Robotics and Microprocessors

William C. Mohr
Program Chairman

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Preface

At the Annual Meeting in 1983, the N.I.C.E./C.E.C. Colloquium dealt with the subject of "Robotics and Microprocessors." This topic was further covered in the N.I.C.E. program at the 1983 Pacific Coast Regional Meeting. Written copy was solicited from all the authors involved. The proffered papers are published herein for the edification of ceramic engineers and scientists. It is the especial hope of N.I.C.E. that this volume will prove of value to ceramic schools—to the professors in their lectures and to the students in their pursuit of learning.

As 1982–83 N.I.C.E. Program Chairman, I wish to thank the authors who contributed their papers to this volume.

William C. Mohr, Chairman
1982–83 Program Committee
National Institute of Ceramic Engineers

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William J. Smothers

Productivity Technology and International Competitiveness

KEITH E. MCKEE

IIT Research Institute, 10 W. 35th St.
Chicago, IL 60616

A comparison of U.S. industries with the international competition demonstrates that major problems exist. Even the most successful U.S. industries are being challenged. Possible solutions are presented with emphasis on the role that technology can play in improving productivity.

Introduction

For the first time we are being challenged for "our hill." At the end of World War II the United States was the unquestioned king of the economic hill—the creators of new products, processes, and procedures. The result was a U.S. average standard of living unchallenged by any other nation. Our mines, factories, mills, chemical plants, and farms were all the biggest and the best. Our technical leadership was unquestioned with the new rapidly replacing the not so new. Tomorrow would always be better than yesterday. Technology was the keystone for this economic power and accepted without question as the solution to the problem.

A funny thing happened to the United States on our way to the 1980s. Our economic growth slowed from a steady walk to a faltering gait with even an occasional fall backward. As a nation we tended to have totally rational reasons why these were aberrations that really did not count. The apparel and shoe industries were labor intensive and clearly the U.S. industry could not hire labor for pennies per hour as the international competitors were doing. There was some concern about the loss of these industries which had provided entry level jobs for newcomers to this nation, but not any national concern. Those intimately involved in these industries cared, but the general wisdom was that these industries were better left to Third World nations.

The consumer electronics industry was essentially an American invention. The proliferation of electrical devices in American homes was a measure of the rapidly increasing standard of living. When foreign competition showed up with bottom-of-the-line, cheap products no one was much concerned. Obviously, it was because of the cheap labor and again adjustments were made by opening assembly plants outside the United States and by buying foreign products for resale. The U.S. consumer electronics industry had all but disappeared before we noticed that the top-of-the-line, high quality products were being made outside.

The steel industry had long been the "macho" of the industrial nation. Every nation needed to have their own steel industry. The initial signs that the U.S. steel industry had competition were treated with disbelief and cries of "foul." Years later it is generally accepted that the U.S. steel industry has lost, and such philosophical questions are being considered as the national defense requirements for this U.S. industry's continued existence.

Perhaps the seriousness of international competition did not really hit home until the automotive industry was badly shaken by imports. The U.S. auto industry which had long been considered the premiere manufacturing industry in the United States, was losing on their own turf. A lot of questions, accusations, and excuses were initially offered. It is concluded that the U.S. automotive industry has been bested where it counts most—on the bottom line. The Japanese are able to produce a quality automobile at a cost of $1500 to $2000 less than the American equivalent. This is perhaps the first U.S. industry that has recognized its plight early enough and has come back fighting. They still have a long way to go, but their return to profitable operation is a sign that they are not dead. The automotive companies and their unions seem dedicated to put up a good fight. This will clearly be a long, hard struggle. It literally took decades to get into such bad shape and it is likely to take a decade or more to recover.

Obviously one could write a paper or book on each of the above and a variety of other industries. Traditionally strong U.S. industries, such as computer, electronic, and aircraft, are already seeing significant competition and will undoubtedly be challenged. Some people argue that the United States does not have to compete in manufacturing but can become a service economy. We remain convinced that a nation must have an internationally competitive manufacturing base to stay alive in the world trade market. A nation that has only services to trade will pay whatever price the world wants for other goods.

Productivity

Productivity is a measuring of the efficiency with which capital, energy, technology, management, and manpower are used. The optimum approach to productivity improvement can vary with time and place. For example, in an area of low salaries and limited capital resources, the optimum approach might be manpower intensive with only limited capital equipment. In a free market situation, the cost would be a direct measure of the productivity—the lower the cost and price, the better the productivity. There is a relatively free market in the United States, and the more productive company within an industry prospers over its less productive rivals. The international money market, exchange rates, tariffs and export incentives all cloud international price comparisons on a microscopic scale. On a macroscopic scale, the balance of payments represents a good indication of relative productivity among nations. The United States had a trade deficit in excess of $30 billion in 1981.

