In full surface staining, the goal is to even out the depth of colour tone on the panel surface, particularly in veneer cut from a wood species that shows some degree of difference in the absorption and reflection of light between the tight and loose sides of the veneer sheet. In other cases, full staining is used to deepen the shade or give the panel surface another color. Thus the success of this operation principally depends on the ability of the human eye to detect the areas that need more stain or to determine the amount of stain to be sprayed on the panel surface. The operation therefore can hardly be automated.

Filling

The common prime material in filling is the wood-filler with a quick-drying oil. The objective is to pack the pores of the veneer surface with filling material to obtain a smooth surface after the top coat has been applied. The key to success in this operation involves the use of devices that can effectively push the filler particles into the pores of the wood. An air-operated reciprocating machine with felt-padded shoes is commonly used in this operation. The machine is hand-operated. A rotary filler-padding machine has shown better results than a reciprocating padding machine. This operation is discussed in detail under sample problems, case C.

Sealer coat application

Sealer coat is normally applied by hand spraying, but, in some medium-size furniture plants, it is applied with a pressure curtain coater. With a sealer material properly formulated for the machine, a tremendous amount of material and labour can be saved. Since only two edges of the panel, in addition to the top surface, can be coated in one pass through the machine, a device that returns the coated panel to the feed-end of the machine greatly helps to speed up production. Figure 106 shows such a system with an automated panel turning device.

On assembled furniture items sealer coat is applied by spraying. If the volume of the spraying job justifies automation of this operation, an automatic spraying system with the use of LCA devices can be designed (see figure 6, page 7).

Scuff sanding

Some sealers raise nibs on the wood surface, and thus light sanding to cut off the nibs is necessary. It is best done manually.

Top coat application

The top coat is also normally applied by spraying. The methods and devices recommended in the paragraph on sealer coat application are also applicable in this operation.

Finished surface polishing

Polishing helps to heighten the gloss of finished surfaces. A portable air-operated or electric-motor-driven buffing machine with a rotating disc padded with a bonnet made of lamb's wool is best used for assembled furniture. However, in systems where the panels are finished before assembling, a heavy-duty buffing machine is usually used to polish panel surfaces. This machine is equipped with a cylindrical head, which rotates on its axis at a predetermined speed. The rotating head is padded with a fine woollen material that polishes the panel surface. In other models the rotating head is equipped with closely packed strips of fine woolen material instead of one sheet wrapped around the buffing cylinder. The panel surface is brought into contact with the buffing material by a platform that is raised or lowered manually. In some models, a limit switch is installed to prevent the platform from moving beyond a certain distance nearer to the buffing head. This feature helps prevent burning of the finished surface as a result of overheating.

LCA can be applied to this operation when heavy-duty buffing machines are used. A device can be installed that will automatically raise the buffing platform up to a desired level, move the panel forward until the rear edge is polished, and maintain contact between the rotating buffing head and panel surface for a predetermined length of time, and lower the buffing platform thereafter. Loading and unloading the platform can also be automated (see figure 107).

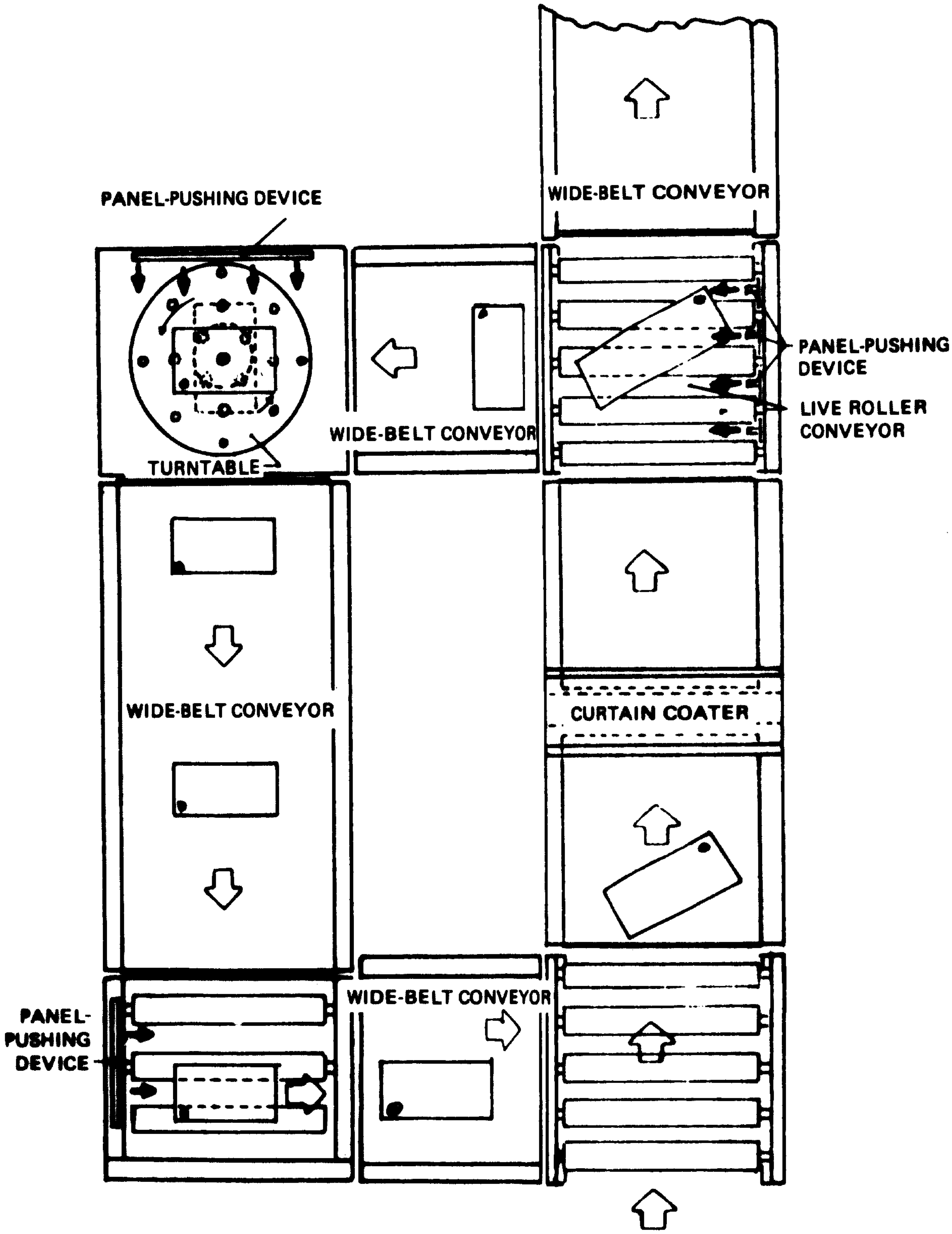
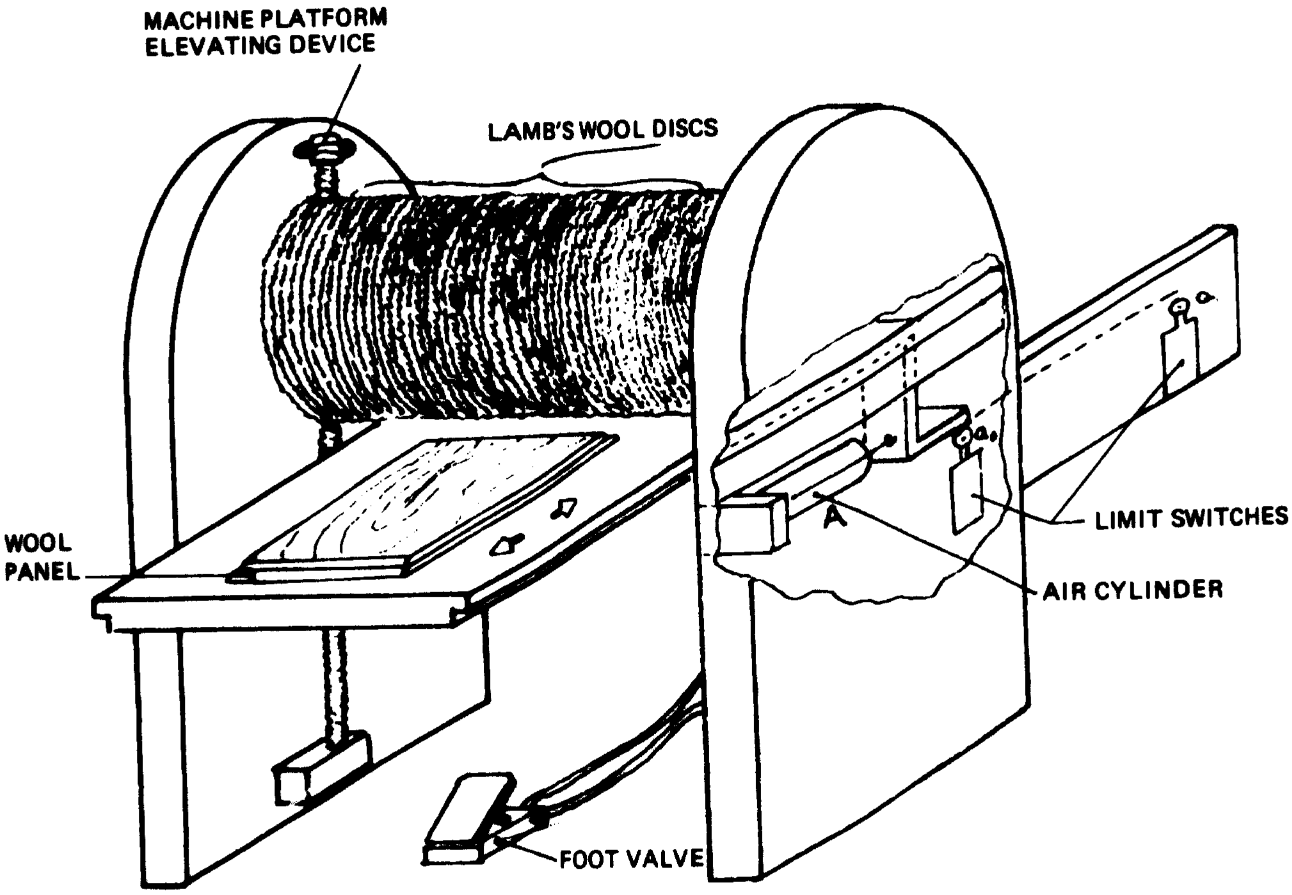
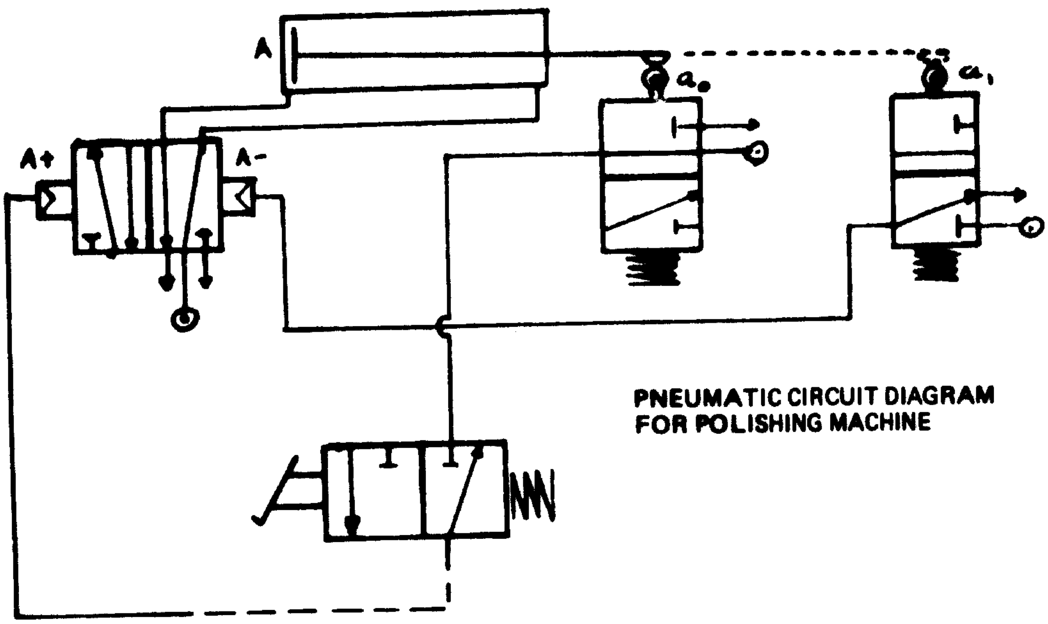


Figure 106. Panel return conveyor, curtain coating operations



HEAVY-DUTY PANEL POLISHING MACHINE



PNEUMATIC CIRCUIT DIAGRAM
FOR POLISHING MACHINE

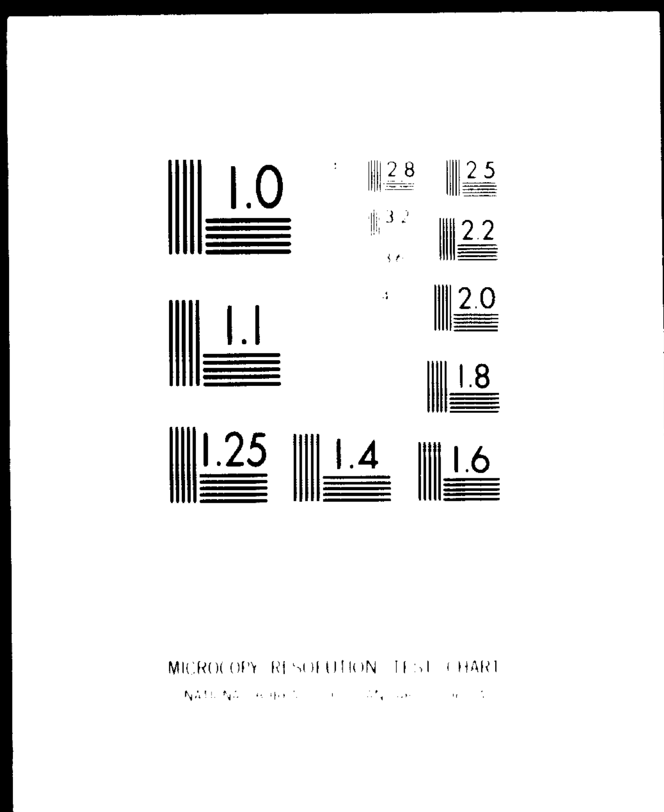
Figure 107. Automated buffing machine

C-179

83.08.11

AD.84.06

2 OF 2



24x

F

F. Possible applications of low-cost automation in handling and transport of materials being processed

The foregoing discussions have often indicated that automating operations in the manufacture of panel-based furniture will be successful if the handling and transport system for the materials in process is adequate. Space constraints do not permit detailed discussion of the handling and transport system devices that can be set up for each of the operations covered in this monograph. However, illustrative examples of such devices are presented in the following paragraphs in the hope that the reader will be motivated to apply such devices, wherever possible, in his own manufacturing operations.

The design of handling and transport systems for materials being processed should be guided by the following considerations:

(a) Transporting the material or product component from one operating station to another is safe and speedy;

(b) The quantity to be transported is sufficient to ensure that operations at the succeeding station shall be continuous;

(c) The cost of fabricating, installing and operating the handling and transport devices is justified by the benefits to be derived from their use.

Machine-feeding techniques and devices

M. Koch and F. Lestouvka have presented a number of machine-feeding techniques and devices, aided by hopper feeds operated by LCA systems, applicable to solid-wood or panel components. Figures 108 to 111 are schematic diagrams of such hopper-feed devices.

Transport of panels

Certain situations require that panels transported on a live conveyor be turned 90° or 180° to facilitate feeding of the next machine. Figure 112 illustrates how such a device can be installed in live conveyor systems.

Other devices

Workpiece holding and clamping systems often produce better results if toggle-clamps, air-cylinder-operated clamps, eccentric clamps etc. are used, particularly in operations where vibration of the workpiece leads to poor machining quality. Some of these clamping accessories are shown in figure 113. It will be noted that each type of clamp has its own specific mode of use.