The American Productivity Center has projected the international productivity trends, 1978 to 1990, and Fig. 1 shows this anticipated performance.[1] The United States is still "king of the hill" but about to be overtaken. This figure uses value added per worker for the overall economy.

Overall and Sector Productivity[2]

Thanks to the Japan Productivity Center we have comparative productivity figures on the major industrial nations. The comparisons use 1973 international monetary exchange rates so the data may not be totally accurate, but are certainly the best we have. The use of Japan as 100 in 1973 is the basis for the plots but has no significance. The plots are comparative and any nation could equally well be considered as 100 in 1973. Figure 2 compares gross domestic products per capita. On this overall scale the comparisons have stayed fairly consistent. Japan has gained vis-a-vis Great Britian but the other nations have essentially maintained a constant relative position.

Figure 3 which shows gross national product per engaged persons has France and Germany gaining noticeably on the United States. Japan is gaining and has surpassed Great Britian but still has a long way to go.

Figures 4 through 10 show comparative productivity for different sectors of the economy. The measure here is value added per engaged person. Figure 4 shows agriculture, forestry, and fishing. The United States is vastly in the lead and has maintained that lead, obviously a major success area for the United States and a problem for Japan.

Figure 5 considers mining and quarrying. The United States has flopped in the decade considered. Japan (and we really do not know what mining and quarrying are done in Japan) has achieved significant improvement and, in fact, now is the world leader.

In the case of manufacturing (Fig. 6) it seems that everyone in the world is catching up with the United States except, of course, the United Kingdom. Note that based on trends indicated, by 1982 France and Japan are likely to have caught up with the United States. Based on data up to 1979, German improvement has slowed and it would be several years before they catch up. The United Kingdom is again out of the action. We must also note here that salary differentials would influence the meaning of these results. Germany and France have essentially salary equality with the United States, but Japan and Great Britain pay noticeably smaller salaries and effectively they have an additional advantage.

Figure 7 considers electricity, gas and water. The United States has shown no improvement. France and Germany have shown noticeable improvement. Japan has shown modest improvement but nevertheless has caught up with the United States.

The falling performance of the United States construction industry is shown in Fig. 8 with Germany now ahead of the United States. Construction productivity in other nations has remained essentially constant. Figure 9 shows the United States with a significant lead and constant improvement in transportation, storage and communication. Figure 10 considers commerce, finance, insurance, real estate and services. The United States has remained constant but still a significant leader. Germany, France, and Japan are improving, but not that rapidly. With all of the above it is relatively obvious why Japan is still far behind the United States, France and Germany on an overall basis.

Manufacturing Productivity Overall

Overall international comparisons are of interest but do not provide much useful information. Considering comparisons among industrial sectors is more interesting.[3] For our purposes here, primary interest is in the manufacturing sector. The history up to 1979 and projections to 1982 are shown for manufacturing on Fig. 11.[4] These data come from a report by the Japan Productivity Center.[5] According to Fig. 11, both France and Japan have surpassed the United States in manufacturing productivity (based on value added per employee), and Germany is gaining on the United States. In overall manufacturing the United States has been bested.

Even the manufacturing sector is too broad—one should really compare individual industries (and preferably individual companies). The limited data that are available[6] indicate that foreign manufacturers have improved productivity the most for industries that compete in international trade. As a result, the situation may in fact be more serious than shown in Fig. 11 with the foreign competitors having more of an advantage in those industries.

Table I is a comparison of labor productivity for various manufacturing industries in the United States and Japan. The data in Table I are based on value added per hour worked rather than value added per worker. As indicated in Table II,[7] this does make a significant difference. Using the 1980 data, this indicates that the Japanese work an additional 133% of the hours worked by U.S. workers. Using this factor for 1980, the 72% shown in Table I for all manufacturing would be 96% of U.S. productivity which is the same as shown in Fig. 11.