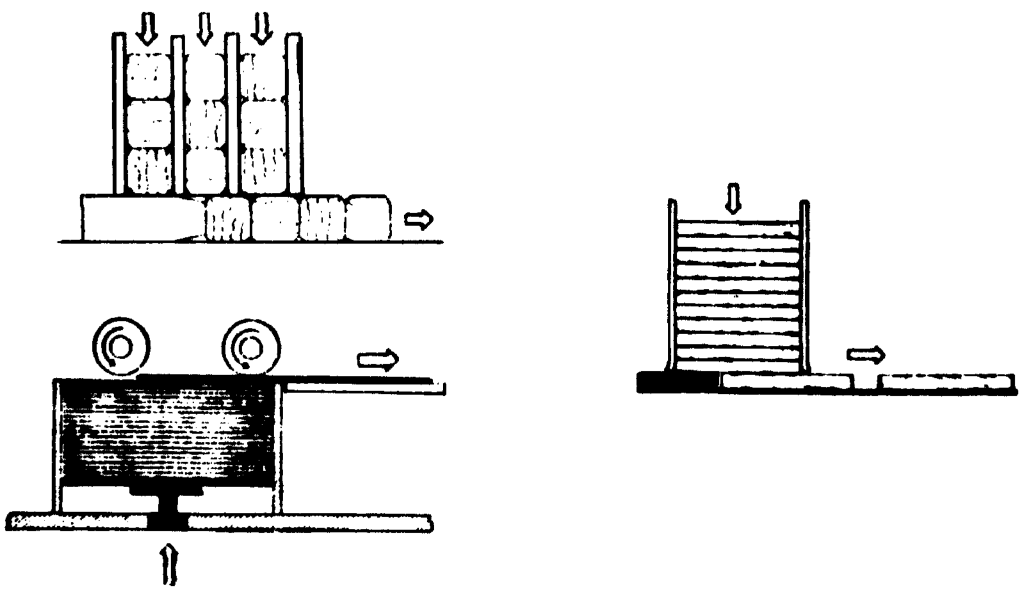


Figure 108. Hopper-feed systems

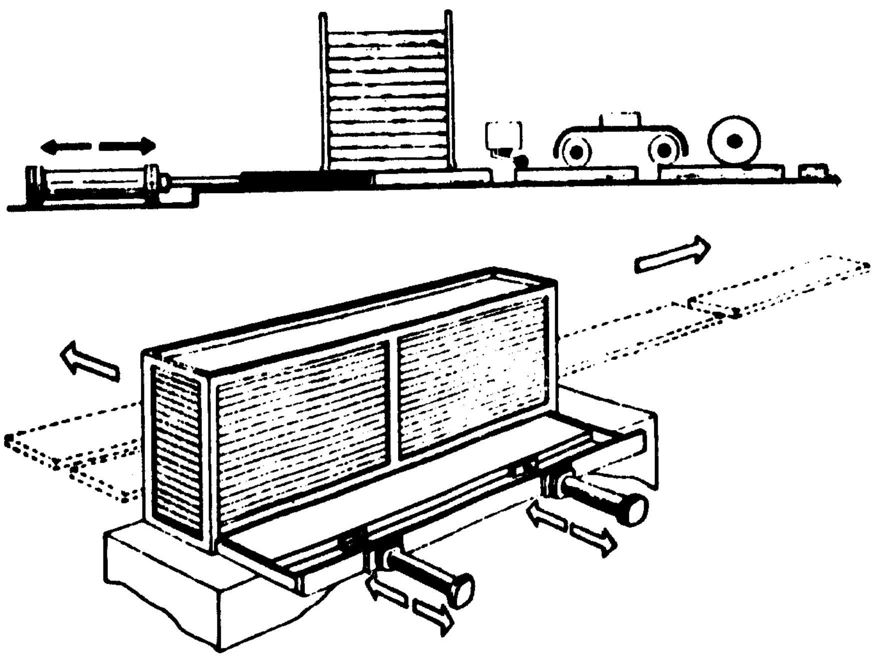


Figure 109. Stacked hopper with pneumatic ejector

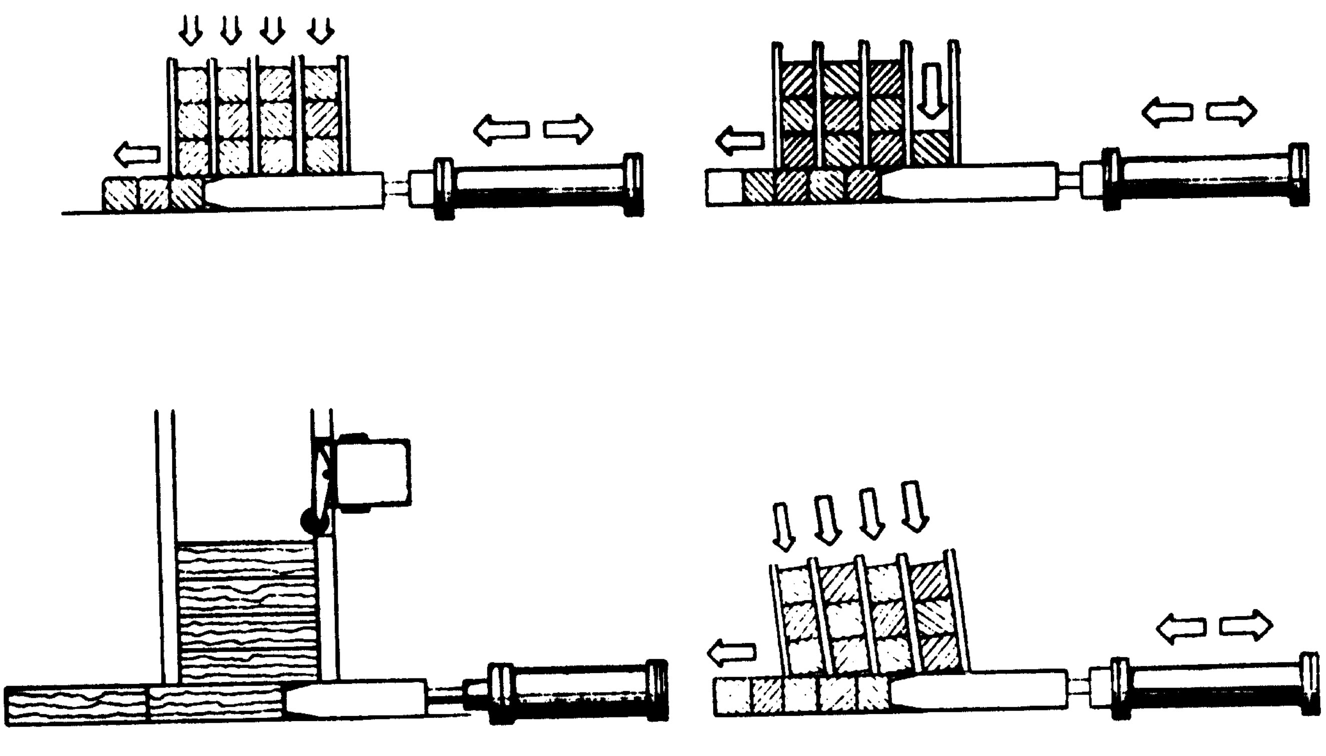


Figure 110. Multi-stacked hopper devices

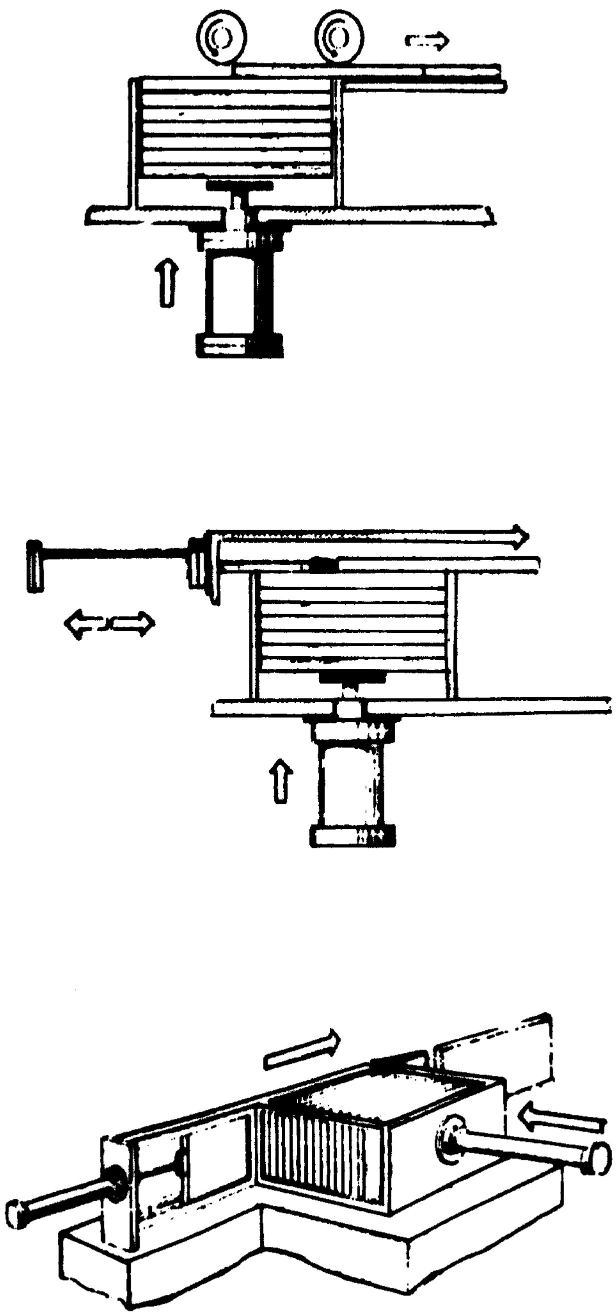


Figure 111. Panel feeding devices

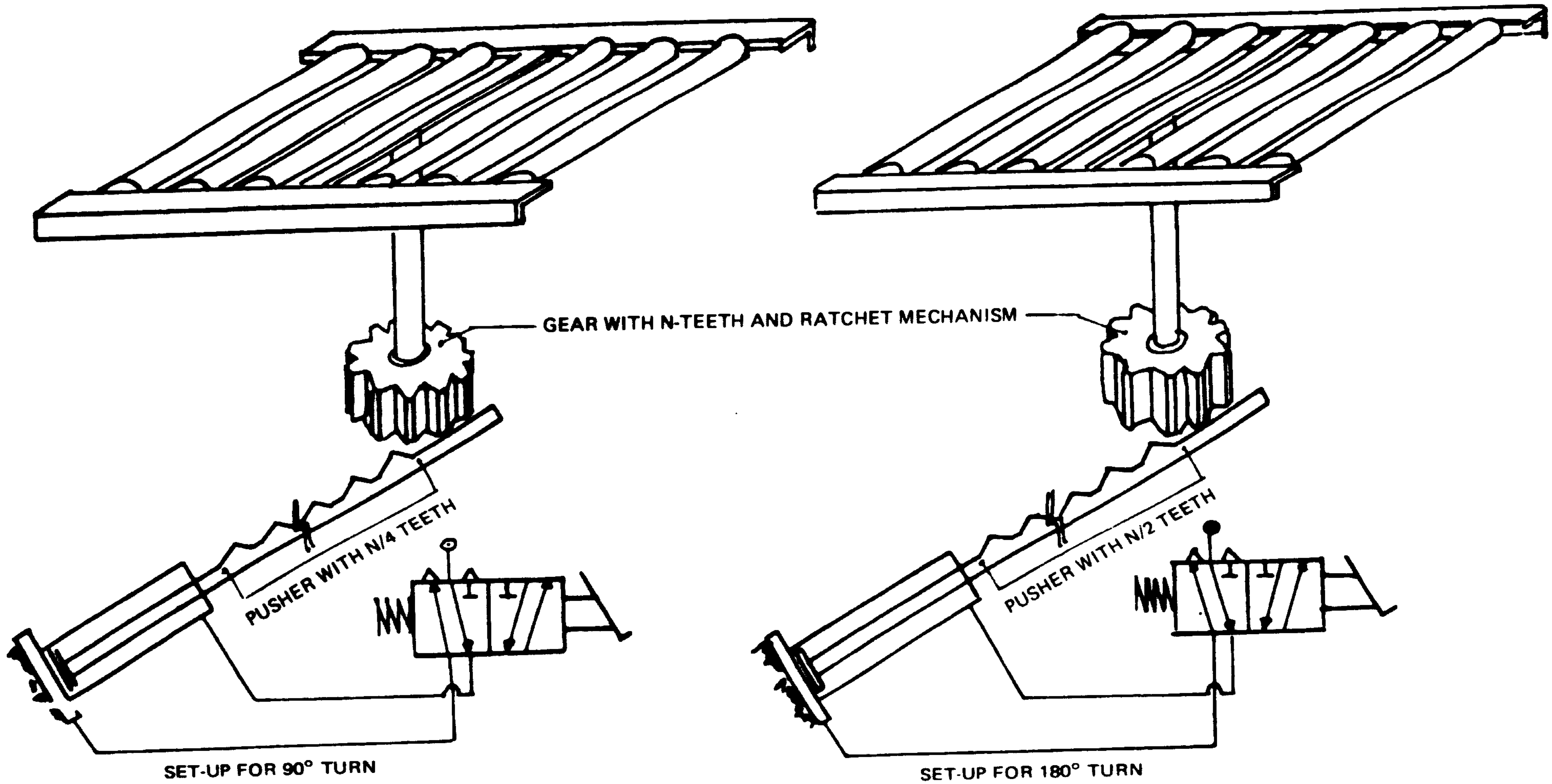
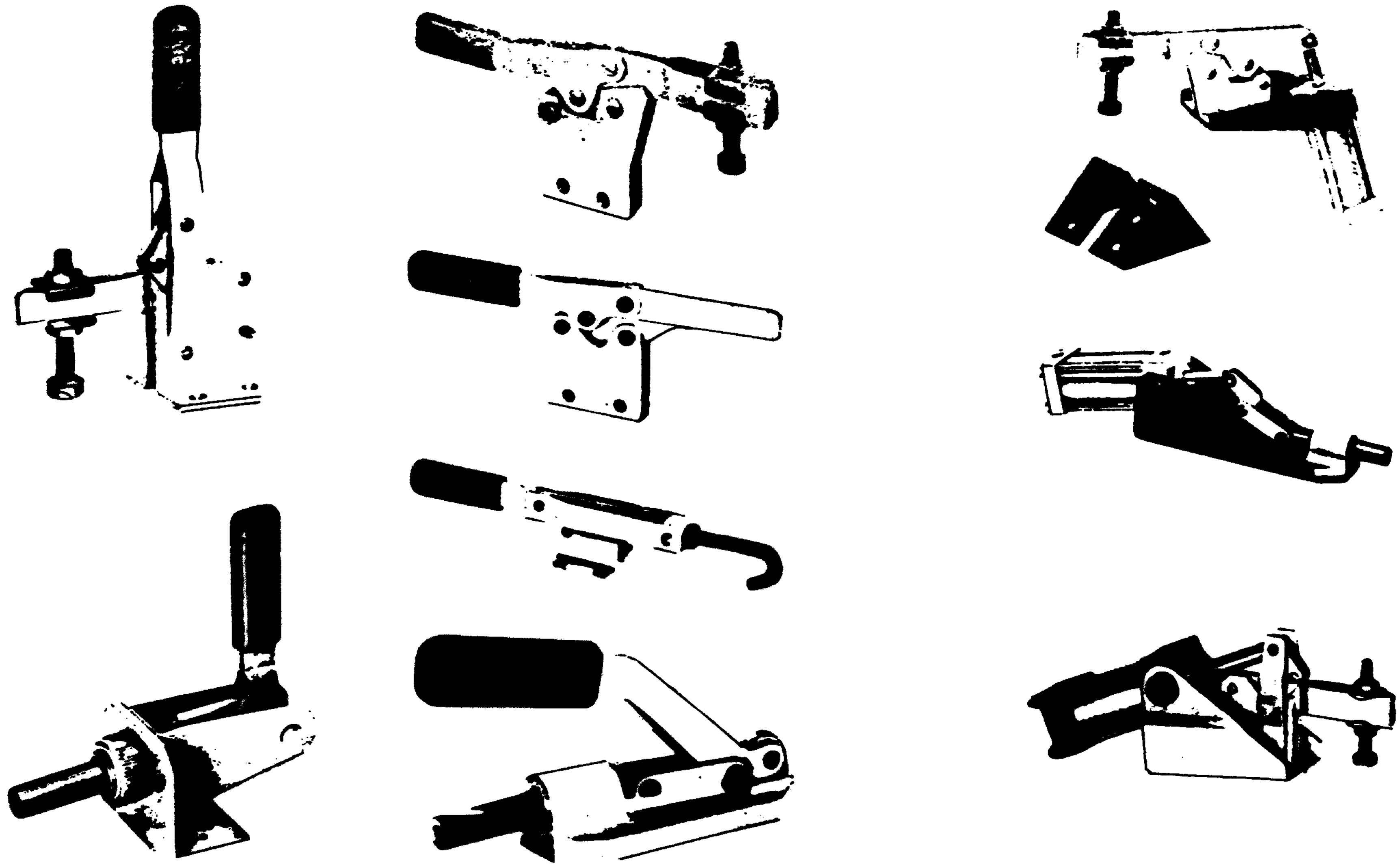


Figure 112. Devices for turning panels 90° or 180°



MECHANICAL (TOGGLE) CLAMPS

PNEUMATIC CLAMPS

Figure 113. Samples of clamping devices

VIII. Sample problems of panel-based furniture manufacture and their solution by low-cost automation

Some examples of problems encountered in medium-size panel-based furniture plants are given below in the hope that the reader will gain some idea of how LCA can help in solving manufacturing problems and also serve as a guide in situations where a decision has to be made as to whether to automate or not.

A. The case of routing cut-outs on panels

Situation

A panel-based cabinet factory producing 400 units per week intended to double its production in 24 months, with the following conditions:

(a) The factory floor area under the expanded operations was to be reduced by one third to provide space for another line of product to be produced;

(b) The labour force was still to work one eight-hour shift per working day, but only five working days per week, instead of the current six working days per week.

In short, to meet the proposed production target, capacity would have to be increased by 140 per cent. Among the potential bottle-necks studied was the routing in the panel-machining section. Two heavy-duty routers were available, both manually fed and of the fixed-head and elevating-table type. The current routing work load on the two machines was about 80 per cent of the available machine time, excluding machine set-up time. Further investigation showed that 90 per cent of the routing time was taken up in routing cut-outs on two of the panel components of the cabinet.

Problem

The problem was how to attain the necessary increase in production output and still comply with the two major constraints on floor space allocation and working hours per week.

Options available

The following options were found to be available:

(a) Replacing the two routers with specially designed, more advanced models featuring automatically controlled routing fixtures. It would take about 6 months to put in running condition from date of ordering the machines. This option would increase routing capacity to 300 per cent of the present capacity and cost $18,000, installed and operational;

(b) Keeping the routers and running them 3 shifts. This option would require an additional 4 router operators, 4 more maintenance technicians (2 electricians and 2 mechanics) and 2 foremen. Furthermore, the diesel-electric generating set would be run 24 hours per day;

(c) Replacing the steel table of the existing routers with routing fixtures equipped with an appropriate LCA system that would move the workpiece to make the desired cut-outs on the panels, permit performance of other routing jobs, simplify loading and unloading the routing fixtures using pneumatic clamps actuated automatically, and position the workpiece correctly with respect to the router bit. This option was expected to increase routing capacity by 175 per cent; require the same number of workers as before; and cost approximately $10,000, fabricated, installed and operational.

Value analysis of options

Option *(b)* was rejected outright because it did not conform to the working-hours constraint set by management. Options *(a)* and *(c)* were evaluated as follows:

(a) Both options would require the same number of workers and same skill level of workers;

(b) Under option *(a)* routers would have to be modified in some respects to enable them to perform other routing jobs, aside from making cut-outs on panels;

(c) Power and air consumption of the machines in both options were about the same;

(d) The conversion job under option *(c)* required materials that were available locally. Only a few of the LCA components might have to be imported by the local representative of the manufacturing firm;

(e) Maintenance requirements of the machines in both options were about the same;

(f) The existing routers could be sold at $2,750 each, including the frequency changing units;

(g) Both options met the expanded capacity requirements.

The cost comparison between the two options was as follows (dollars):

Item	*Option (a)*	*Option (c)*
Book value of existing machines		4 500
Machine acquisition and installation cost	18 000	
Machine modification cost	750	9 000
Total costs	18 750	13 500
Less: resale value of existing machines	5 500	
Net cost	13 250	13 500

Pure economic considerations indicated that option *(a)* would be more advantageous. The fact that the capacities of the machines under option *(a)* exceeded the expansion requirements by 60 per cent while those under option *(c)* gave a lower excess capacity of 35 per cent did not matter significantly, since both excess capacities were well above the required machine capacity.

Management then made an inquiry as to whether the capabilities of the machine shop personnel and the available machine shop facilities were adequate to do the conversion job on the routers without adversely affecting current production output. Their findings, together with the schedule of conversion work for the two routers, proved that the job could be done satisfactorily in the company's machine shop.

Management's decision

Considering all the available data and findings submitted by the evaluation committee, management decided to convert the routers to more automatic operations, option *(c)*. The slight ($250) advantage of option *(a)* was considered too small as compared with the knowledge to be gained by the company's personnel in automating their old machines.

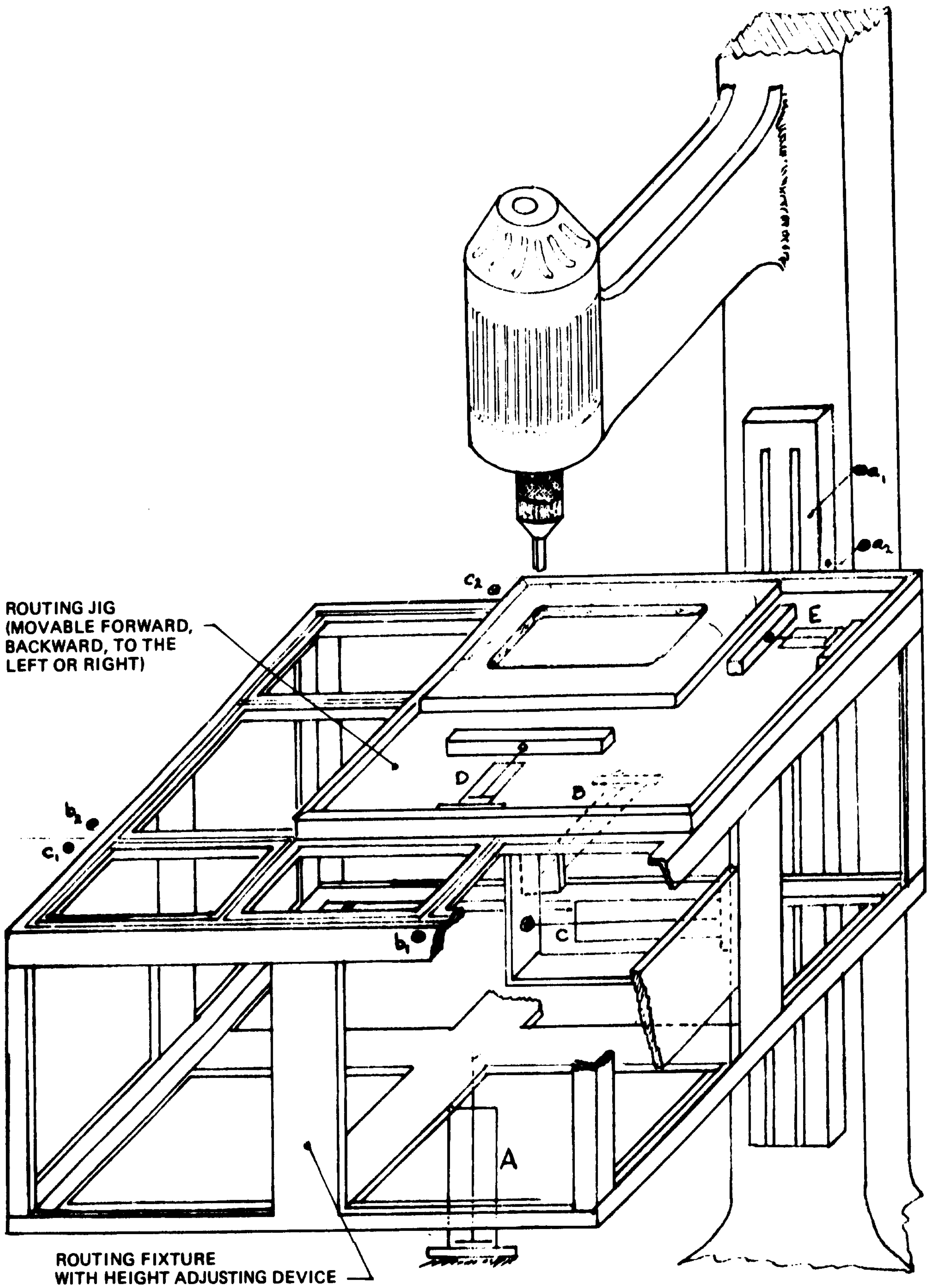
It will be noted that management did not even bother to determine whether the project cost would be within the maximum allowable investment levels simply because no additional factory space would be required by the routers.

The LCA system adopted for the conversion of the routers is illustrated in figures 114, 115 and 116.

B. The case of the special panel sander

Situation

A factory producing panel-based cabinets was having problems with the final sanding of the top panels. The daily rate of panel rejects owing to sanding through the veneer ("sand-through") had been averaging 6 per cent since the start of operations. However, the rate at times would go as high as 12 per cent. Six workers had already been trained and assigned to the sanding job, yet management felt that the 6 per cent average reject rate was becoming unbearable as a result of the increasing costs of materials and labour. The final sanding was done on a double-belt stroke sander, using first a 180-grit sanding belt, then a 240-grit belt.