By using the 96% factor for all industry, the result is Table III for 1980, estimated. (Note that 1.33 is used for all industries, although clearly some variation would be expected depending on the industry.) Table III gives a basis for comparing productivity among manufacturing sectors in Japan and the United States. The United States has a significant advantage for food, apparel and footwear, pulp and paper products, leather and products, and fabricated metal products. Japan has a significant advantage for iron and steel, chemical industry, electrical machinery, automobiles, and instruments. It is interesting to note that the U.S. advantage is for products which rarely enter the international trade market, while Japan has the advantage in exported products. Although not qualified here, Fig. 11 and Table I both indicate that in Japan the productivity for manufacturing and for most industries is increasing faster than it is in the United States. For those industries which show near parity in 1980 for Japan and the United States, it is likely that Japan by now has an advantage. As indicated by Fig. 11, Japan is not the only nation that has caught up with the United States. France has already caught up and Germany is not far behind and is closing the gap.

Conclusion

The United States is losing in international competition and productivity improvement is the key to regaining our status. It is up to each of us in our personal activities, our organizations, and our companies to take action to improve productivity. Equally important, and perhaps of even greater importance, institutional changes are likely to be required such as:

(1) Long-range consistent national planning,

(2) More extensive cooperation between government, industry, professional societies, and universities,

(3) Industry working together on generic problems, and

(4) Managers of technology giving more thought to why work is being done.

References

[1]Productivity Perspectives: 1981 Edition. American Productivity Center, Chicago, IL.

[2]All data in this section are taken from a report on the title subject by the Japan Productivity Center (JPC). The work was conducted under the supervision of Dr. Kazukiyo Kurosawa, Chairman of the JPC measurement Committee. Full and total credit and thanks are given to Dr. Kurosawa for all of the data used in this article. The interpretations can be blamed on the author.

[3]K. E. McKee, "International Comparison of Labor Productivity," *Manufacturing Productivity Frontiers*, **6** [11], 1–4 (1982).

[4]K. E. McKee, "Comparative Manufacturing Productivity," *Manufacturing Productivity Frontiers*, **6** [11] 5–9 (1982).

[5] "International Comparison of Labor Productivity," report by the Japan Productivity Center (JPC). The work was conducted under supervision of Dr. Kazukiyo Kurosawa, Chairman of the JPC Measurement Committee.

[6] Op cit, *Manufacturing Productivity Frontiers*, **6** [11] 5–9.

[7] K. E. McKee, "Hours Worked," *Manufacturing Productivity Frontiers*, **6** [6] 20–21 (1982).

Table I. Comparative Japanese Labor Productivity*

	1978	1979 (est)	1980 (est)
All manufacturing	65	68	72
Food	47	46	44
Textile	70	63	74
Apparel and footwear	41	39	39
Lumber and wood products	65	71	73
Furniture and fixtures	60	—	—
Pulp and paper products	49	51	48
Printing and publishing	46	—	—
Chemical industry	83	84	89
Petroleum products	—	—	—
Rubber products	65	69	73
Leather and products	54	49	50
Stone, clay and glass	62	61	65
Iron and steel	127	144	151
Nonferrous metal	67	72	70
Fabricated metal products	57	57	55
Machinery except electric	71	78	78
Electrical machinery	81	84	95
Automobiles	83	92	101
Other transportation equipment	71	—	—
Instruments	50	63	86
Miscellaneous	54	—	—

*Value added per h (United States=100)

Table II. Average Hours Worked Annually

Year	Japan	Germany	France	U.K.	U.S.
1913	2588	2584	2588	2624	2605
1960	2432	2083	1983	2174	1795
1980	2127	1716	1724	1609	1605

Table III. Comparative Productivity by Industry*

	1980 (est)
All industry	96
Food	58
Textile	98
Apparel and footwear	52
Lumber and wood products	97
Furniture and fixtures	—
Pulp and paper products	64
Printing and publishing	—
Chemical industry	118
Petroleum products	—
Rubber products	97
Leather and products	67
Stone, clay and glass	86
Iron and steel	201
Nonferrous metal	93
Fabricated metal products	73
Machinery except electric	104
Electrical machinery	126
Automobiles	134
Other transportation equipment	—
Instruments	114
Miscellaneous	—