NOTE: ⊗ MARKS APPROXIMATE LOCATIONS OF LIMIT SWITCHES

Figure 114. Automated heavy-duty router

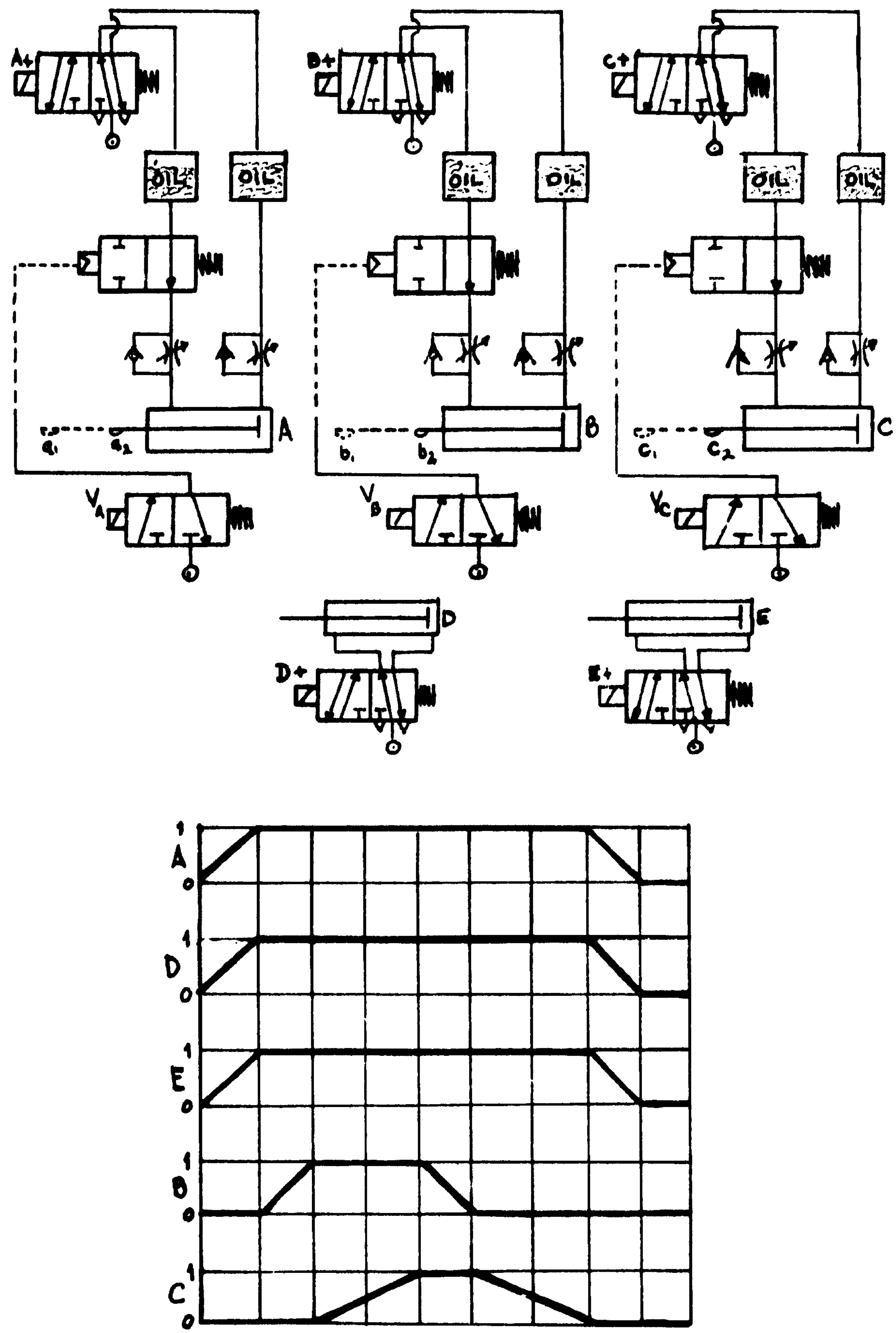


Figure 115. Pneumatic and time-motion diagrams for automated router

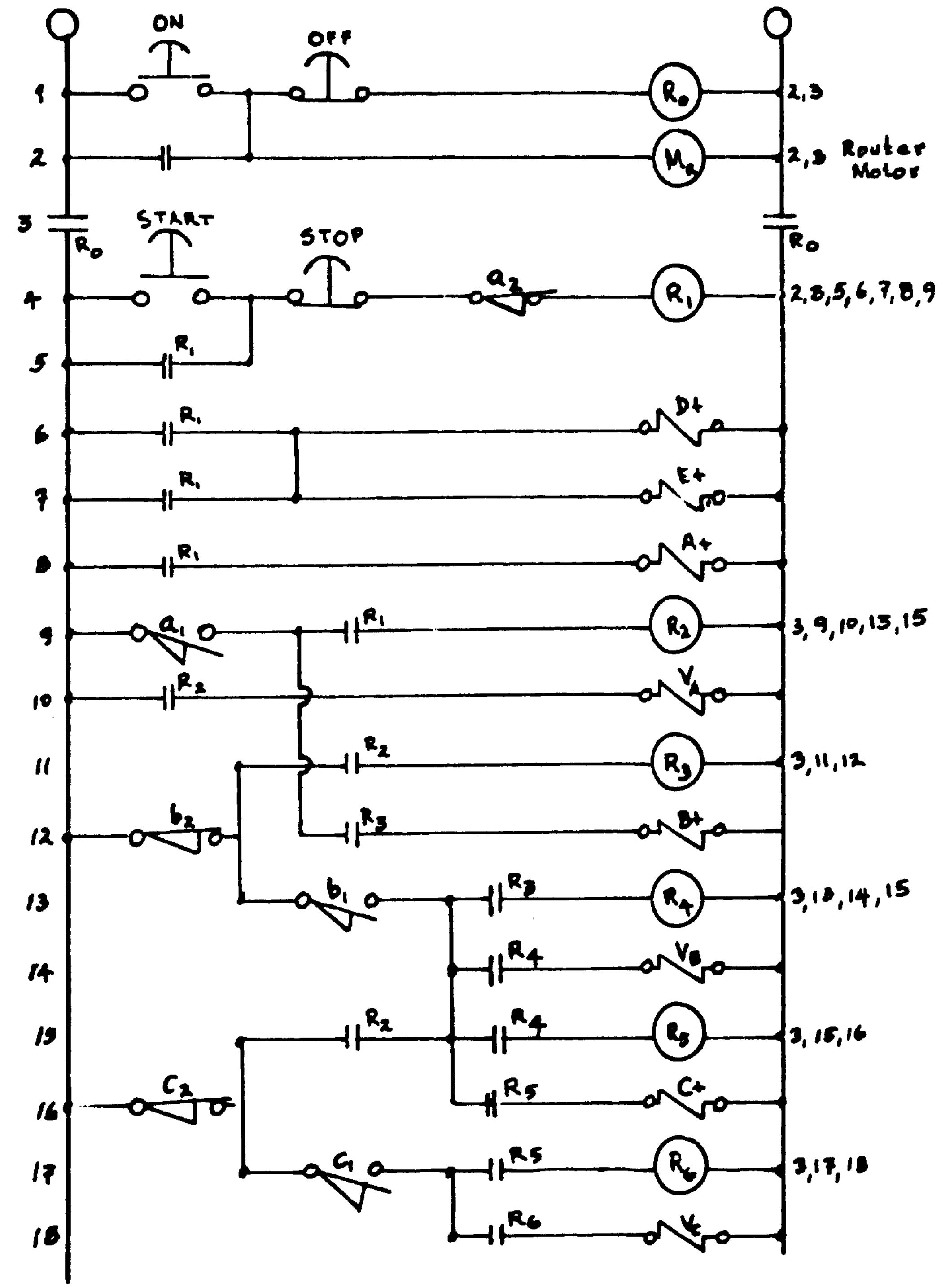


Figure 116. Electric circuit diagram for automated router

Problem

The problem was how to improve the final sanding operations, significantly reducing the reject rate, or possibly eliminating rejects entirely.

Analysis of the problem

The company loss as a result of veneer sand-through was calculated at $6,093 per year.

A performance check on the six workers who were assigned to the stroke sander showed no appreciable variation in their individual reject rate.

All the rejects were due to veneer sand-through on the edges of the panels.

The first sanding pass was tried with a 200-grit sanding belt, the second with a 280-grit belt. Production output dropped to 75 per cent of the standard for the operation, while the reject rate dropped to 4 per cent. This result was still unacceptable to management.

A thorough analysis of the stroke sanding operations indicated that 90 per cent of the rejects occurred during the following periods of the daily work cycle of the machine operators:

The first half-hour of the working day;
The half-hour after each break period;
The half-hour before the end of the work shift.

These findings indicated that:

(a) It took about half an hour for the worker to regain his skill in applying the correct pressure on the stroking pad after any rest period;

(b) Work fatigue at the last half-hour of the work-shift made the worker lose his "touch".

The industrial engineering department recommended the acquisition or fabrication of a panel-sanding machine that could apply uniform pressure of the sanding belt on the panel surface regardless of the machine operator's physical and mental readiness for work.

Options available

The following options were found available:

(a) Import, install and operate a double wide-belt sander, with feed mechanism and the necessary sanding-belt-pressure control at a total cost of $9,500;

(b) Design and fabricate the special sanding machine in the company's machine shop at a total cost of $9,750, operational;

(c) Design the machine in the company's engineering department, have it fabricated by a local machine shop and then installed by company personnel at a total cost of $9,500, operational.

Value analysis

Option *(a)* would take six months from the date of placing an order for the wide-belt sander to put it in operation, or an additional loss of $3,046, before the veneer sand-through problem was solved. The machine would also require an additional worker at its panel-discharge end. However, less skill would be required of the worker feeding the machine. The machine was expected to completely solve the sand-through problem. The sanding capacity would be increased by 300 per cent.

Both options *(b)* and *(c)* would take 60 days to put into operation and were expected to reduce the reject rate to below 1 per cent, and all the rejects would require only minor repair. Only one worker was required by the machine in the two options. Sanding capacity was expected to increase by 50 per cent. The skill level required of the machine operator was two levels below that of the present operator.

The cost comparison among the options was as follows (dollars):

Item	*Option (a)*	*Option (b)*	*Option (c)*
Costs (based on 5-year depreciations period)			
Machine acquisition and installation	9 500	9 750	9 300
Labour	6 200	3 100	3 100
Sanding belt	9 500	6 500	6 500
Power and air	4 500	2 700	2 700
Other maintenance supplies	3 200	2 850	2 850
Total cost 5 years	32 900	24 900	24 900

Item	Option (a)	Option (b)	Option (c)
Benefits			
Annual savings in repair and "dead cull" losses from rejects	6 093	5 077	5 077
Total value of savings in materials in 5 years	30 465	25 385	25 385

Pay-back period

To check whether the proposals complied with company policies requiring a pay-back period of not more than two years for such projects, the following pay-back periods were obtained:

Option	Pay-back period (months)
(a)	19
(b)	23
(c)	23

Maximum allowable investment for the project

The maximum allowable investment for the project was calculated from the formula in chapter III, section A, using the following values for the variables: i = 14 per cent per annum, n = 5 years, N = 310 working days per year times 8 hours per day = 2,480 hours per year, Q_1 = 23 panels per hour, Q_2 = 25 panels per hour, m = \$0.30 per hour, w = \$0.30 per hour, p = 35 per cent, V_1 = \$0.97 per hour and V_2 = \$0.83 per hour. The result was I = \$17,000.

The actual net investment was the project cost less the resale value of the stroke sander, which was (dollars):

Option			
(a)	9 500	4 800	4 700
(b)	9 750	4 800	4 950
(c)	9 300	4 800	4 500

Hence, all three options were well within the maximum amount of investment allowable for the project.

Management's decision

In reply to management's inquiry on current regulations governing the opening of letters of credit for importing machinery, the Central Bank informed the company that a deposit of 50 per cent of the face value of letters of credit was required. The cost of money to the company was about 20 per cent per annum. Hence, in spite of the apparent economic advantage of option *(a)*, as shown in the preceding sections, the actual project cost for that option would be increased by the money the company could make on the amount deposited for opening the letter of credit if the amount deposited were available for the company's disposal for the six-month period, which would be about \$475. Hence, the actual investment in option *(a)* would be \$9,975. Thus, management narrowed down the choice to options *(b)* or *(c)*. The difference in project cost was \$450 in favour of option *(c)*. However, management felt that this was a small amount if weighed against the opportunity for the company's engineering personnel to learn how to automate machines in the factory. Thus, management decided to implement option *(b)*.

Figures 117 and 118 illustrate the LCA solution under option *(b)*.

C. The case of the filling line crew

Situation

The filling line of the finishing department of a panel-based furniture factory was manned by eight men, including the filler sprayer. The output was 120 panels per eight hours with an acceptable filling job. Management insisted that the filling line could be manned by at most five workers, including the filler sprayer, if some method could be developed to speed up the filler-padding phase of the operation. The engineering department was directed to solve the problem immediately.

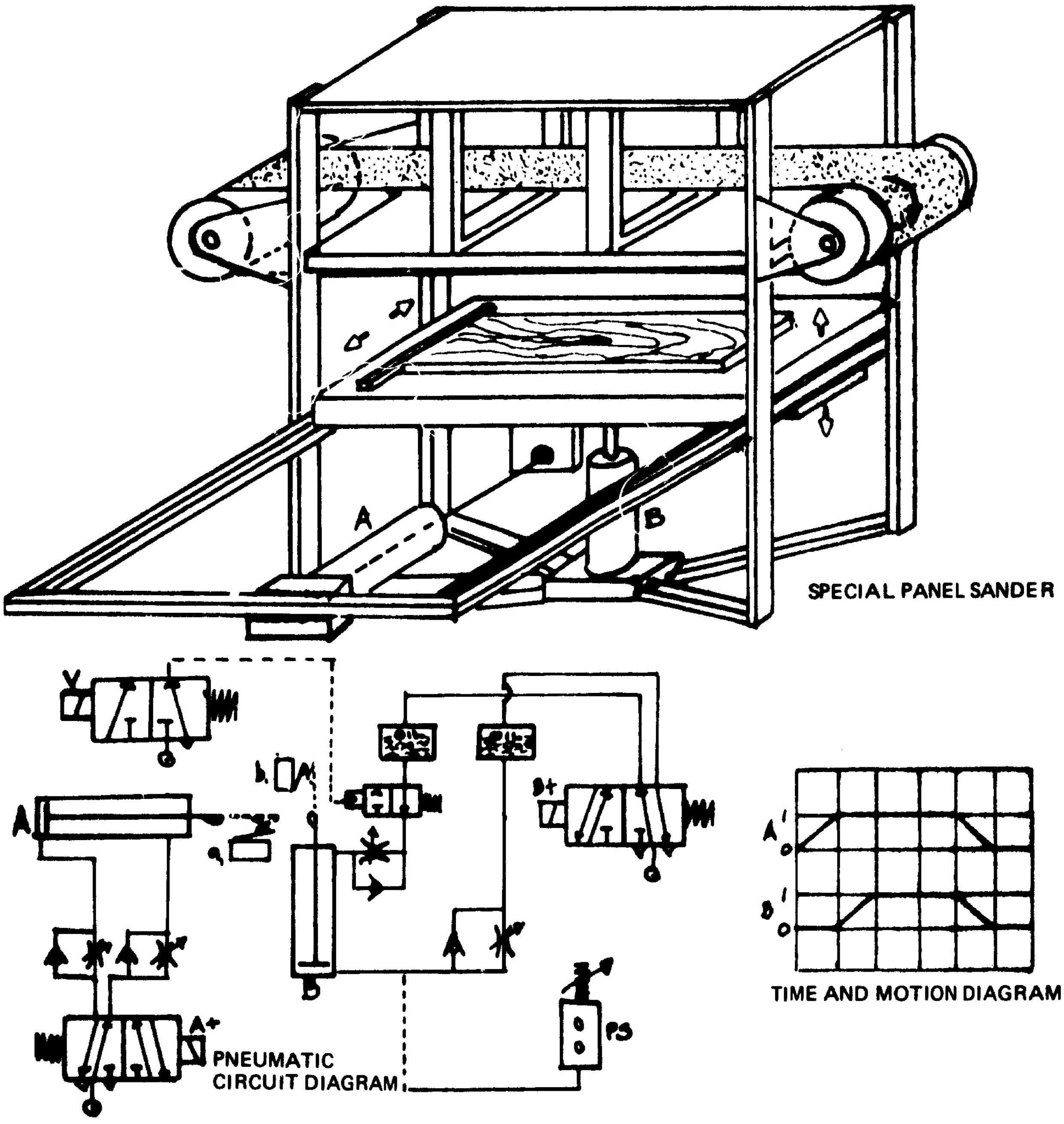


Figure 117. LCA solution to sanding problem and corresponding time-motion diagram

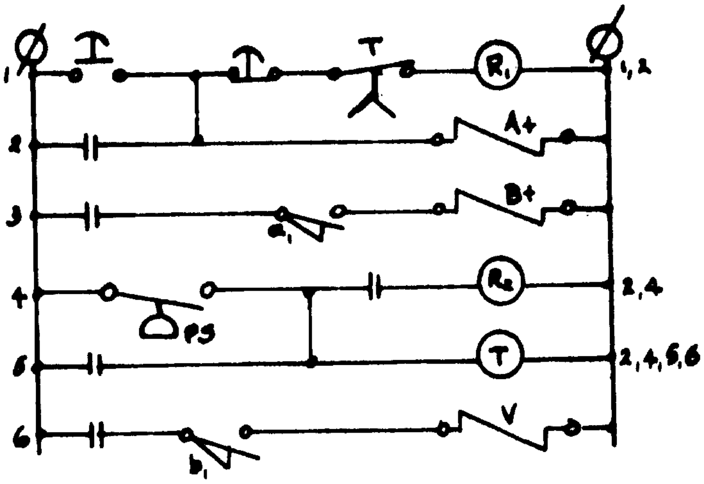


Figure 118. Electric circuit diagram of special panel sander

The filling operation was as follows:

(a) Spray filler mixture on panel surfaces and edges, 1 worker needed;

(b) Permit filler to flash off, no workers needed;

(c) Massage or pad filler by hand, three workers;

(d) Wipe excess filler off the filled panel, 2 workers;

(e) Inspect filled panels and repair or touch-up when necessary, 2 workers.

Problem

The problem was to determine the bottle-neck in the filling line and to find means of eliminating it.

Technical analysis of the problem

The industrial engineering section conducted a time-and-motion study of the line operations and found the areas of low output to be rubbing the filler down and wiping off the excess filler.

Experiments showed that the most effective pore-filling action was given by the combined padding and shearing motion of a medium-hard felt pad material over the wooden surface to be filled. The shearing action generated by passing the workers' palms in a circular motion across the panel surface was not enough to push the filler pigments deeper into the pores of the panel surface. Consequently, the panel surface was loaded with excess filler, which became hard to wipe off the surface once the filler started to set. In their efforts to clean the panel surface properly, the filler wipers unintentionally dislodged some of the filler particles out of the filled pores. Thus, about 40 per cent of the panels had to be sent back to the filler sprayer to be done all over again.

Options available

Two options were found to be available:

(a) Import a rotary filler-padding machine at a cost of $450, installed and operational. This option was expected to reduce the filling line crew to 5 workers and increase the filling output by 30 per cent;

(b) Fabricate a portable, air-operated rotary filler-padding device at a cost of $480, installed and operational. This option was also expected to reduce the filling line crew to 5 workers and increase the output by 25 per cent.

Value analysis

The imported rotary filler-padding machine could be operational 6 months from the date of order, while the locally made machine could be put in operation within 60 days. The difference in cost was only $30. Management could not wait for 6 months to save $30. Instructions were given to the engineering department to proceed with the design and fabrication of the rotary filler-padding machine.

Maximum allowable investment for the project

For the record, the engineering department went ahead with the calculations for the economic justification of the proposed machine. The maximum allowable investment I for the project was calculated from the formula in chapter III, section A, using the following values for the variables: i = 14 per cent per annum, n = 3 years, N = 310 days per year times 8 hours per day = 2,480 hours per year, Q_1 = 15 panels per hour, Q_2 = 18.5 panels per hour, m = 0, since no machne was being used, w = \$0.30 per hour, the average direct hourly wages of the filling line crew, p = 35 per cent, V_1 = \$0.18 per hour, and V_2 = \$0.26 per hour. The result was I = \$4,130.

The estimated project cost of \$480 was well below the maximum allowable investment for the project.

Pay-back period

Again, for the record, the pay-back period was determined as follows (dollars):

Costs (3 years)	*Present*	*Proposed*
Machine, installed and operational		480
Direct labour	2 332	1 395
Power and air	840	970
Supplies and spare parts		220
Administrative	1 166	698
Total	4 338	3 763

Net savings 4 338 − 3 763 = 575 in 3 years, or 191.67 per year

$$\text{Pay-back period} \frac{480.00}{191.67} = 2.5 \text{ years}$$

Management's decision

Management gave more weight to the small investment involved and waived the company policy setting two years as the maximum pay-back period for this particular project. It further confirmed its initial decision to go ahead with the fabrication of the rotary filler-padding machine. Figure 119 shows the design of the padding machine and the pneumatic circuit involved.

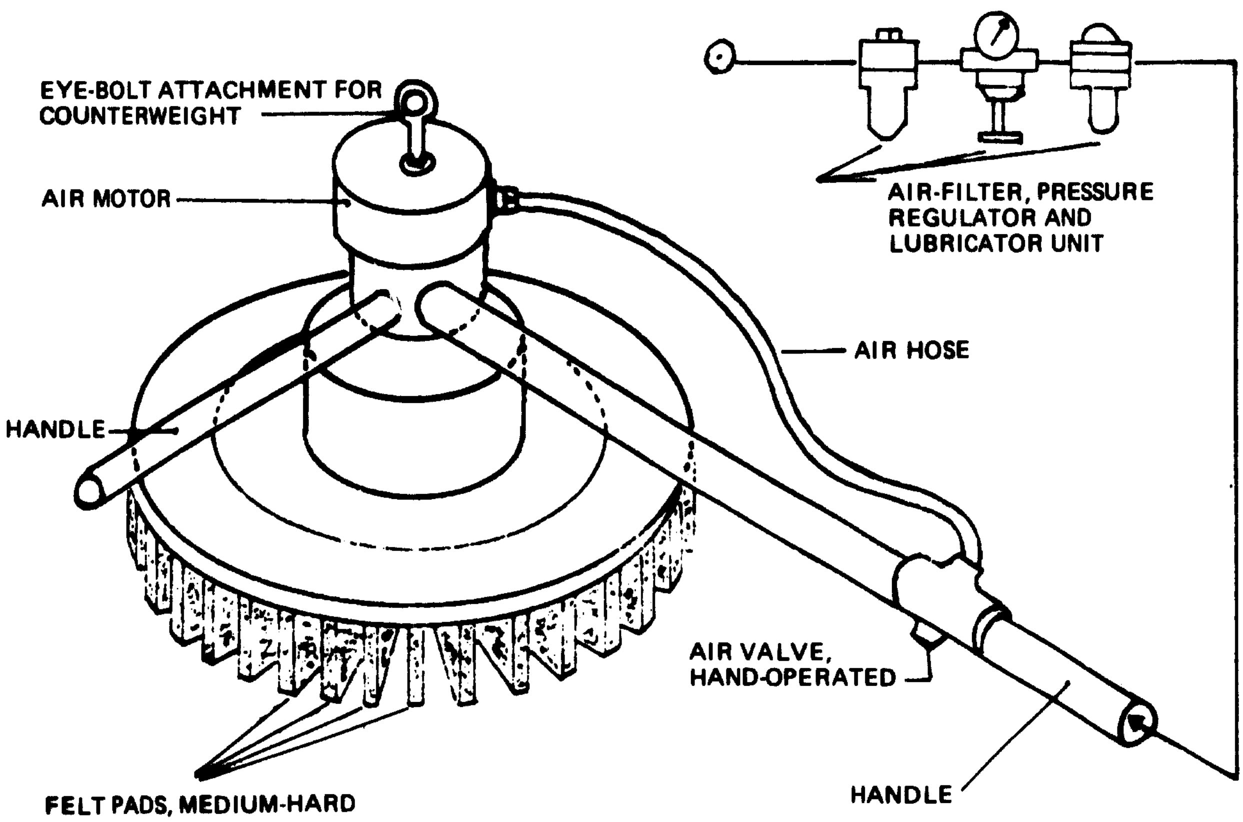


Figure 119. Rotary filler padding machine

IX. Examples of low-cost automation applications

In this chapter, other examples of LCA applications are 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 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 bar, one can readily inject compressed air (normally at 10 bar) 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 tyre-valve fitting.

An example is the clamping frame in figure 120, 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.