*United States = 100

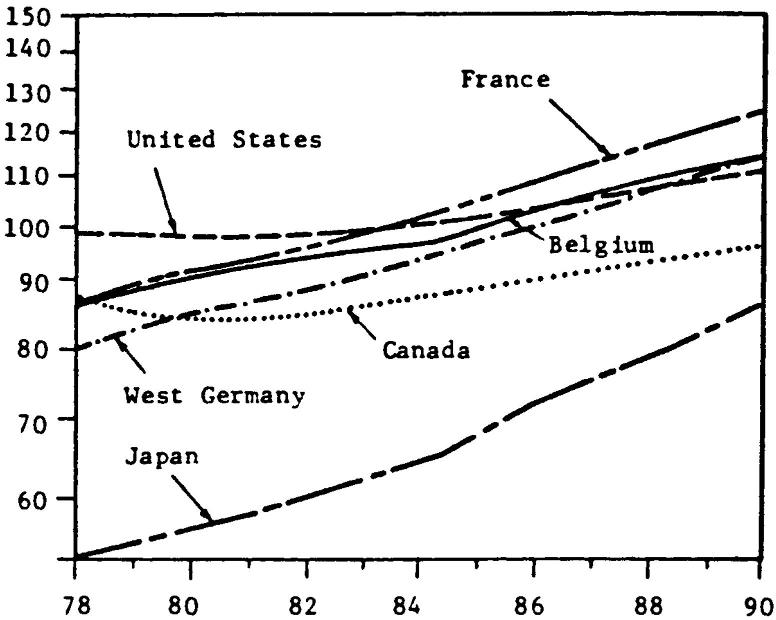

Fig. 1. Projected international productivity trends, 1978-90 for six nations leading in national productivity levels.

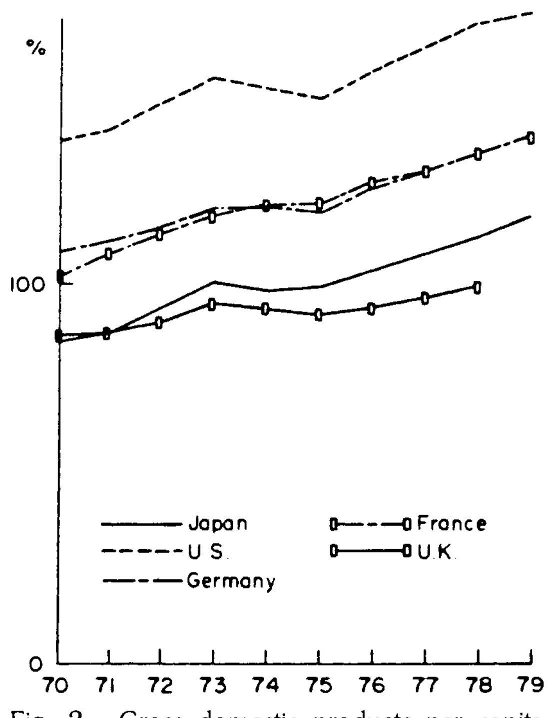

Fig. 2. Gross domestic products per capita. (Japan, 1973 = 100).

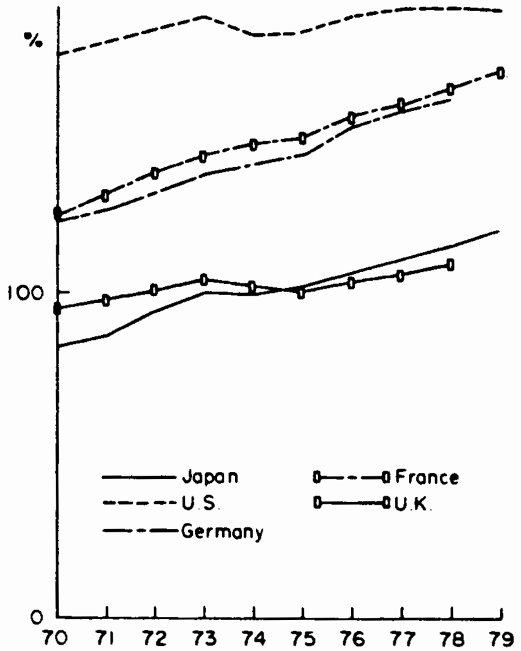

Fig. 3. Productivity level index, gross domestic product per labor force engaged. (Japan, 1973 = 100).

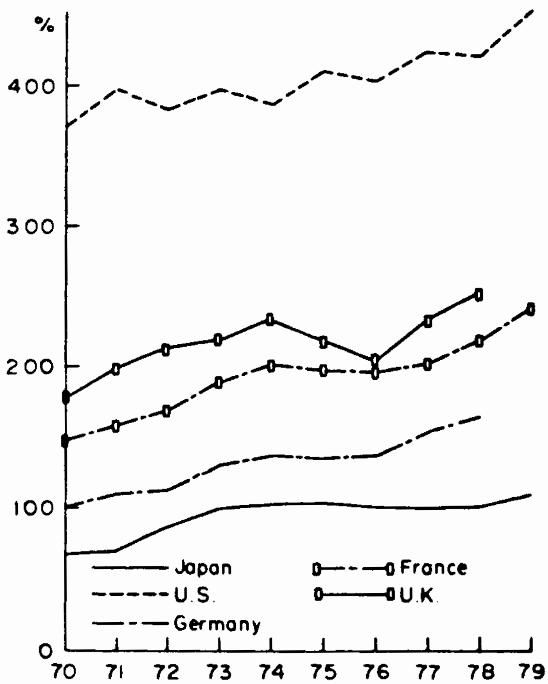

Fig. 4. Agriculture, forestry, fishing productivity level index.

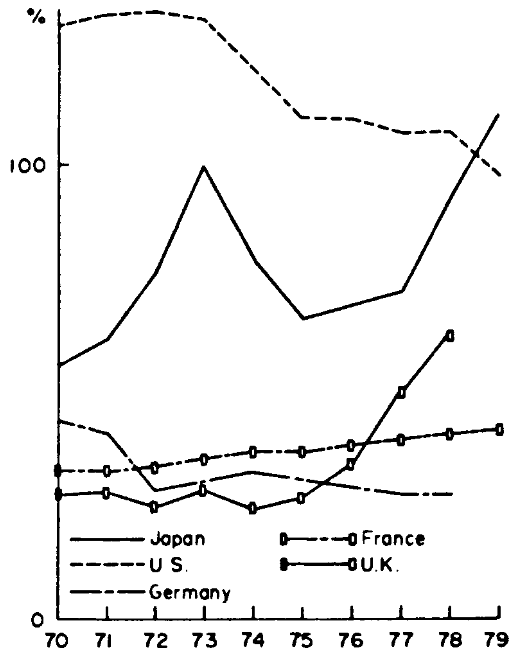

Fig. 5. Mining, quarrying productivity level index.

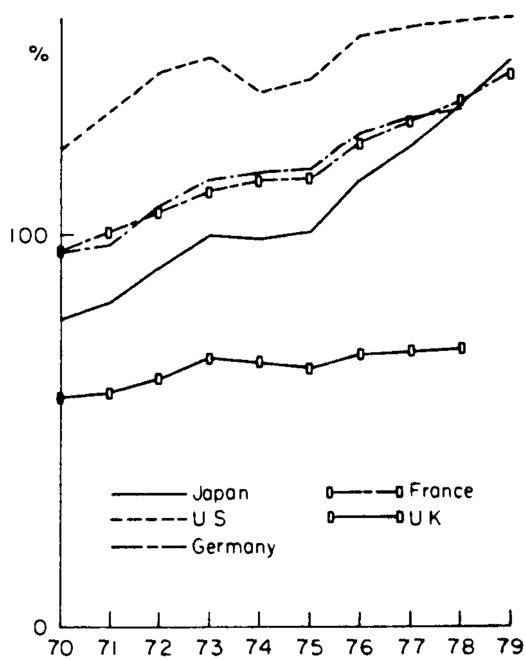

Fig. 6. Manufacturing productivity level index.

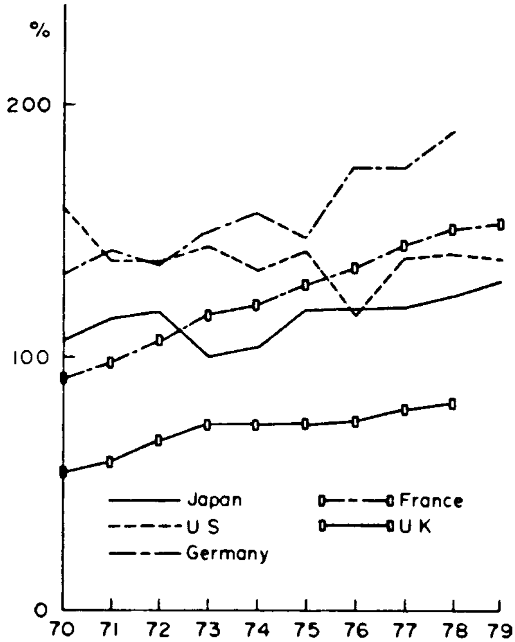

Fig. 7. Electricity, gas, water productivity level index.