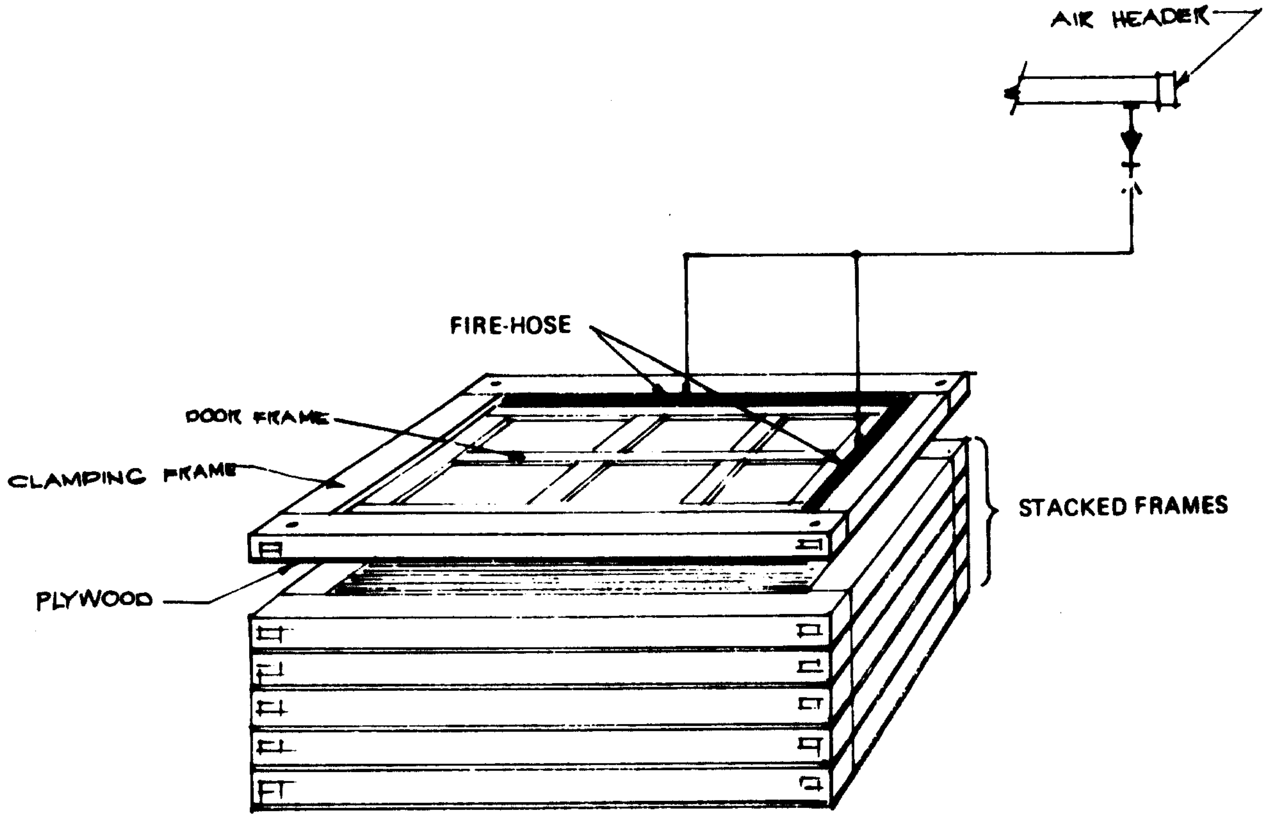


Figure 120. Fire-hose clamp

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	$ 85
Fire-hose (scrap)	—
Fittings	50
Total	$135

Conditions before LCA

Labour cost	$0.10 per frame
Capacity	16 frames/day

Conditions after LCA

Labour cost	$0.08 per frame
Capacity	21 frames/day

Benefits

Savings in labour cost $0.02 per frame
Investment recovered after producing 6,750 frames (12.4 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 121. When the "on" button is depressed, the fire-hose is inflated. When enough presure 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 $113.

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 122 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 workers. The following data pertain to a factory producing window frames.

Investment cost

LCA components	$291
Jigs	225
Fire-hose (scrap)	—
Total	$516

Conditions before LCA

Labour cost	$0.06 per frame
Capacity	21 frames/day

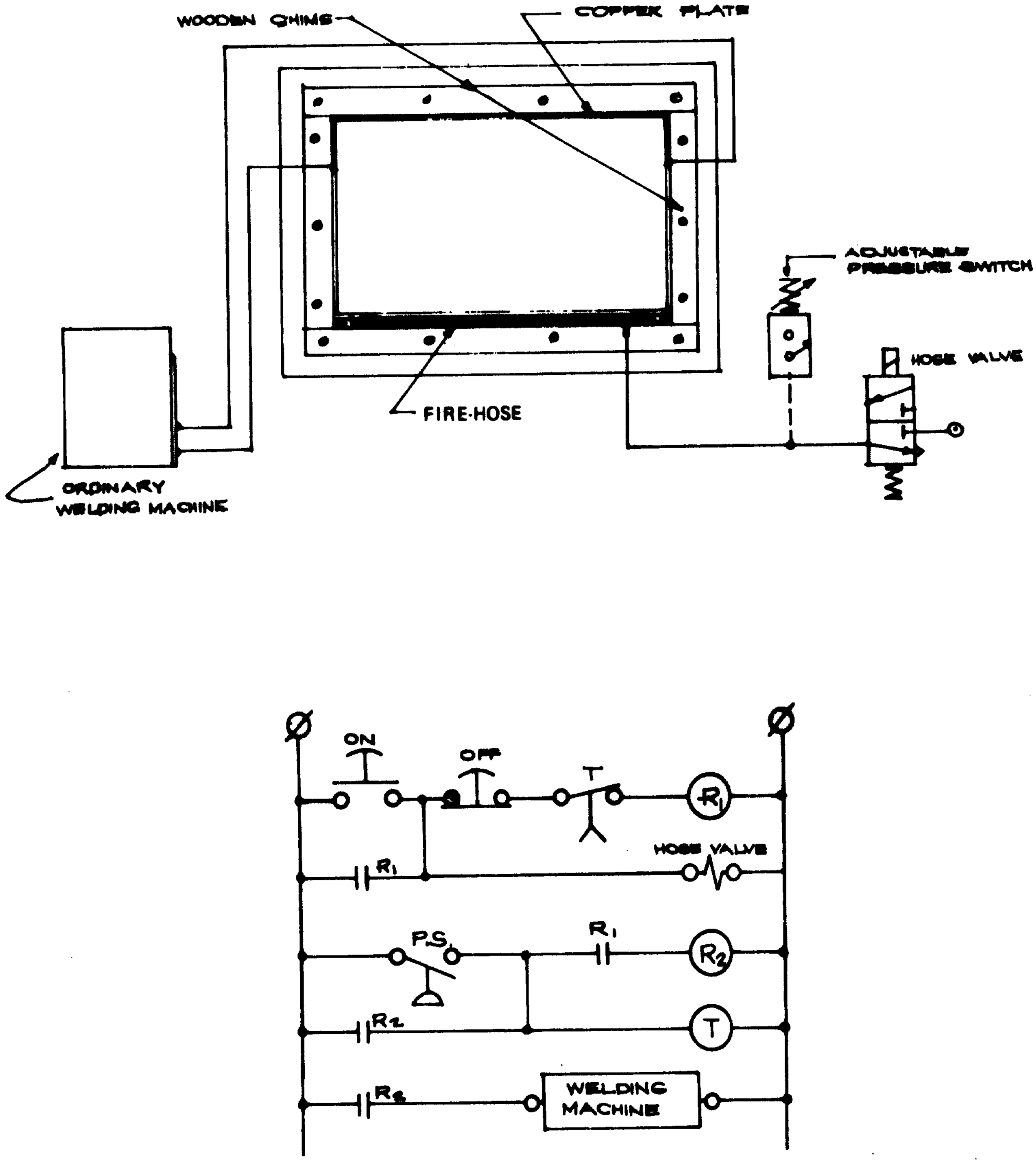


Figure 121. Fire-hose edge binder

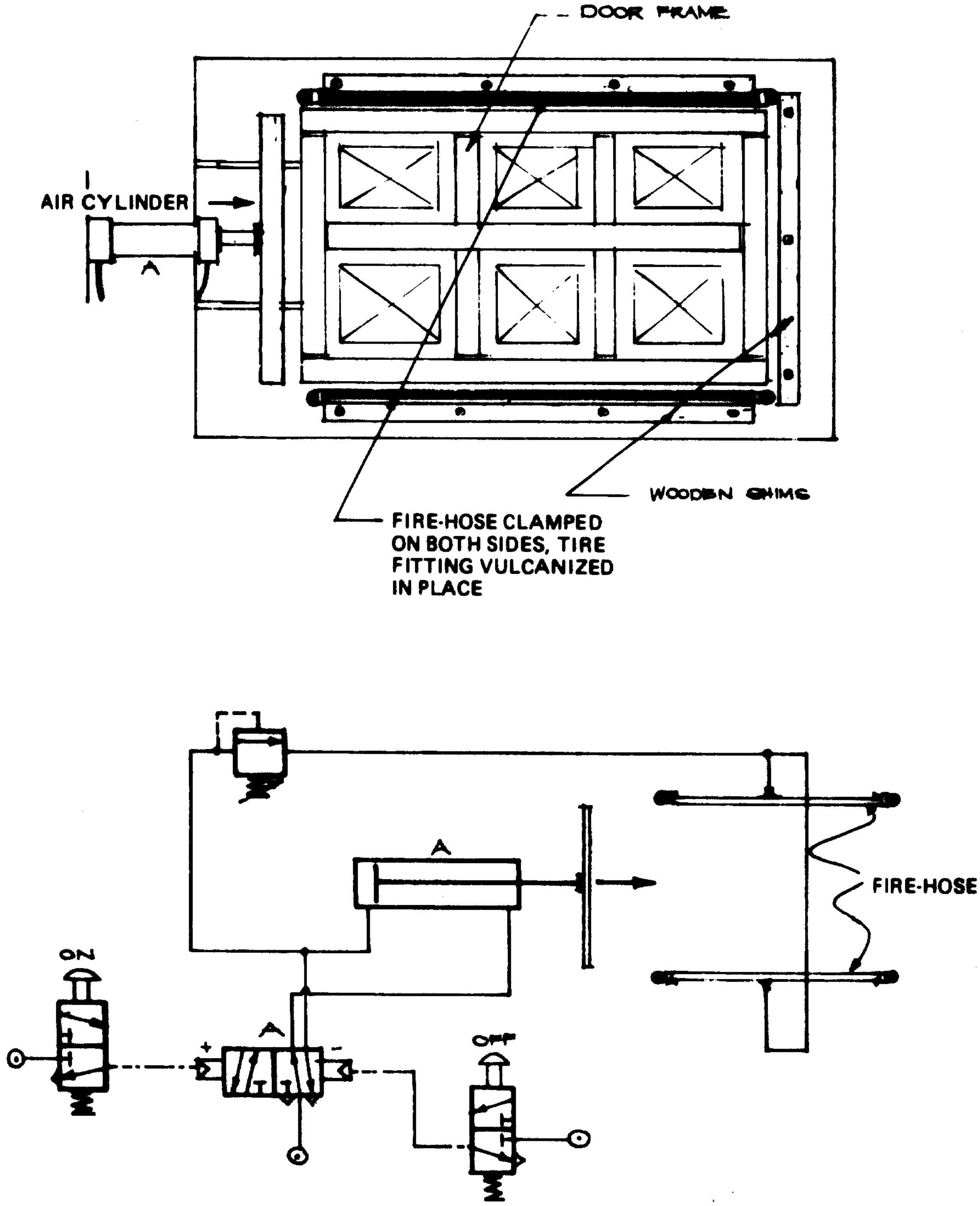


Figure 122. Door-frame assembler

Conditions after LCA

Labour cost	$0.0107 per frame
Capacity	104 frames/day

Benefits

Savings in labour cost $0.0493 per frame
Investment recovered in four months
Quality improved

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 loading into such guns. In the absence of available standard pneumatic nailers, the system shown in figure 123 is suggested when the need is for nailing equiping 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 $1,025, of which $550 is for the LCA components and $475 for jigs, fixtures etc.

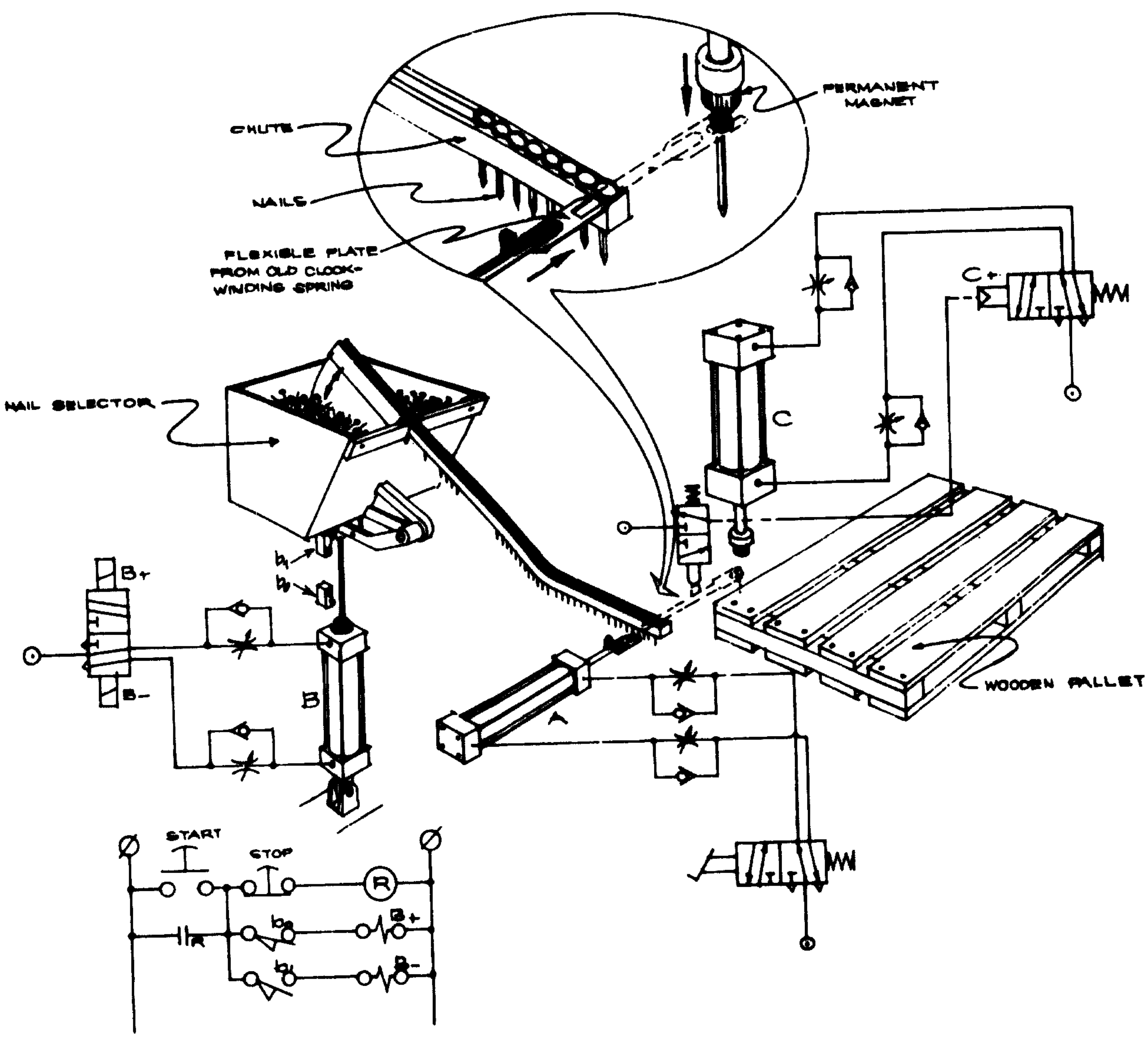


Figure 123. Pneumatic spike driver

E. Pneumatic impact riveter

By making use of an impact cylinder, tremendous instantaneous forces can be achieved. For example, a 4-in. (10 cm) impact cylinder supplied with air at 7 bar pressure can deliver a force of approximately 2 t. Impact cylinders may be used for riveting purposes and for the insertion of metal connector plates.

The set-up in figure 124 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.

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

Investment cost

The set-up costs approximately $635.

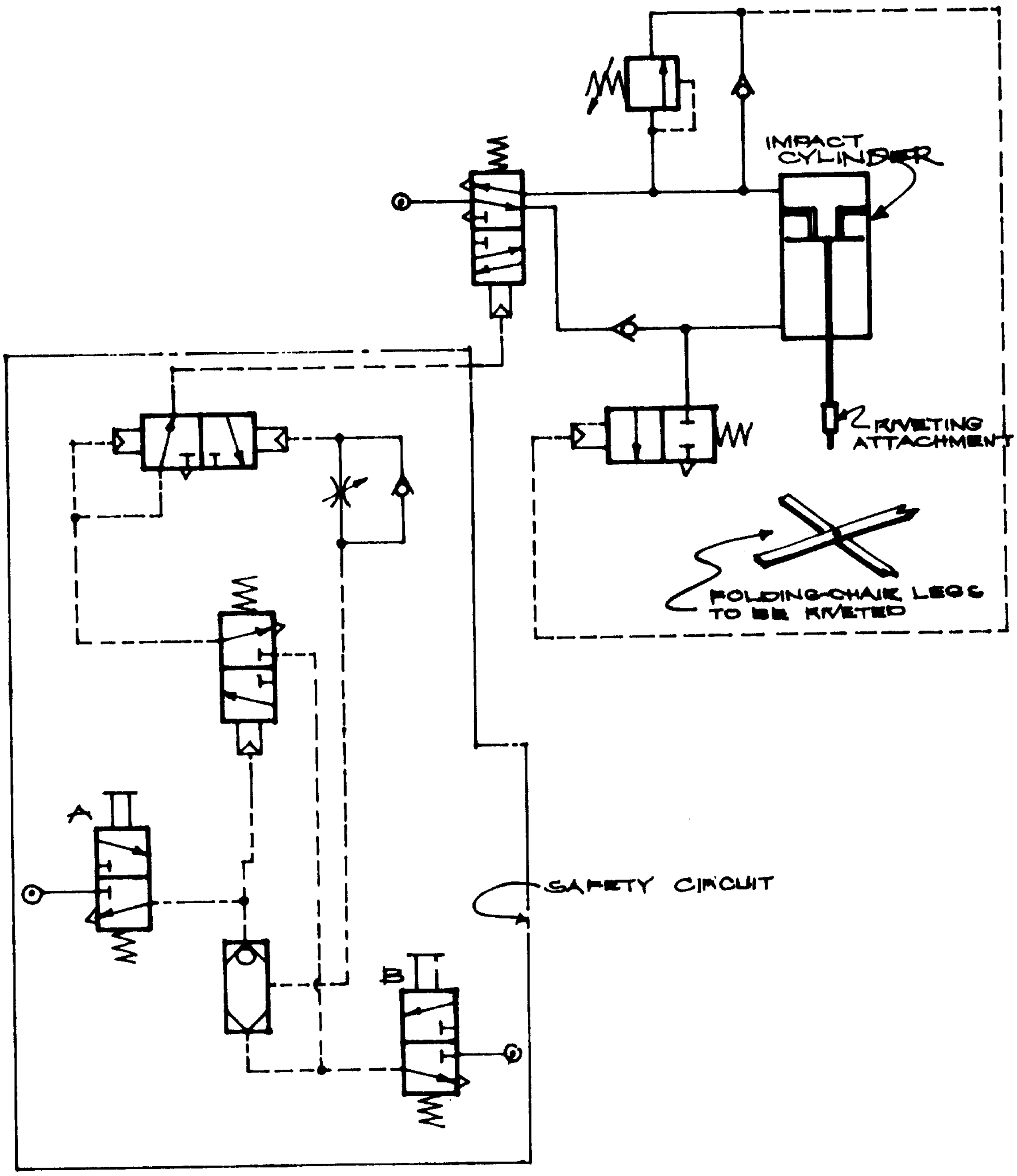


Figure 124. Pneumatic impact riveter

Conditions before LCA

Capacity	120 chairs/day
Labour cost (two workers one to position rivet, the other to set it	$0.0375 per chair

Conditions after LCA

Capacity	600 chairs/day
Labour cost (two workers as before)	$0.009 per chair
Power cost	$0.012 per chair

Benefits

Savings $0.0165 per chair
Investment recovered in 11 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 125, 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	$636
Components and fixtures made in the shop	175
Total	$811

Conditions before LCA

Number of operators	2 (one feeds, the other stacks machined lumber)
Total wages	$4.50 per day
Fixed cost of machine	$250 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	$2.50 per day
Savings by improved machine utilization	$100.00 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 126a 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 126b shows how the clamp also was converted to pneumatic operation. It can be seen from the diagrams in figure 126c 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.