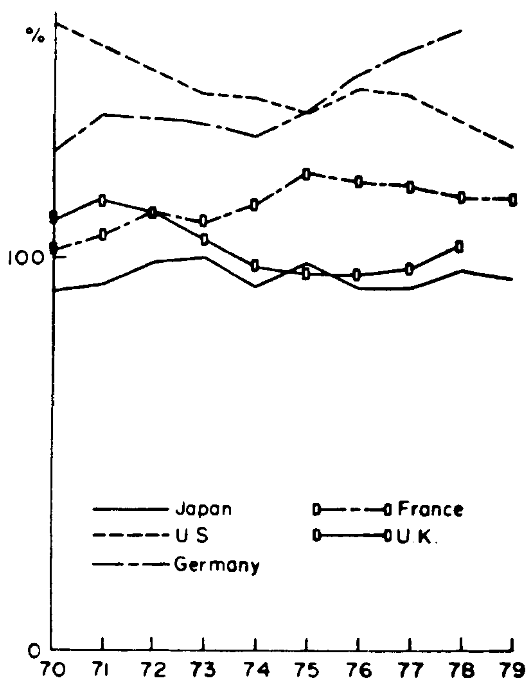

Fig. 8. Construction production level index.

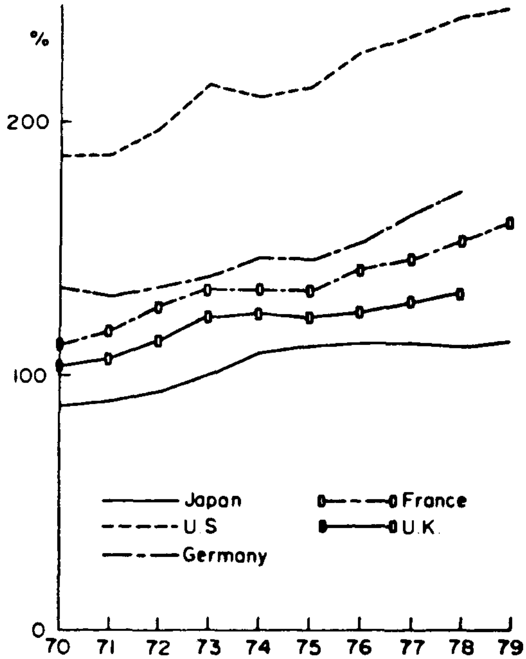

Fig. 9. Transport, storage, communication productivity level index.

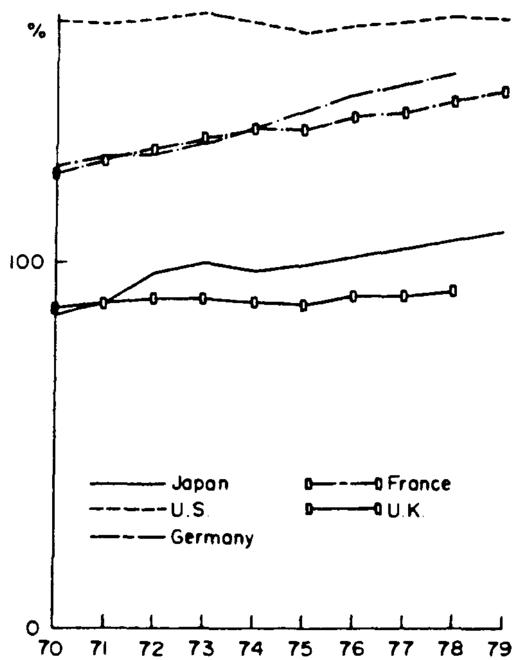

Fig. 10. Commerce, financing, insurance, real estate and services productivity level index.

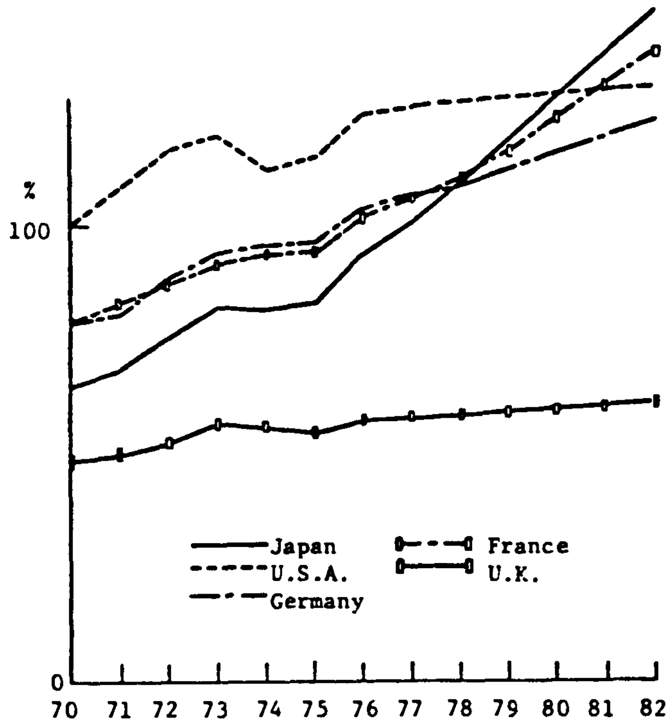

Fig. 11. Projected manufacturing productivity level index. (United States, 1970 = 100).

Ceramic Engineering and Sciences Proceedings
William J. Smothers

Critical Management Factors in the Successful Application of Robots

LARRY L. SPEAKMAN

Coors Porcelain Co.
600 Ninth St., Golden, CO 80401

The justification for robotics may be predominantly mechanical and economic in nature, while the changes in management and engineering philosophies are often overlooked. This paper discusses how to address these changes successfully.

As of this writing, most of the applications of robotics have been in areas where labor is unwilling to work; for example, in hazardous, in depressing, or in extremely boring environments. The support of labor for a robotic system in most of these cases has been easy to get. The future of robotics, however, if it is to be assured, must address all types of manual working environments and all aspects of reaction. The goal of this paper is to discuss these aspects of reaction as found in the "satisfactory" or "normal" working environment.

Before proceeding further, two points need to be established. Viewed strictly, a robot is like other technological improvements. However, it can be argued that the robot is a unique and a slightly different form of technological improvement because the robot provides (1) a composite automation system; (2) a technological improvement which can serve as a foundation for further improvements and yet which in and of itself will never be eradicated once established; and (3) a method of operation through which the highest productivity with the lowest labor input can be achieved. Finally, one could argue that the robot is unique due to all the fascination and emotion which it evokes.

This perception of uniqueness, regardless of foundation, is critical when considering robotic implementation. First and foremostly, the basis of perception among those involved must be ascertained. Then, that perception must be either eradicated (if negative) or re-enforced (if positive). A lack of understanding about how the robot is perceived could prove disastrous.

The second point which must be established is the relationship of the "computer revolution" to the future of the robot. As managers and engineers become more accustomed to the computer, particularly the micro-processor, there will be more desire to experiment with robots and what they can do. If it is correct that two of the biggest obstacles to robotic implementation are from ignorance and fear, then the "computer revolution" should help make managers and employees more aware and amenable to trying and using the robot. It would therefore be more likely that robotics could be implemented in a company where micros are all in use, as opposed to a company which has only a limited familiarity with computers.

For most technological justifications, certain factors such as economic feasibility, return on investment and availability of capital are primary considerations. But for the robots these considerations are just the beginning. First of all, the ultimate goal of the robotic system must be articulated; i.e., is it discrete in function or in space; will it provide a foundation for a systems integration of manufacturing? Second, is there an internal technical staff capable of supporting and interfacing between the robot designers and the company employees who must be trained, guided, and eventually productive using the system? Third, is the company prepared to deal with the labor shift that will occur in the area of automation? Has the company formulated a policy of re-training or of out-placement that will benefit the company and not harm the relationship of the company to the surrounding community? Fourth, has the company discussed and addressed the various personal, sociological, and philosophical reactions and questions that surround the robot and its impact on people's lives? Fifth, is the company aware of, able to take advantage of, and prepared to solve, all the accruals attendant to robotic systems, such as clarification of functions (systems analysis), clarification of standards (quality and work performance), and planning goals over time (marketing and costs). These are the major aspects which ought to be considered as one implements a robotic system, particularly in a "normal environment."

The obvious starting point for discussing the aspects of implementation is in the area of human reaction to a robot. For the employee, the biggest negative reaction to the robot is the perceived loss of job security. Another reaction is a phobia brought forth in many science fiction stories which depict robots in control (or out of control!). Another reaction is an apprehension over adaptation: Will the company allow adaptation or will the employee be passed by the technology or by new employees, brought in to support the new system? Another reaction comes from uncertainty: What has become the company direction and what will be the future relationship of the company to its employees?