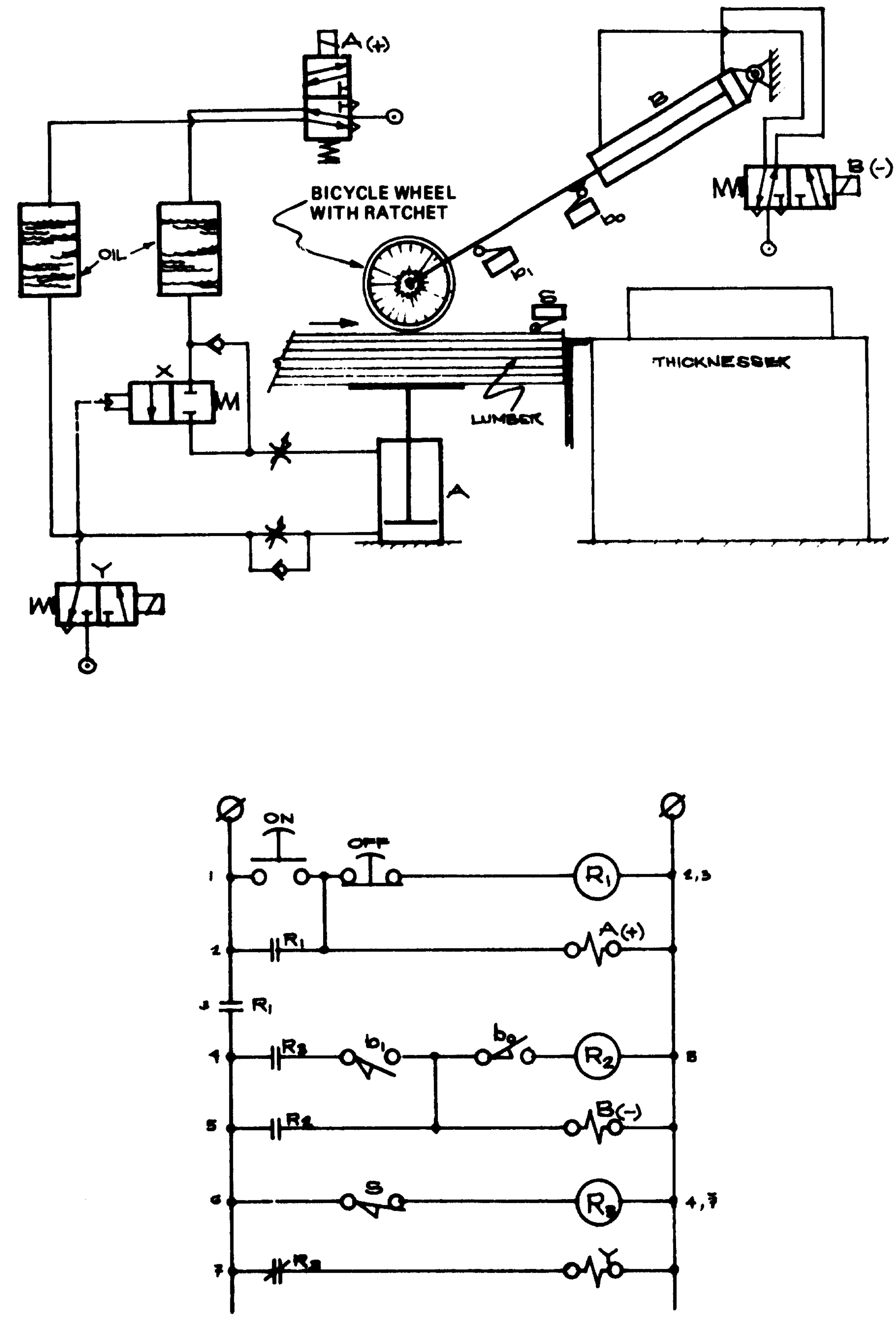


Figure 125. Thicknesser feeding mechanism

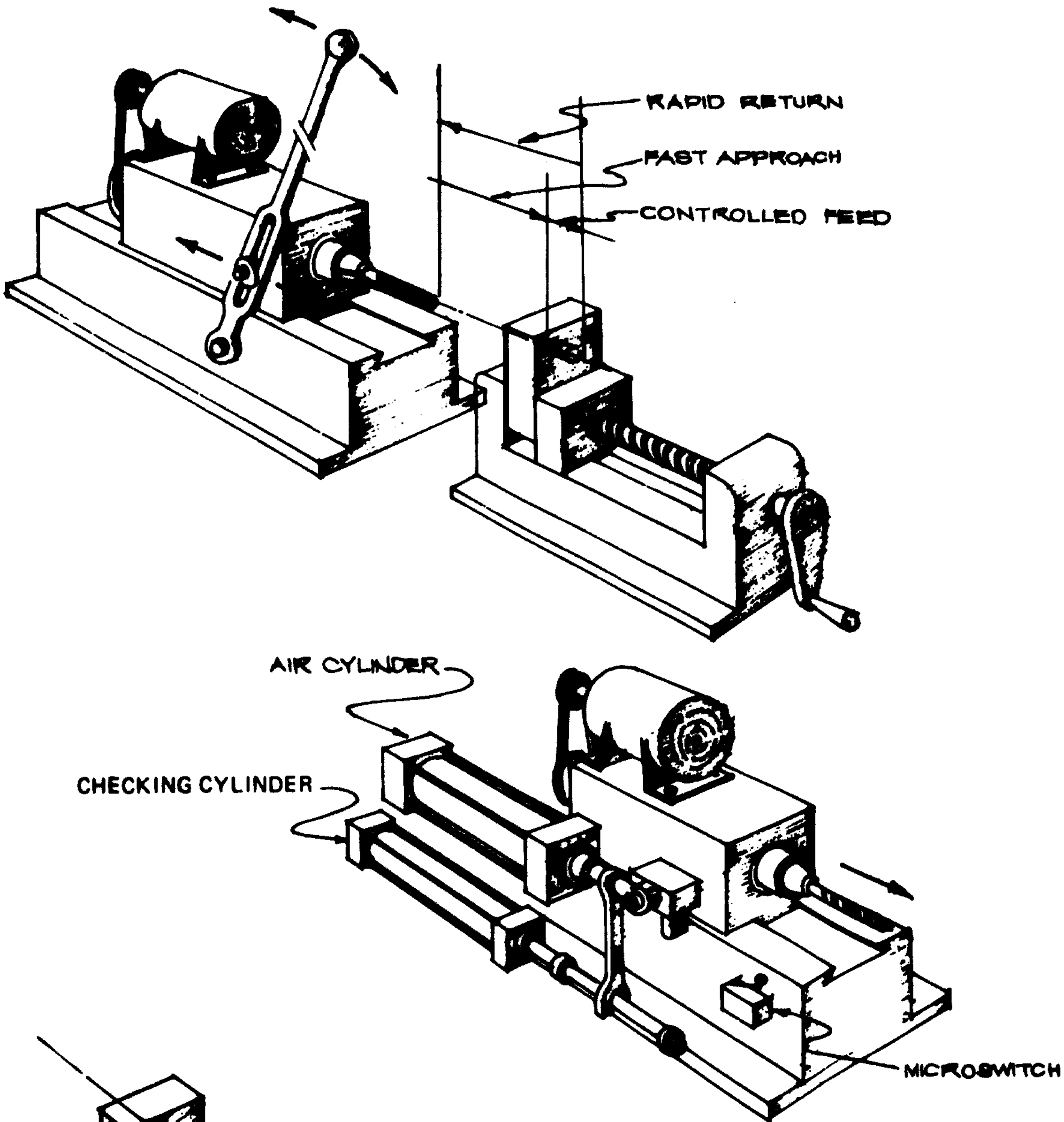


Figure 126a. Automated drill set-up: comparison with original set-up

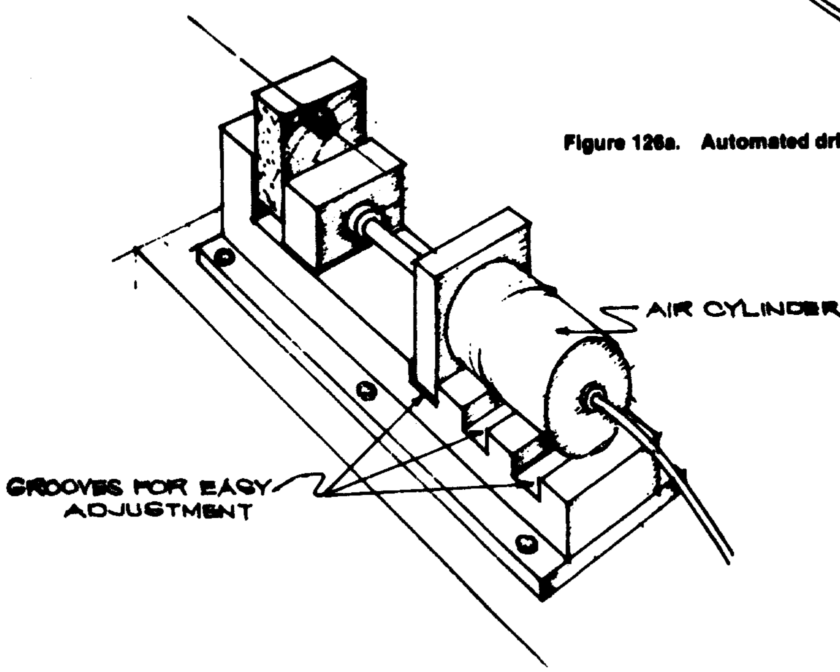


Figure 126b. Automated drill set-up: pneumatic clamp

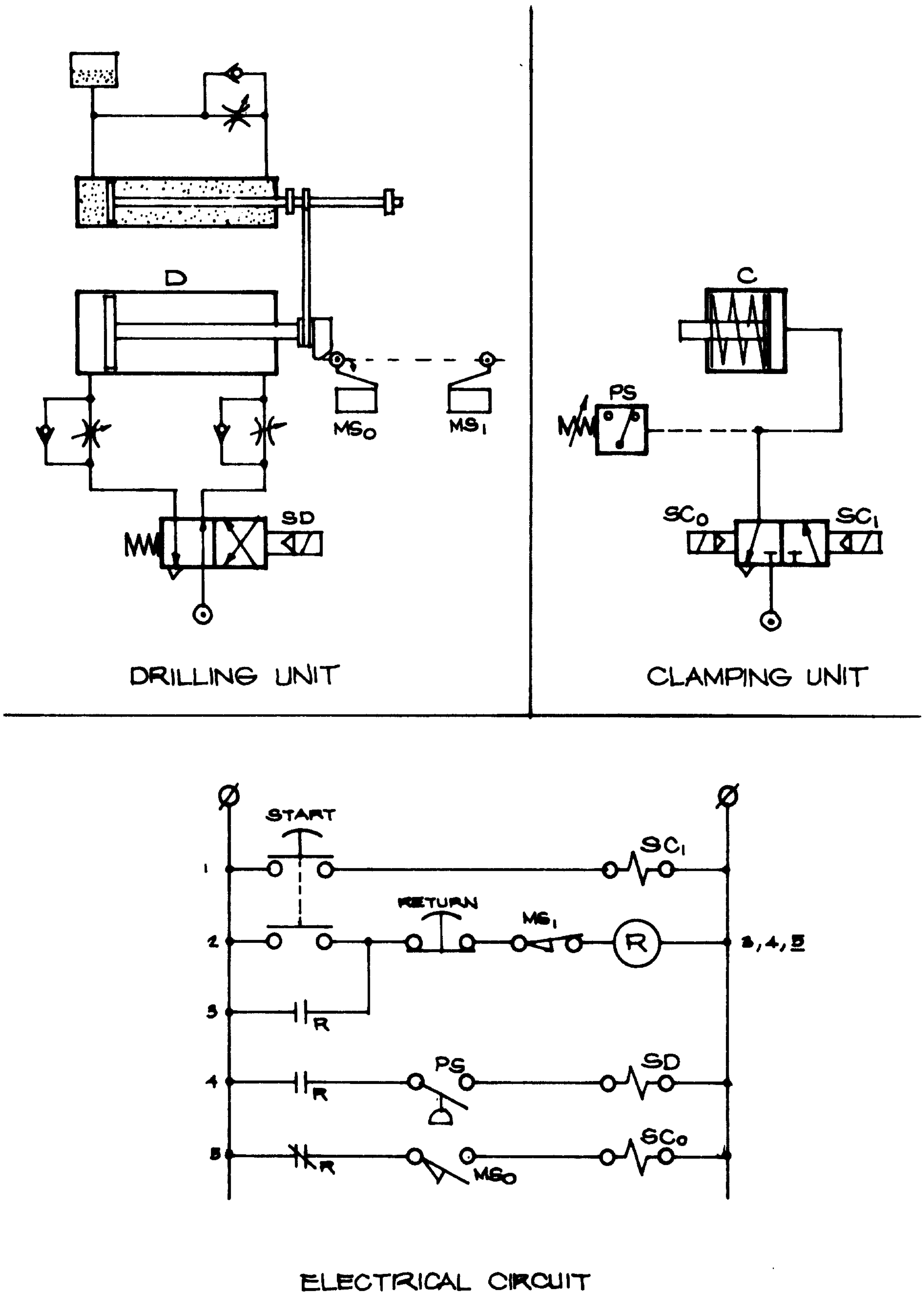


Figure 126c. Automated drill set-up: pneumatic and electrical circuit diagrams

Investment cost

The approximate cost of the attachments is $500.

Benefits

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

H. Automated drill press

Figure 127a shows another ordinary drill press which was equipped with an air cylinder and an oil checking cylinder. The circuit diagram in figure 127b 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 $400.

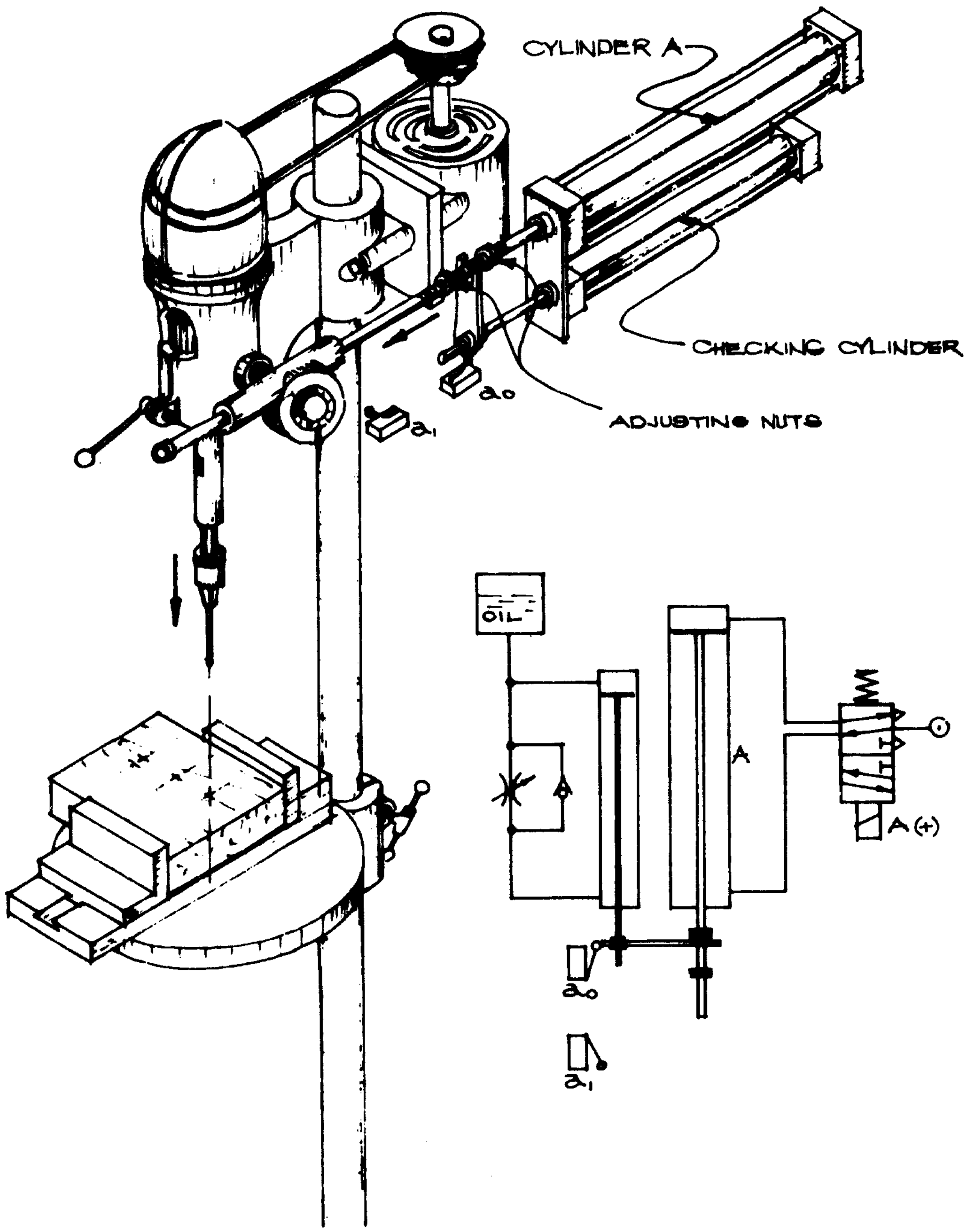


Figure 127a. Automated drill press: pictorial diagram and pneumatic circuit

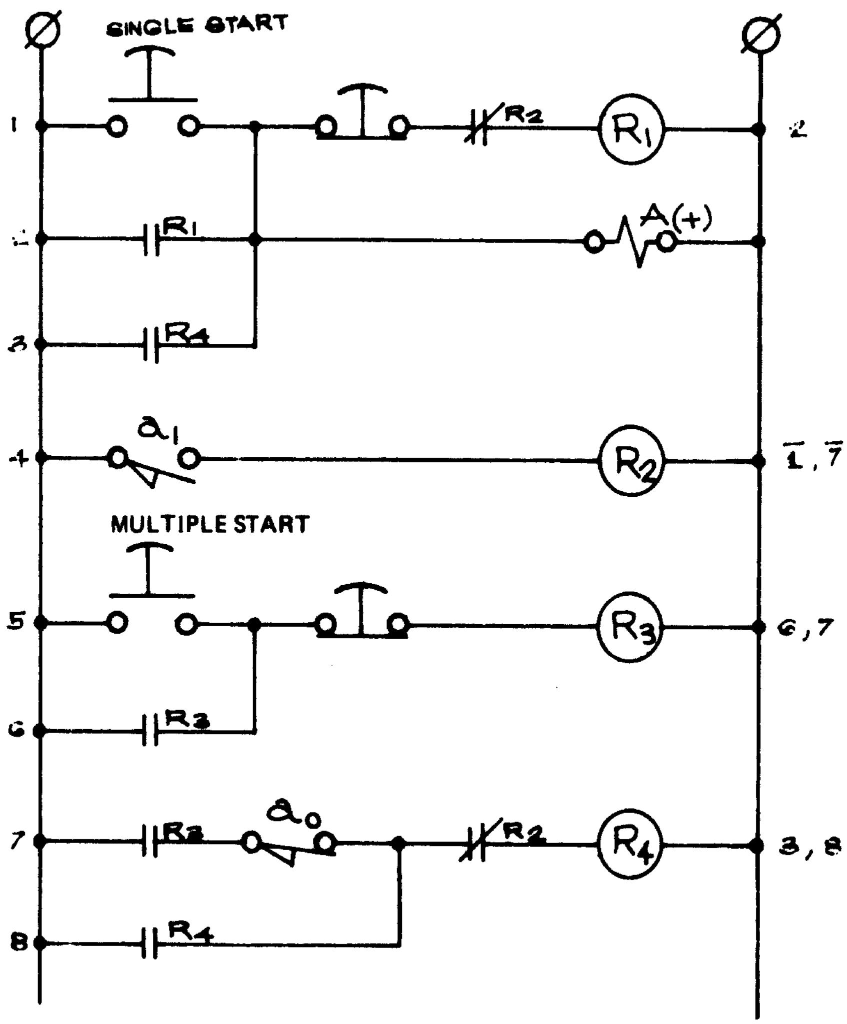


Figure 127b. Automated drill press: electrical circuit diagram

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.

I. Door-lock mortiser

The automatic door-lock mortiser shown in figures 128a and 128b 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.

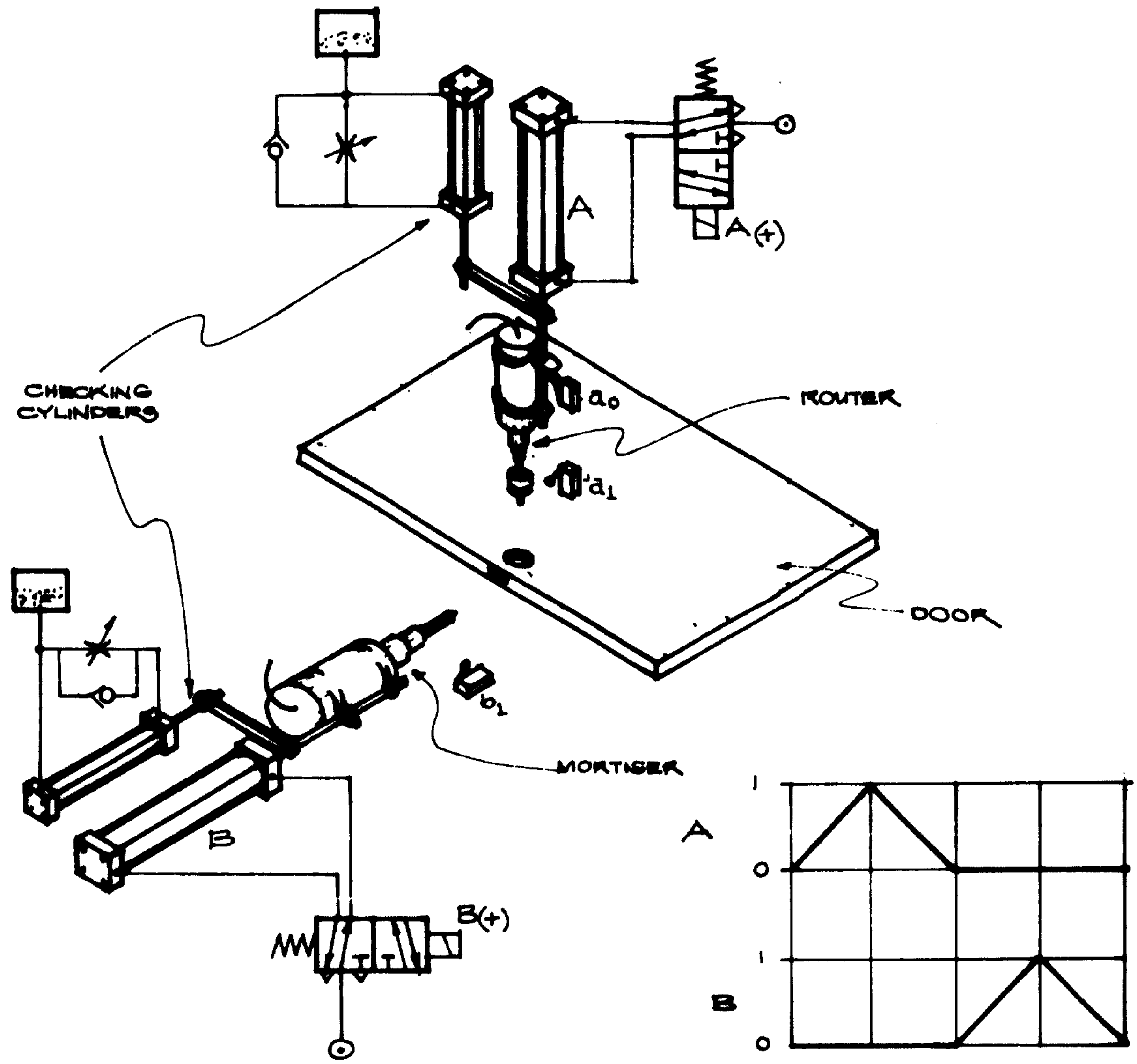


Figure 128a. Door-lock mortiser: pictorial and time-motion diagram

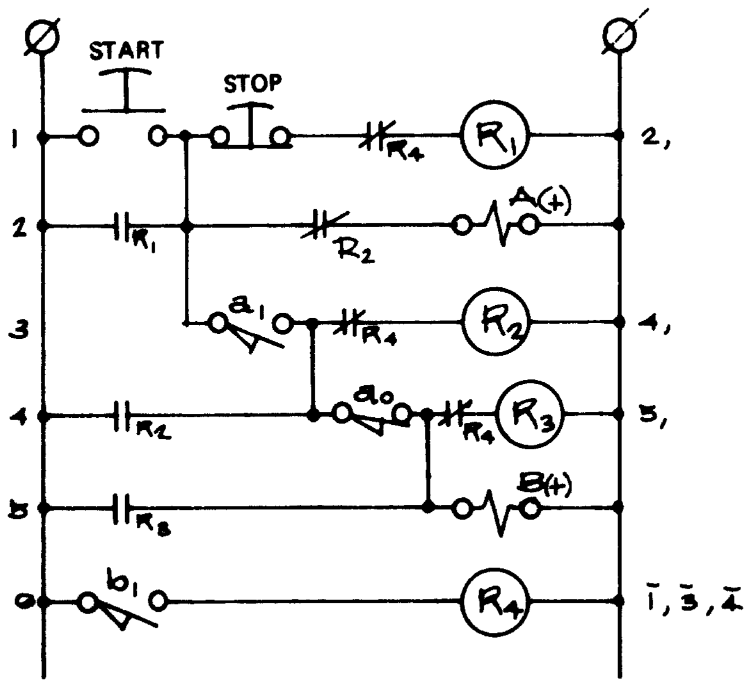


Figure 128b. Door-lock mortiser: electrical circuit diagram

Investment cost

Approximate cost of the components is $760.

Benefits

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

J. 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 129a to 129c 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 $2,165.

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.

K. Radio-TV cabinet slotter

Figures 130a to 130c 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 $2,600.

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 $8,250 per year. More important, less-skilled personnel could now be hired to do the operation

L. 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 131a and 131b 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.

Investment cost

The pneumatic components cost $485, the old roller conveyors, nothing.

Benefits

Wood selection became 200 per cent faster and more reliable.

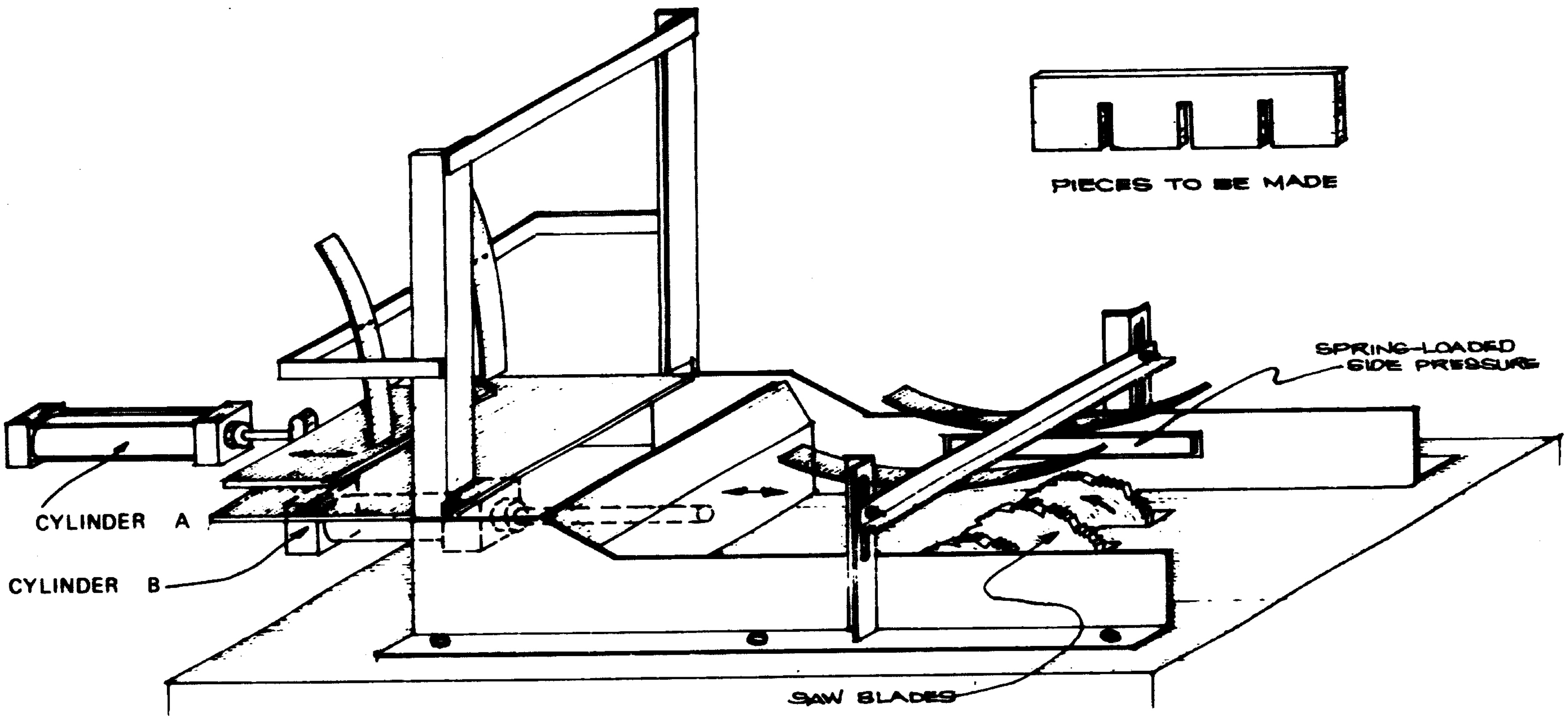


Figure 129a. Beverage-case partition slotter: general view

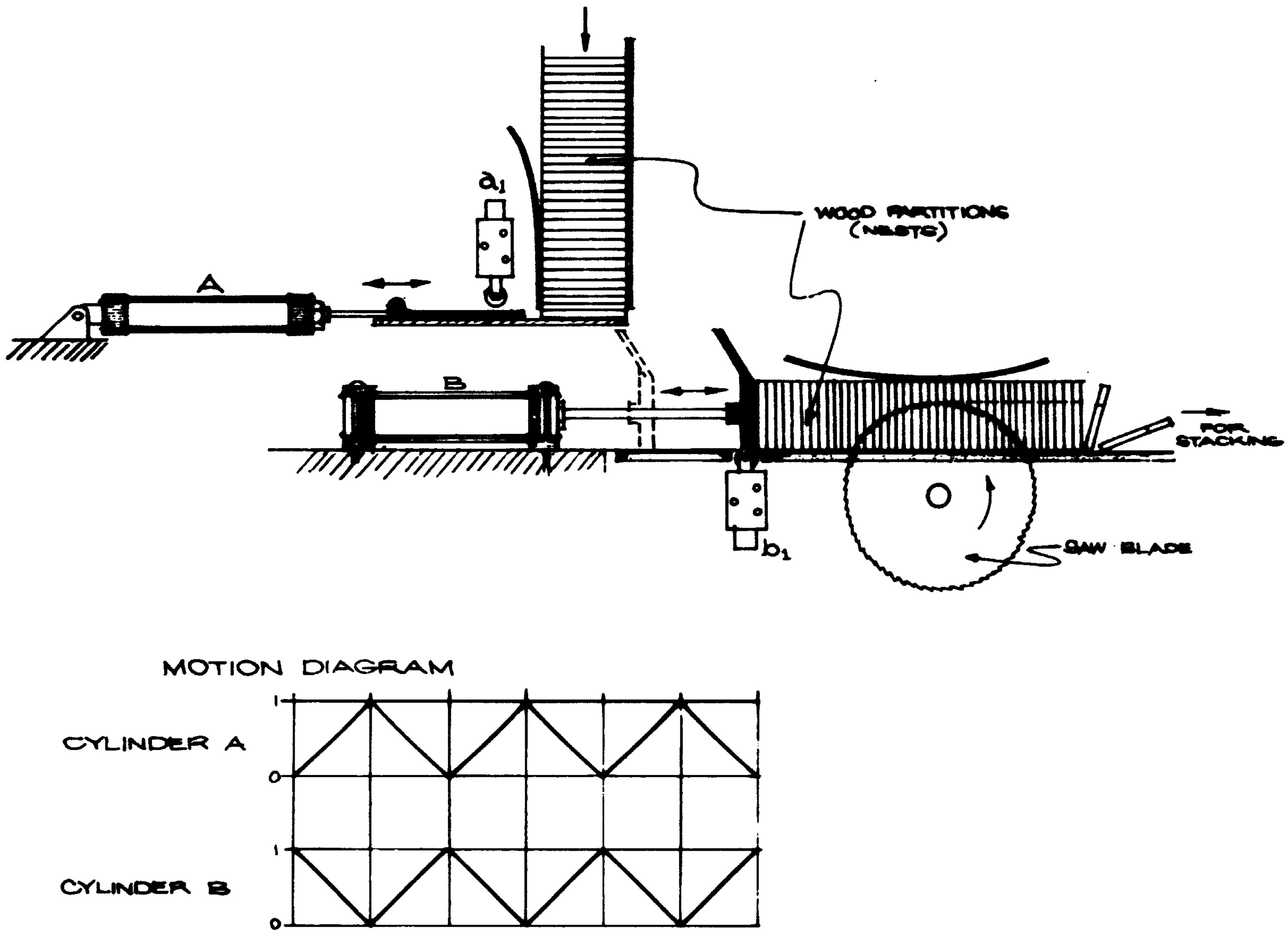


Figure 129b. Beverage-case partition slotter: side view and time-motion diagram

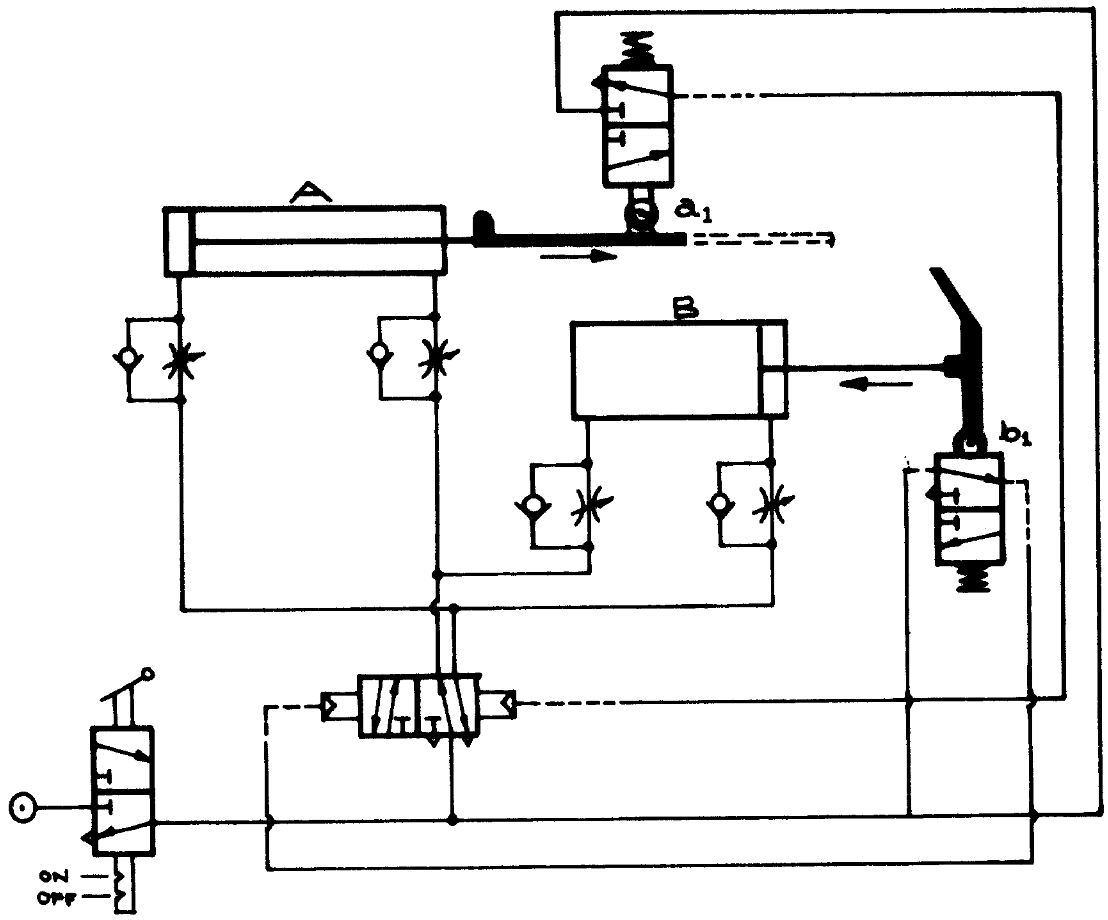


Figure 129c. Beverage-case partition slotter: pneumatic circuit diagram

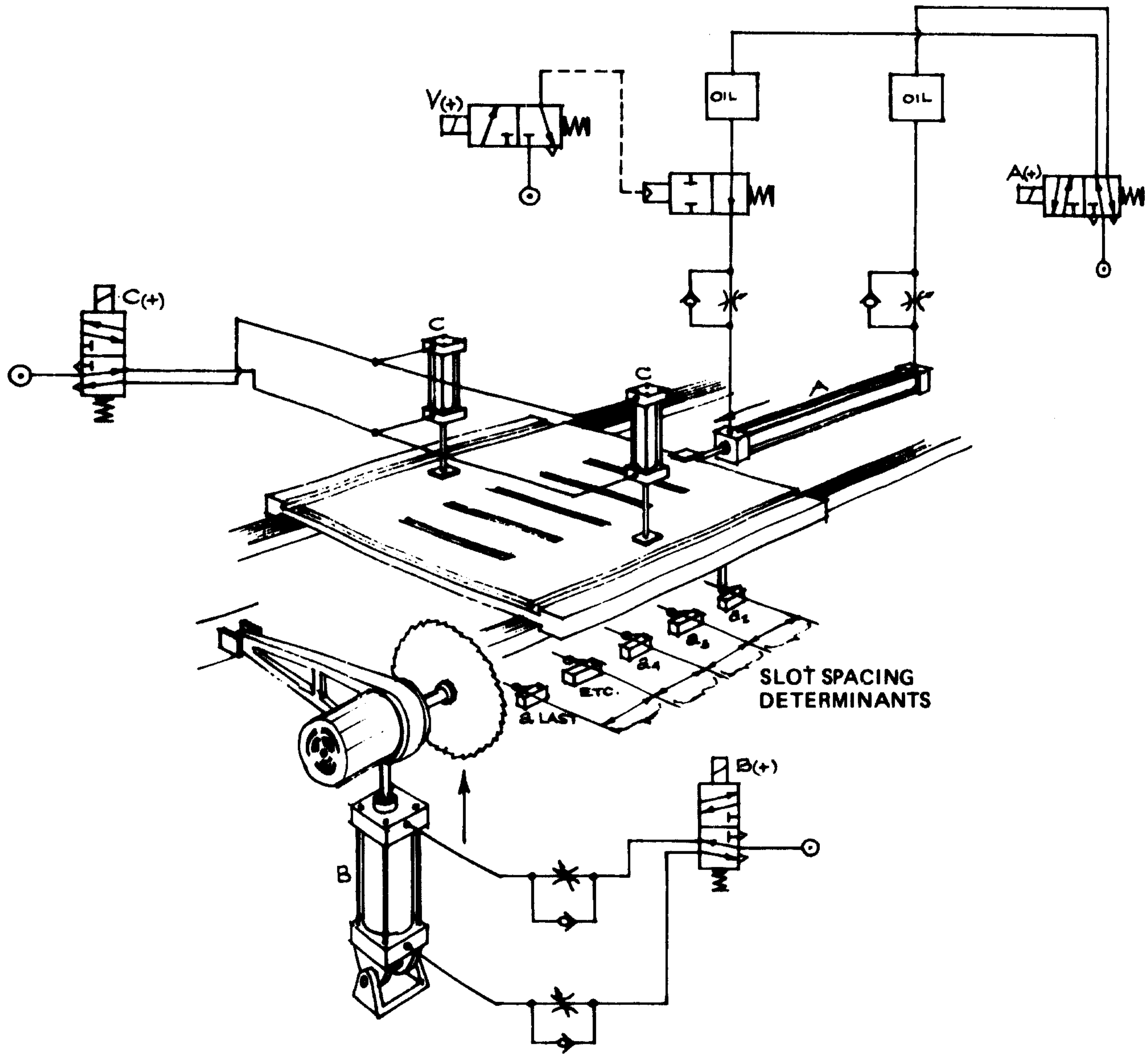


Figure 130a. Radio-TV cabinet slotter: pictorial diagram

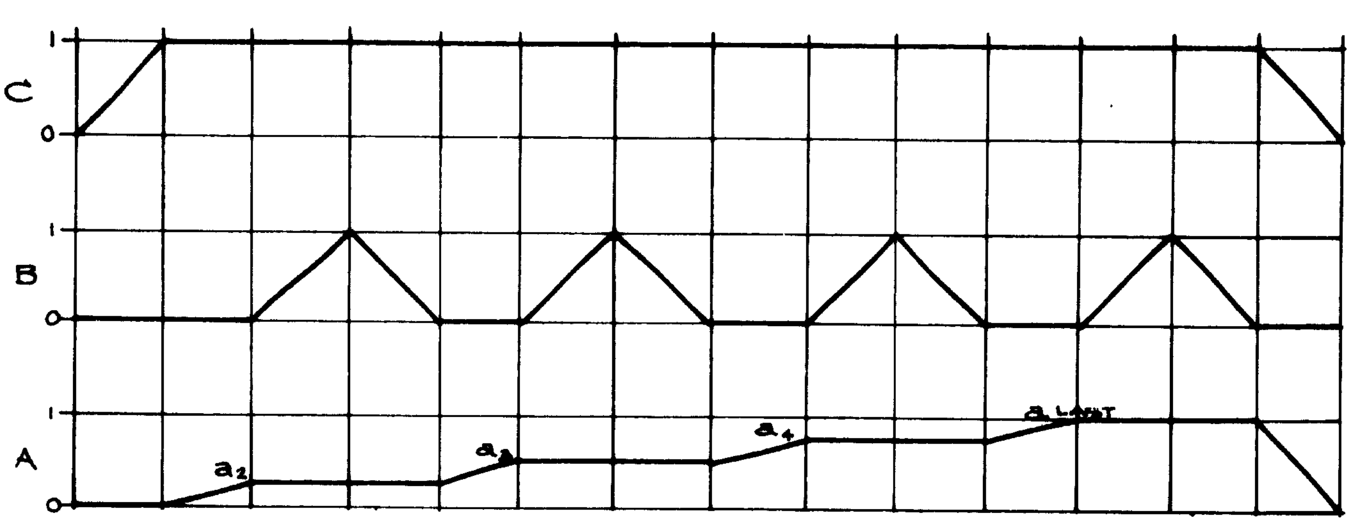


Figure 130b. Radio-TV cabinet slotter: time-motion diagram

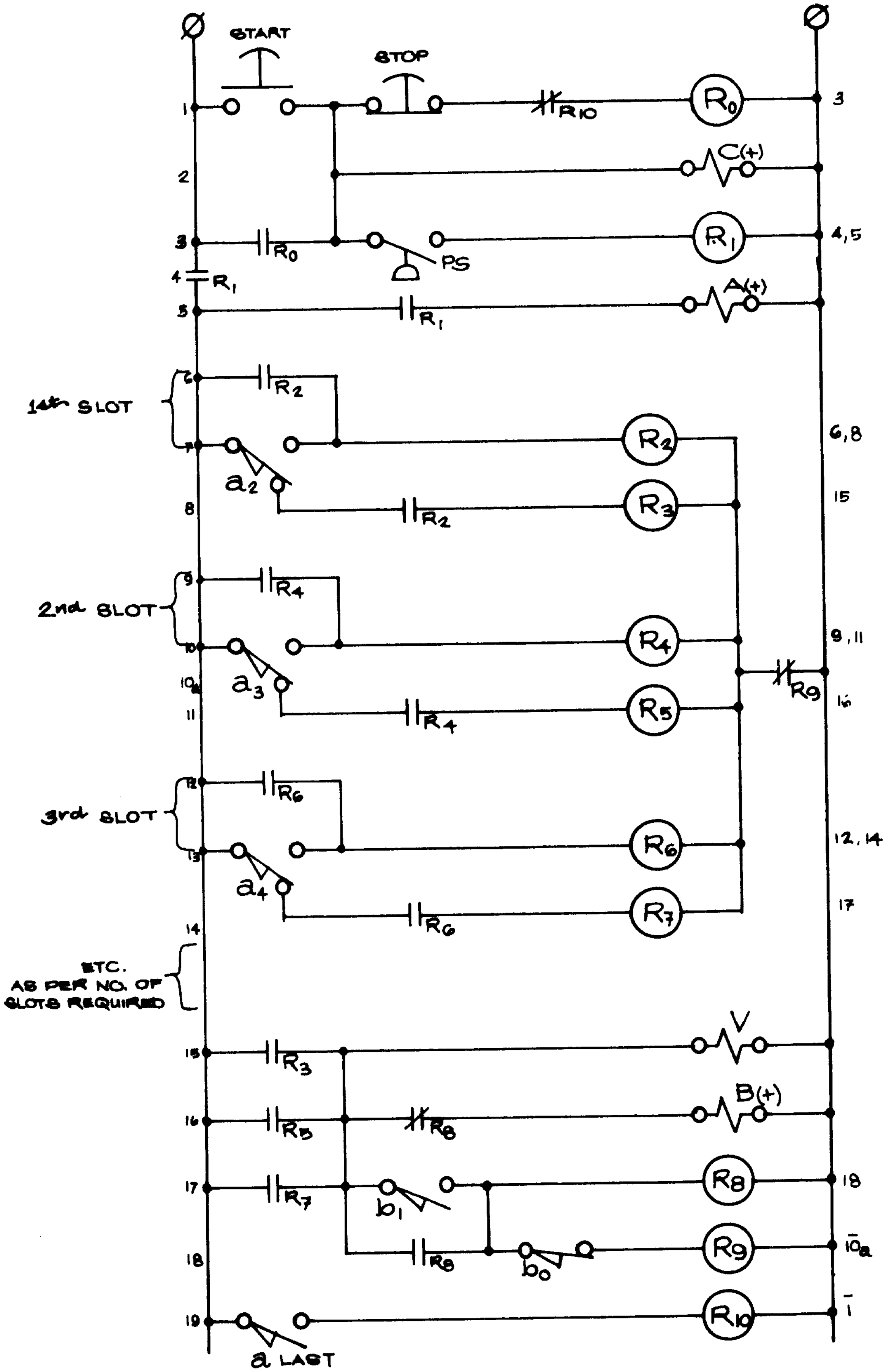


Figure 130c. Radio-TV cabinet slotter: electrical circuit

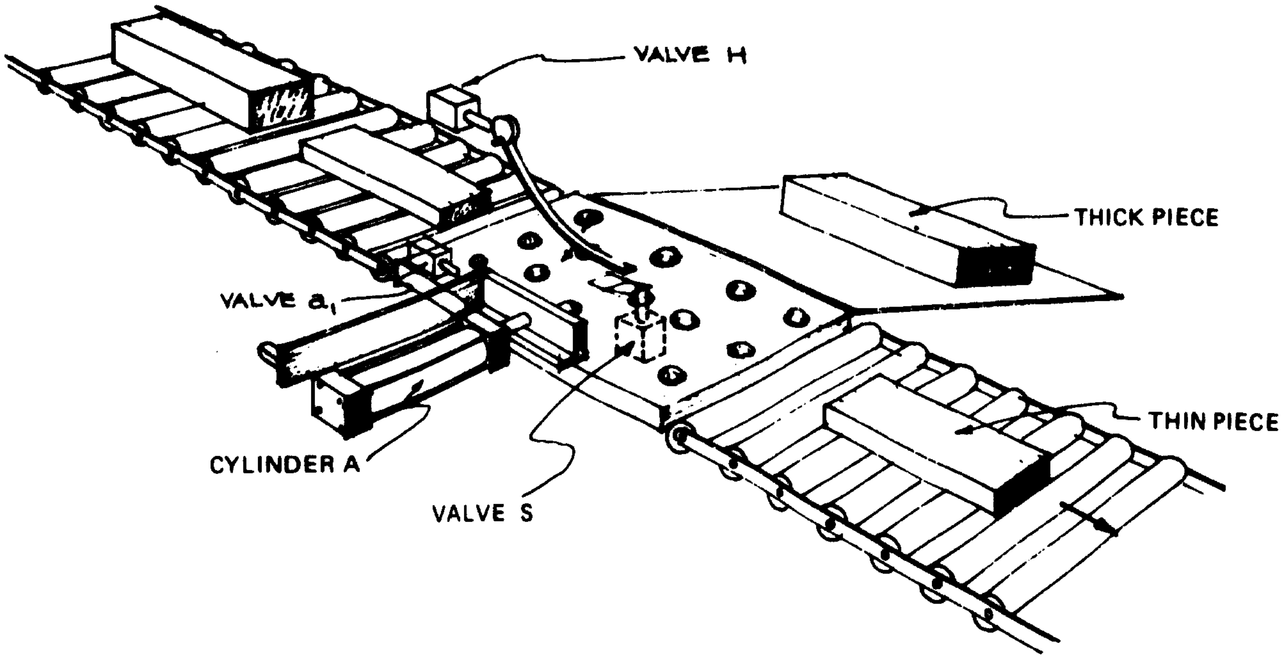


Figure 131a. Thickness selector: general view

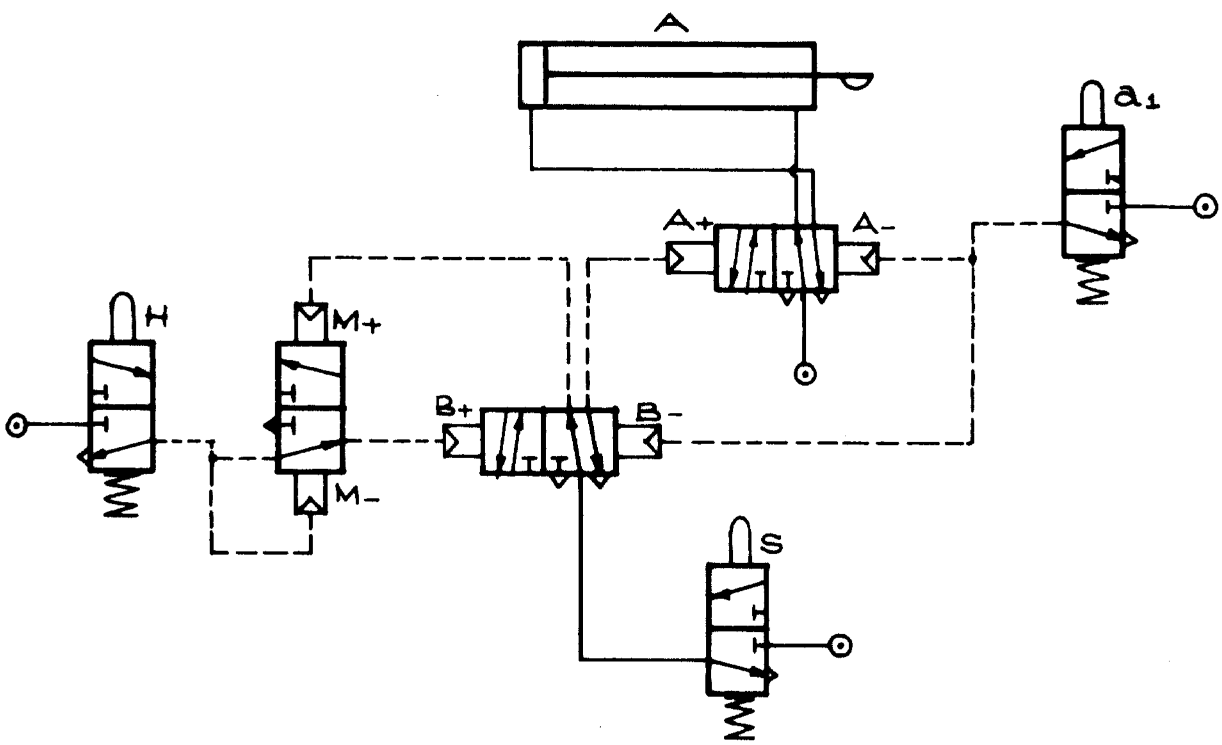


Figure 131b. Thickness selector: pneumatic circuit

M. 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 132a to 132d, 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 $1,460, which can be recovered in five months.

N. Copying attachment

Figures 133a and 133b 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 ($4,750), and it is justifiable only for rather special purposes, probably not for merely increasing productivity.

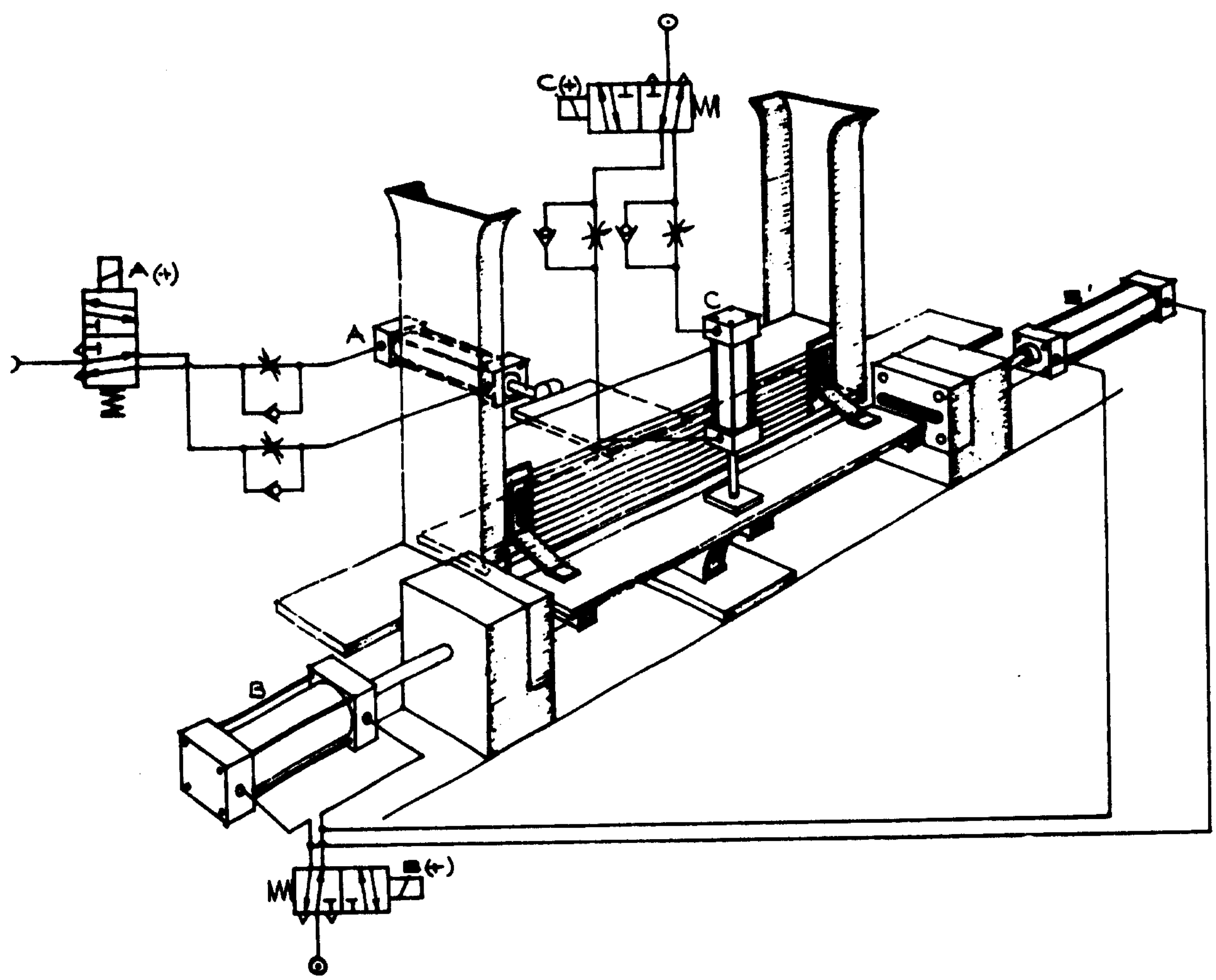


Figure 132a. Upsetting machine: general view

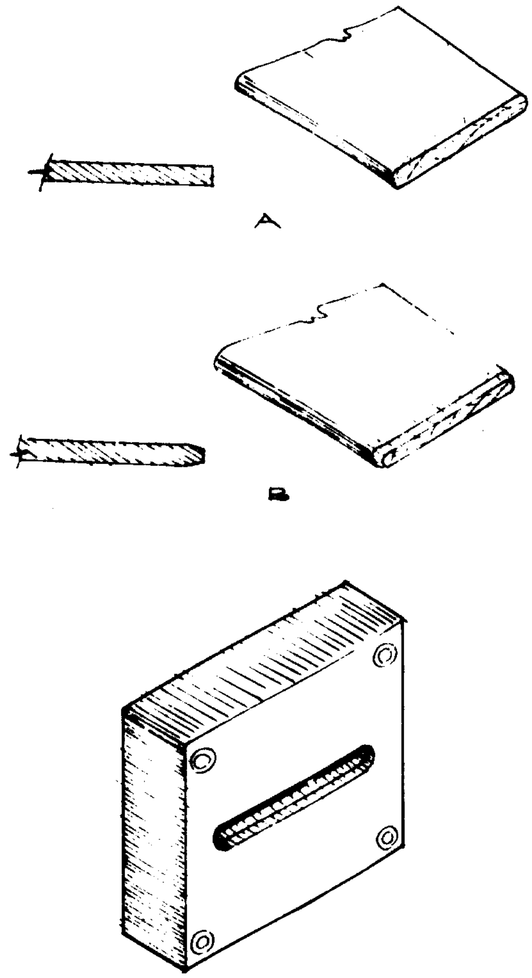


Figure 132b. Upsetting machine: die

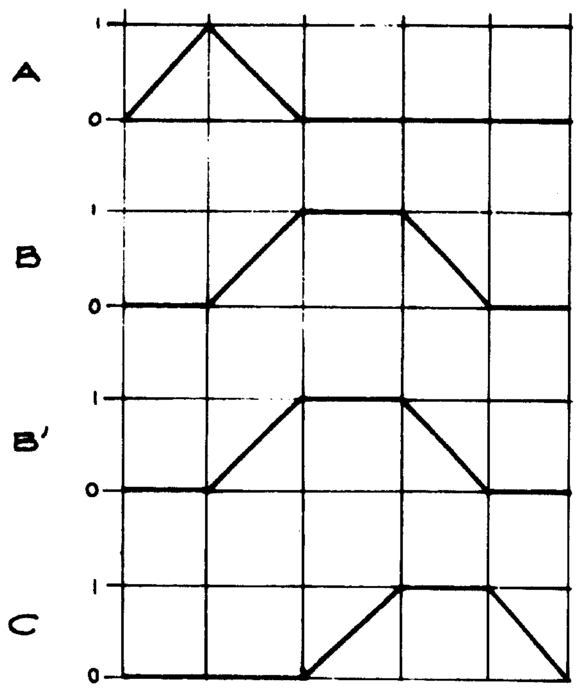


Figure 132c. Upsetting machine: time-motion diagram

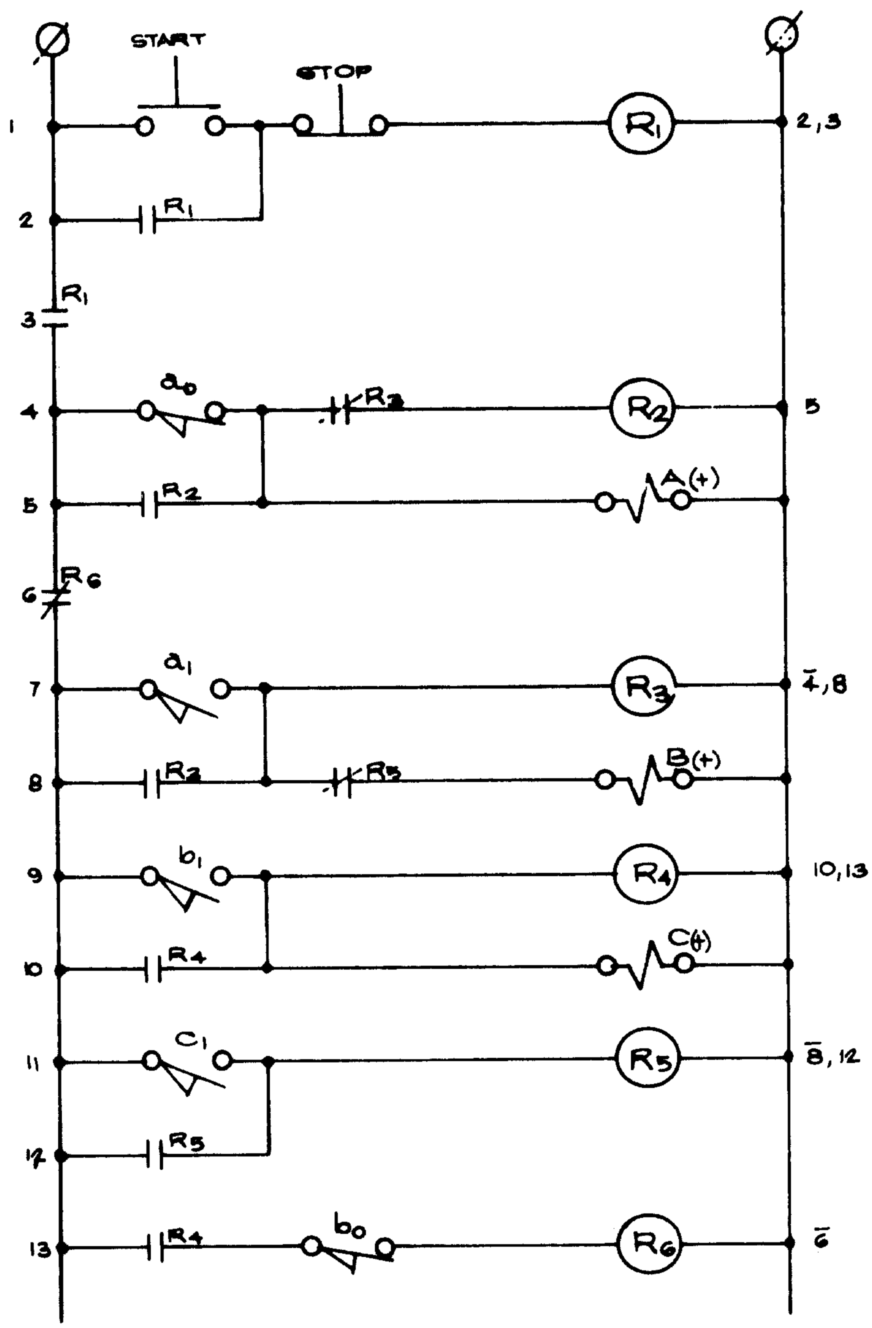


Figure 132d. Upsetting machine: electrical circuit

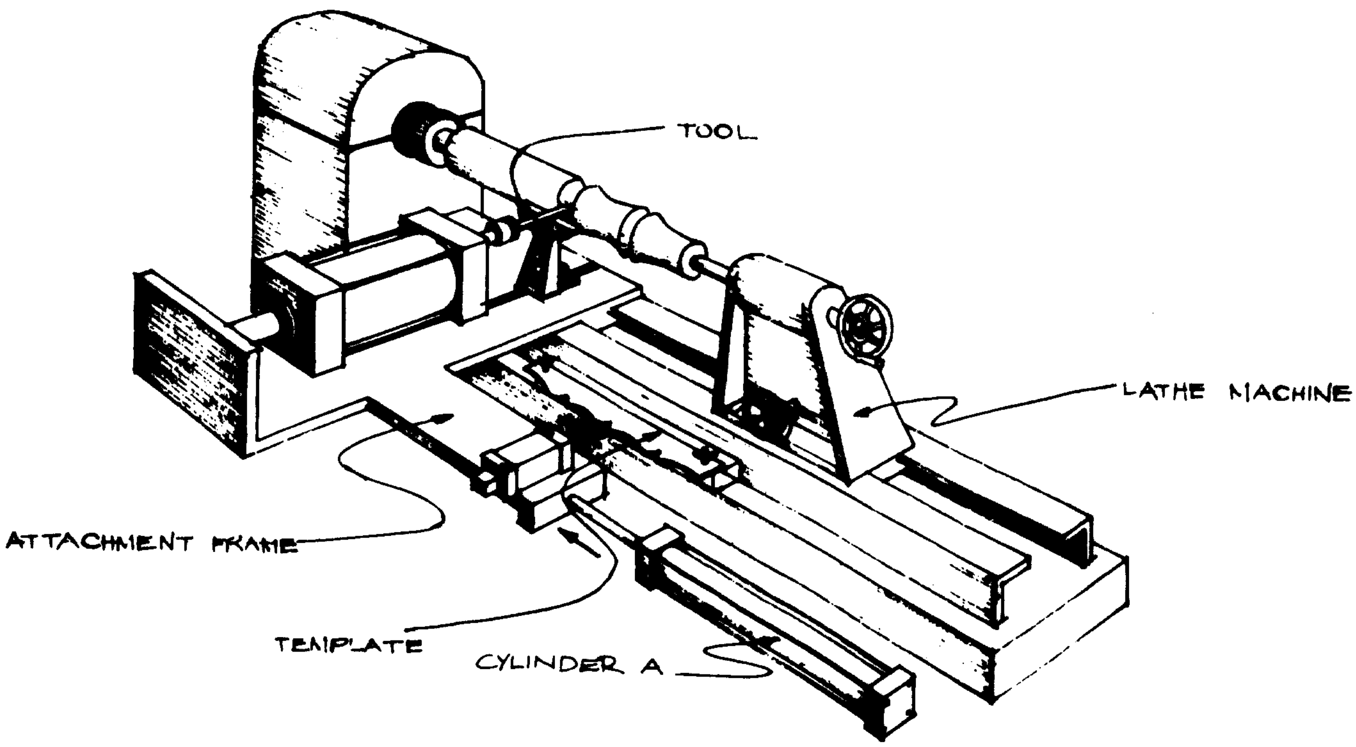


Figure 133a. Copying attachment: general view

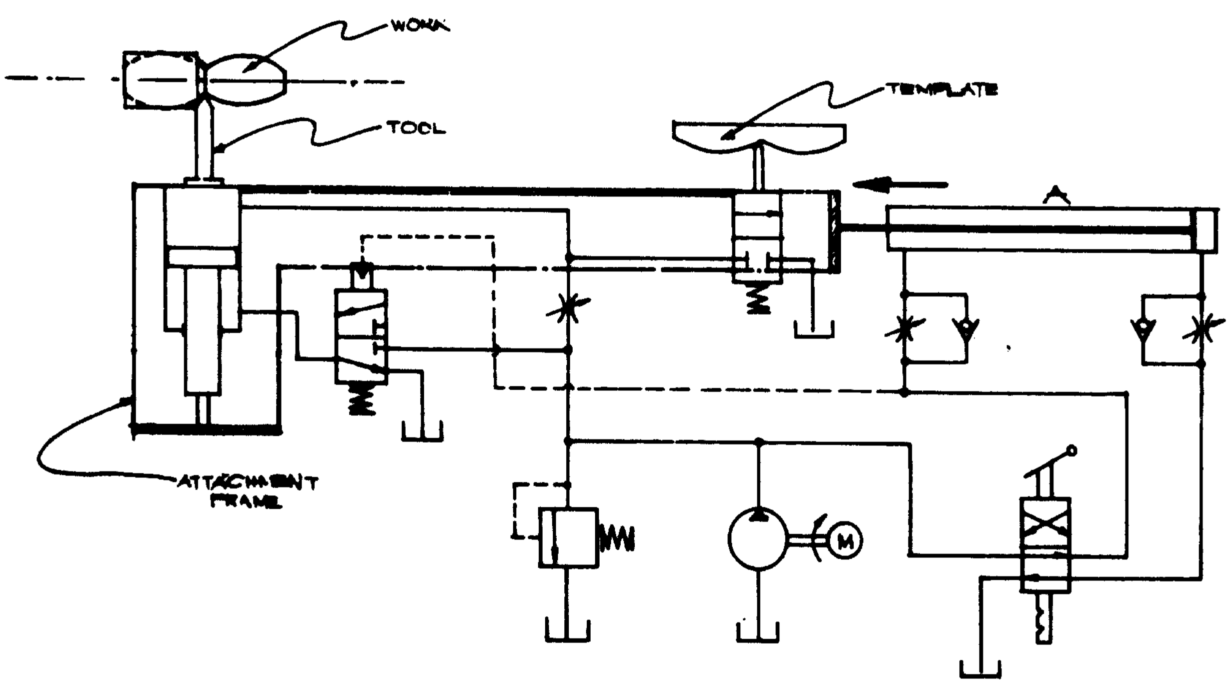
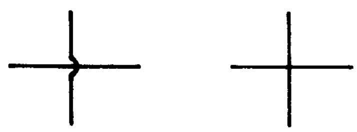
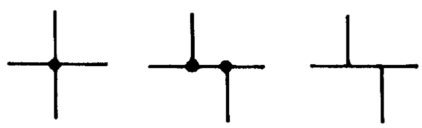
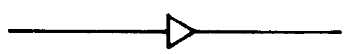
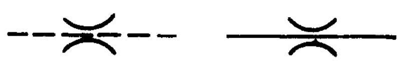
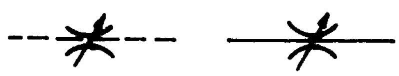
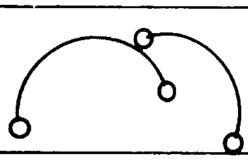


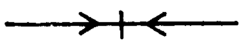
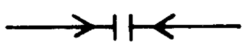
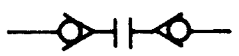
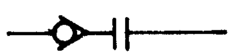
Figure 133b. Copying attachment: hydraulic circuit

Annex I

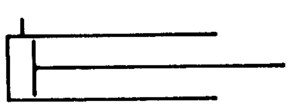
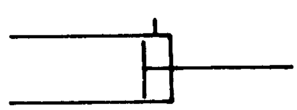
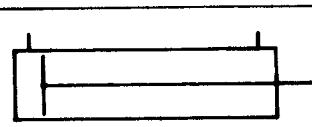
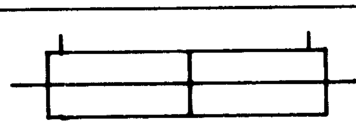
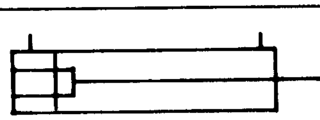
SOME STANDARD CIRCUIT SYMBOLS

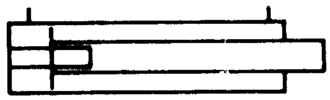
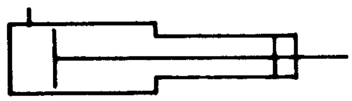
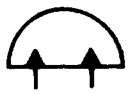
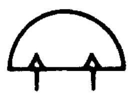
FLOW LINES *and* FLOW CONNECTIONS

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

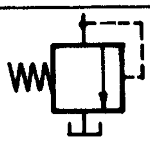
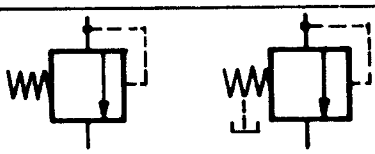
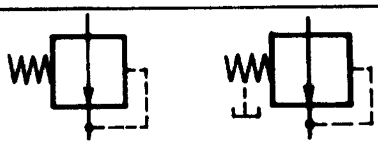
LINEAR & ROTARY POWER DEVICES

	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

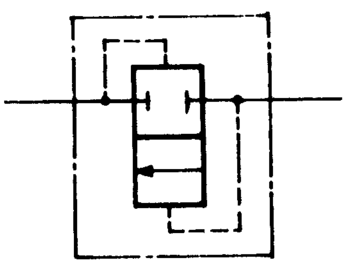
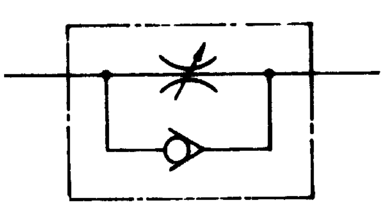
SYMBOL	DESCRIPTION
	DOUBLE-ACTING, BIG ROD WITH CUSHION, ADVANCE AND RETRACT
	PRESSURE INTENSIFIER
	HYDRAULIC OSCILLATOR
	PNEUMATIC OSCILLATOR

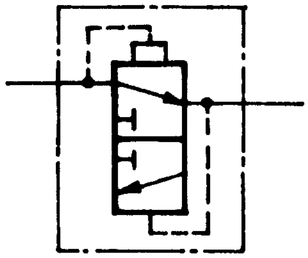
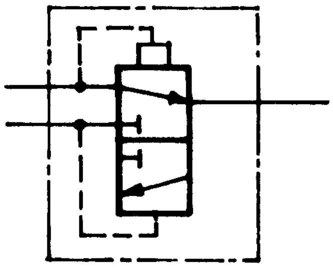
PNEUMATIC DIRECTIONAL VALVES

	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

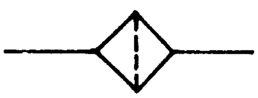
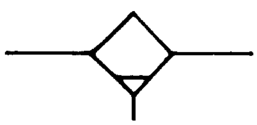
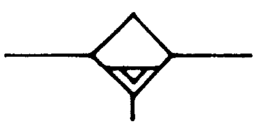
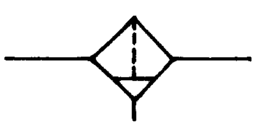
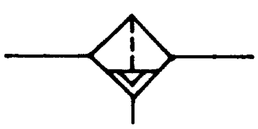
SYMBOL	DESCRIPTION
	5/3 FIVE-PORT, THREE-POSITION, TWO PORTS OPEN TO PRESSURE IN CENTRE POSITION
	4/3 FOUR-PORT, THREE-POSITION, ONE PORT OPEN TO EXHAUST IN CENTRE POSITION
	PRESSURE-RELIEF VALVE, SIMPLIFIED SYMBOL
	SEQUENCE VALVE
	PRESSURE-REDUCING VALVE

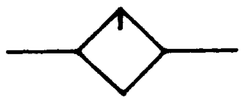
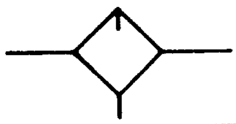
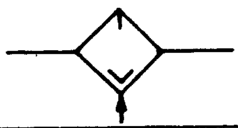
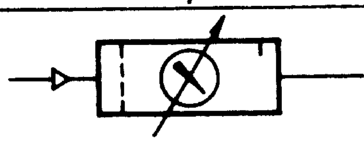
PNEUMATIC AUXILIARY VALVES

	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

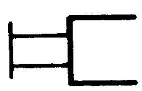
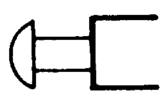
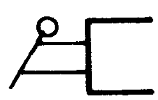
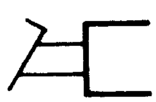
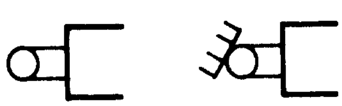
SYMBOL	DESCRIPTION
	QUICK-EXHAUST VALVE
	SHUTTLE VALVE
	SHUTTLE VALVE (SIMPLIFIED)

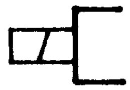
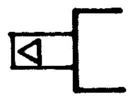
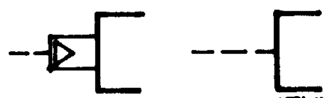
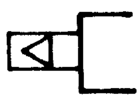
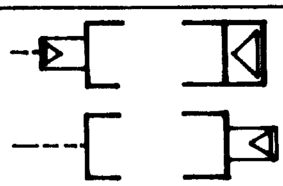
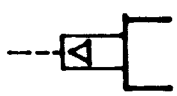
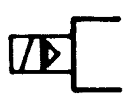
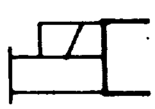
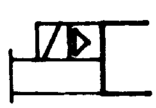
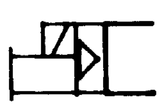
AIR-PREPARATION UNITS

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

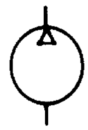
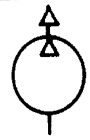
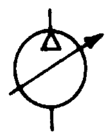
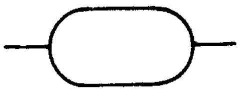
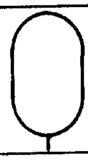
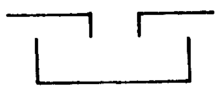
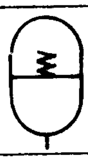
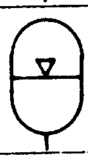
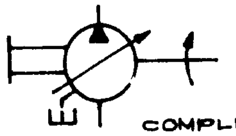
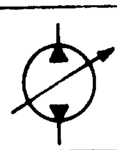
SYMBOL	DESCRIPTION
	LUBRICATOR, LESS DRAIN
	LUBRICATOR WITH MANUAL FILLING
	LUBRICATOR WITH AUTOMATIC FILLING
	AIR LINE COMBINATION F-R-L SIMPLIFIED (TRIO UNIT)

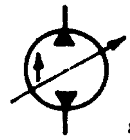
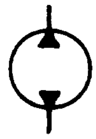
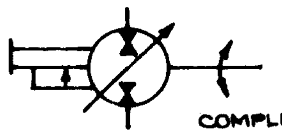
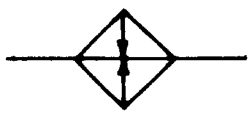
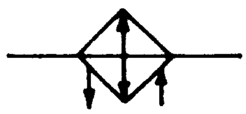
VALVE ACTUATORS

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

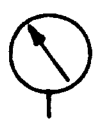
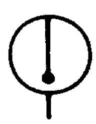
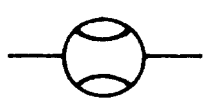
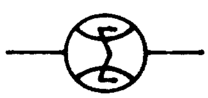
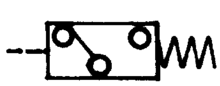
SYMBOL	DESCRIPTION
	DETENT (LINE INDICATES WHICH DETENT IS IN USE)
	SOLENOID
	INTERNAL PILOT SUPPLY
	REMOTE PILOT SUPPLY
	INTERNAL PILOT EXHAUST
	PILOT DIFFERENTIAL
	PILOT EXHAUST TO ATMOSPHERE
	AND COMPOSITE SOLENOID AND PILOT
	OR COMPOSITE SOLENOID OR MANUAL OVERRIDE
	AND/OR COMPOSITE SOLENOID AND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

ENERGY OR POWER SOURCE

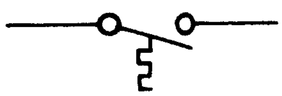
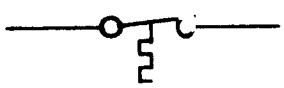
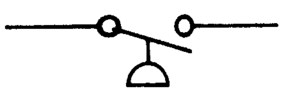
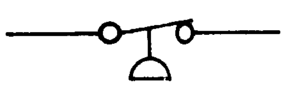
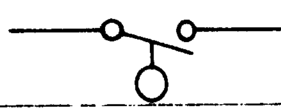
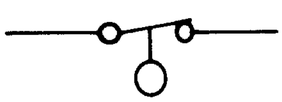
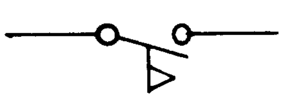
SYMBOL	DESCRIPTION
	COMPRESSOR, FIXED DISPLACEMENT
	VACUUM PUMP, FIXED DISPLACEMENT
	COMPRESSOR, VARIABLE DISPLACEMENT
	RECEIVER
	ACCUMULATOR
 VENTED  PRESSURIZED	RESERVOIR
 ABOVE FLUID LEVEL  BELOW FLUID LEVEL	RESERVOIR WITH CONNECTING LINES
	ACCUMULATOR, SPRING-LOADED
	ACCUMULATOR, GAS-LOADED
 COMPLETE	PUMP UNI-DIRECTIONAL, VARIABLE DISPLACEMENT, NON-COMPENSATED
 SIMPLIFIED	PUMP BI-DIRECTIONAL, VARIABLE DISPLACEMENT, NON-COMPENSATED

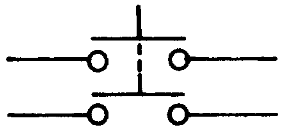
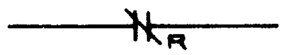
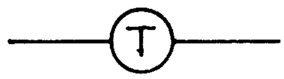
SYMBOL	DESCRIPTION
 SIMPLIFIED	PUMP BI-DIRECTIONAL, VARIABLE DISPLACEMENT, PRESSURE-COMPENSATED
 SIMPLIFIED	PUMP-MOTOR UNI-DIRECTIONAL, FIXED DISPLACEMENT, NON-COMPENSATED
 COMPLETE	PUMP-MOTOR BI-DIRECTIONAL, VARIABLE DISPLACEMENT, PRESSURE- COMPENSATED
	HEATER INSIDE TRIANGLES INDICATE INTRODUCTION 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 several suppliers in Europe and Japan in 1981. 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 none the less prove useful for comparing the prices of different components or of different sizes of the same component.

Control valves

	Port size (inch)	*Price ($)*
5-port, 2-position		
Push-button-actuated, spring-returned	1/8	28.80
	1/4	41.70
Lever-actuated, spring-returned	1/8	30.15
	1/4	46.60
Foot-operated, spring-returned	1/8	30.70
	1/4	46.90
	1/2	95.45
Detent-position (push-pull)	1/8	28.80
	1/4	41.70
	1/2	76.80
Air-operated, spring-returned	1/8	60.35
	1/4	99.05
	1/2	198.10
	3/4	314.85
Double-air-actuated	1/8	54.40
	1/4	90.65
	1/2	181.35
	3/4	287.70
Solenoid-actuated, spring-returned	1/8	61.30
	1/4	102.65
	1/2	158.90
	3/4	193.40
Double-solenoid-actuated	1/8	124.75
	1/4	146.45
	1/2	216.85
5-port, 3-position	1/8	122.15
	1/4	183.20
	1/2	412.35
3-port, 2-position		
Push-button-actuated, spring-returned	1/8	52.40
	1/4	84.85
	1/2	154.70
Lever (cam)-actuated, spring-returned	1/8	42.20
Detent-position (push-pull)	1/8	52.35
	1/4	76.55
	1/2	140.82

	Port size (inch)	*Price ($)*
Air-actuated, spring-returned	1/8	46.85
	1/4	80.20
	1/2	128.35
Double-air-actuated	1/8	54.40
	1/4	98.35
	1/2	166.59
Solenoid-actuated, spring-returned	1/8	81.90
	1/4	108.15
	1/2	152.00
Double-solenoid-actuated	1/8	102.40
	1/4	154.90
	1/2	199.85

Air-flow regulators

	Size (inch)	*Price ($)*
Unidirectional air-flow regulator	1/8	12.45
	1/4	16.70
	1/2	36.10
	3/4	82.40
Non-return valve (ball-check)	1/8	11.40
	1/4	15.70
	1/2	22.00
	3/4	46.75
Shuttle valve	1/8	16.50
	1/4	19.65

Filter–pressure-regulator–lubricator (trio units)

Size (inch)	*Price ($)*
1/2	103.95
3/4	149.55

Air cylinders

	Size (inch)		
	Bore	*Stroke*	*Price ($)*
Single-acting	3/4	1	16.50
	3/4	2	17.50

	Size (inch)		Price
	Bore	Stroke	($)
Single-acting (cont.)	1-1/4	1-1/4	25.00
	1-1/4	2-1/4	26.25
	1-3/4	2	41.50
	2-1/2	2	55.00
Double-acting (non-cushioned)	1-1/4	1-1/2	32.65
	1-1/4	3	34.30
	1-1/4	4-1/2	36.90
	1-1/4	6	38.85
	2-1/2	3	65.00
	2-1/2	6	71.15
	2-1/2	9	77.35
	2-1/2	12	83.25
Double-acting (cushioned)	1-1/4	1-1/2	40.00
	1-1/4	3	42.00
	1-1/4	4-1/2	46.00
	1-1/4	6	48.00
	2-1/2	3	80.00
	2-1/2	6	88.00
	2-1/2	9	96.00
	2-1/2	12	103.00

	Size (inch)		Price
	Bore	Stroke	($)
Heavy-duty double-acting	4	4	162.00
	5	4	193.00
	6	4	258.00
	8	4	392.00
	10	4	827.00
	12	4	998.00

	Energy rating (inch-tons at 80 psig)	Price ($)
Impact	1/10	80.00
	1/4	125.00
	1/2	170.00
	1	355.00
	2	560.00

Miscellaneous

Item	Price ($)
Index table, rotary, diameter 10 in., with 4, 6, 8, 12 or 23 stations	1,060.00

Bibliography

Atlas Copco Tools. Automatic Systems Group. Automation technique. Stockholm, 1971.

_______ Compressed air engineering. Stockholm, 1971. 361 p.

Caldwell, Samuel H. Switching circuits and logical design. London, Wiley, 1958.

Chronis, Nicolas P. Machine devices and instrumentation; mechanical, electrochemical, hydraulic, thermal, pneumatic, pyrotechnica, photoelectric, optical. New York, McGraw Hill, 1966.

Compressed Air and Gas Institute. Compressed air and gas handbook. New York, McGraw Hill, 1973.

Deppert, W. and K. Stoll. Pneumatic application. Federal Republic of Germany, Vogel-Verlag, 1976 and 1979.

Festo Didactic. Introduction to pneumatics. Federal Republic of Germany, 1978.

Groot, Rijn de. Automation in developing countries. Quezon City, Philippines, Institute for Small-scale Industries, University of the Philippines, 1969. 69 p.

Hedges, C. S. and R. C. Womack. Industrial fluid power. Dallas, Texas, Womack Machine Supply, 1965. 144 p. (v.1)

_______ Industrial fluid power. Dallas, Texas, Womack Machine Supply, 1966. 184 p. (v.2)

_______ Fluid power in plant and field. Dallas, Texas, Womack Machine Supply, 1968. 176 p.

Hydraulics and Pneumatics Limited. Advanced pneumatic circuitry. Wolverhampton, England.

_______ Solve your automation problems. Wolverhampton, England.

Jordan Controls, Inc. Industrial static switching handbook. Milwaukee, Wisconsin. 66 p.

Packard, Charles A. Relay engineering. Philadelphia, Struthers-Dunn, 1945.

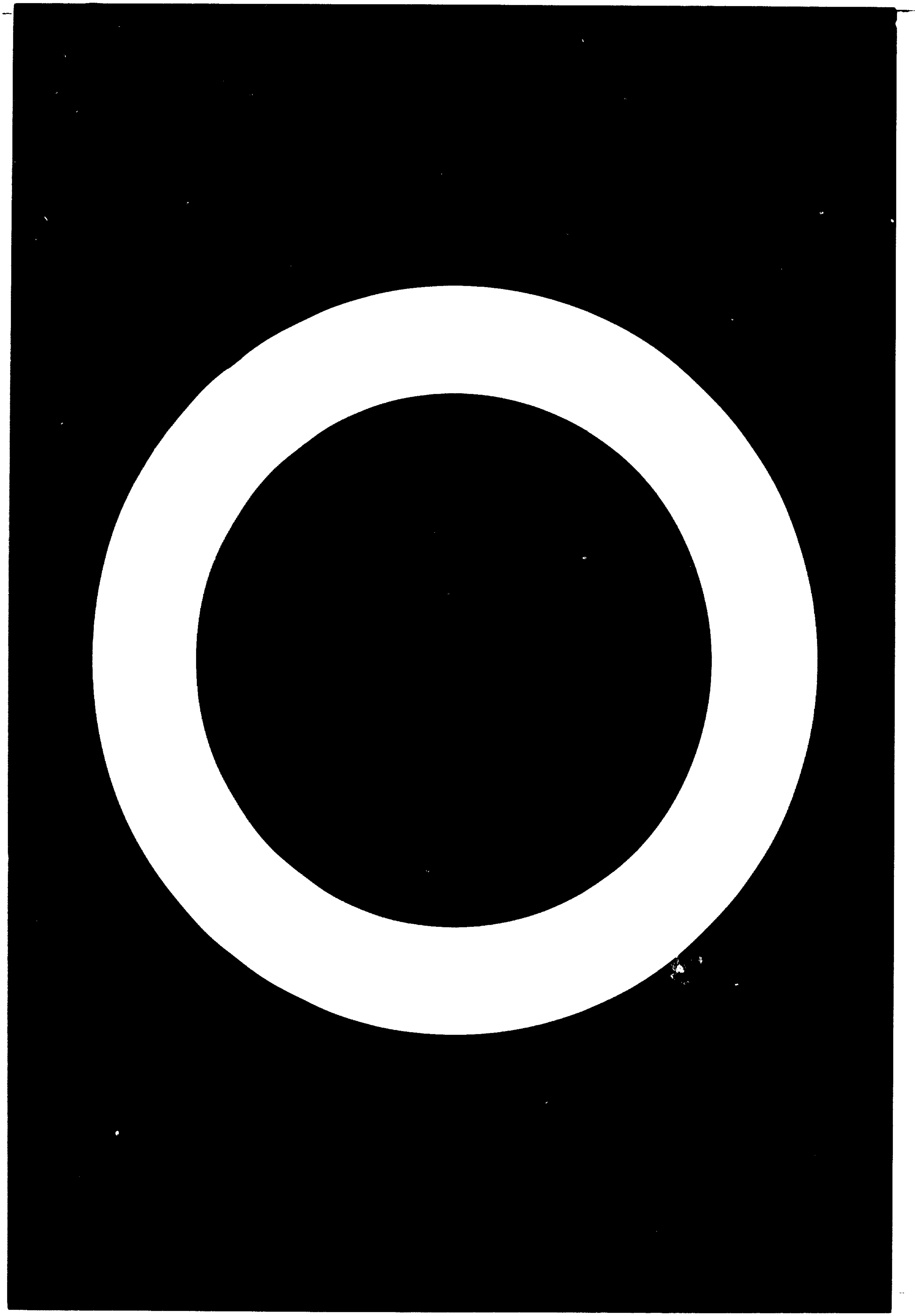
Santiano, W. J. Low-cost automation electricity. Quezon City, Philippines, Institute for Small-scale Industries, University of the Philippines, 1969.

United Nations Industrial Development Organization. Calculation of penumatic systems for furniture and joinery industries. [By M. Kock and F. Lestuvke] 1979. (ID/WG.296/2)

_______ Furniture industry technology. [By P. Paavola] 1973. (ID/WG.105/35/Rev.1)

_______ Low cost automation in the woodworking industries [By Juha Haakava] 1973. (ID/WG.105/45)

_______ Preliminary considerations in planning case good manufacturing industries. [By H. Reuter] 1979. (ID/WG.296/14)



Other UNIDO studies on various uses of wood:

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/Rev.1 and Corr. 1	*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
ID/154/Rev.1	*Low-cost Automation for the Furniture and Joinery Industry*
ID/180	*Wood Processing for Developing Countries.* Report of a Workshop, Vienna, 3-7 November 1975
ID/223	*Adhesive used in Wood Processing Industries.* Report of a Workshop, Vienna, Austria, 31 October-4 November 1977
ID/247	*Technical Criteria for the Selection of Woodworking Machines*
ID/265	*Manual on Jigs for the Furniture Industry*
ID/275	*Manual on Upholstery Technology*
ID/188 UNIDO/LIB/SER.D/4/Rev.1	*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 Boards from Wood and other Fibrous Materials*
ID/214 UNIDO/LIB/SER.D/31	*UNIDO Guides to Information Sources No. 31: Information Sources on Woodworking Machinery*
UNIDO/LIB/SER.D/36	*UNIDO Guides to Information Sources No. 36: Industrial Maintenance and Repair*

Printed in Austria
V.83-[illegible]—January 1983—3,[illegible]

C-179

83.08.11
AD.84.06