The response to these reactions is not easy. First of all, to say that very few technological improvements have occurred where new jobs have not been generated, (and the robotic industry is no different), means very little to the person displaced. His or her concern is for the welfare of himself or herself, for his or her family, and for his or her future. What a given company will or can do to or for that employee is important not only for the employee, but for the company and for the community as well. One response the company may choose is to develop other company jobs and begin re-training programs for all those displaced. Another method the company may choose is to develop out-placement capabilities and find placement in other community jobs. Still another approach is to forget either method and simply allow displacement. The problem with the last approach is that it tends to reenforce many of the phobias and concerns that surround robotics.

Typically, the human reactions to robots are usually negative if no individual or collective gain is perceived. To allow a robotic system in a paint shop is easy because few find that particular job pleasant. So too in a "satisfactory environment." If the robot makes the job more meaningful, less tedious, and more responsible, then the likelihood of the robot being accepted is higher.

Lastly, if the support of the people involved is sought, if these people perceive that the company cares, if they understand why things are being done, then the probability of these people proselytizing to the rest of the company and to the community the worthiness of a robotic system is very probable.

The second aspect which ought to be understood relates to the shift in labor profile, which occurs after all technological improvements, but which yields a slightly different ramification when dealing with robotics. Figure 1 will help to illustrate this point. Derived from Table I, Fig. 1 depicts an established production activity with a defined output and a defined labor quantity. As can readily be seen in Fig. 1(b), labor decreases as the direct result of robotic implementation by L*-L** to maintain the same output Q, as noted in Fig. 1(a). This result is not particularly surprising or interesting until one analyzes Table I. Assuming that this table does depict a fairly typical production process, it will be noted that certain functions, particularly those that are unskilled or semiskilled, have been greatly reduced or eliminated. What is interesting about this is that the labor profile previously required more a mixture of skilled, semiskilled, and unskilled. After robotic implementation, the need for unskilled or semiskilled workers will be reduced substantially; for what functions will the unskilled be needed for now? This shift has several important ramifications. One, where will unskilled and displaced go? Two, will the company need to set up retraining programs? Three, will there be problems of relationship, of motivation, of supervision with the new labor mix? Four, if the amount of unskilled needed is reduced, how will down-time be addressed? Five, what will the community reaction be?

The third aspect which must be studied relates to quality, the standards articulated to attain it, technical staffing, and process control. With the robot, functions must be well-defined, otherwise there is confusion and technical difficulties. There is a negative and a positive side to this aspect. The negative side is if process or quality standards do not exist, or at least are very vague, then the robot will become ineffective. If the process or quality standards must be redone, then there is required a reevaluation of directions, methods, and concepts, which usually results in positive gains. Finally, a reevaluation of staff and its capabilities and work assignments is likely to yield positive and negative gains.

The fourth aspect of concern relates to the time horizon that is generated by utilizing a robot. Obviously, a capital expenditure of the magnitude required for a robotic system requires some sort of long-term commitment. Yet again, the robot offers many subtle advantages and problems over time not explicitly obvious. Figure 2 illustrates this point. As discussed earlier, labor costs in a technological improvement tend to become a smaller part of total costs, and variable cost increases. Again this is not unexpected. With the robot, however, if the uniqueness premises stated earlier are correct, labor should maintain that small portion of total costs longer than other technological improvements. Indeed, if the robot, once established is not likely to be eradicated but improved once established, then the likelihood of labor becoming even a smaller portion of total costs is possible. Now, the shift to more skilled may increase costs. However, with the robot, reduced work weeks, a reduction of health costs, and improved safety practices are possible. Furthermore, with the robot, utilities costs can be reduced (they operate in the dark or even, when so designed, in less than pleasant temperatures). What the long-term reduction in cost yields is shown in Fig. 2(b): Margins are improved as costs become less dramatic in increase and the company is more successful at a constant volume.

The negative aspects of these last two aspects relates to how a company views itself in the community. What responsibility does the company have to make sure that community unemployment is low, that the workforce of the community is adequately educated (skilled)? Also, what perception the company has of itself as a long-term member of the community is important. These are not likely to be aspects which a business is likely to publicly address. However, because the robot is perceived in part along emotional lines, none of these questions must be unanswered. If the company does not care about its community, how long can it last? At the same time, if the company is not going to be in the area long, then what does it matter how it deals or does not deal with the human reactions? But if, as in most companies, there is a concern for the community and a desire to stay in the area, then retraining, educational grants, and out-placement services are the very least that the company must address when considering the reactions wrought from a robotic system.

In conclusion, some format of preliminary discussion is needed to delineate and to address the aspects we have brought forth. The attendant flowchart (Fig. 3) offers a conceptual framework for that discussion by encompassing the major aspects of reaction. We have purposely made this flowchart more general than the text in order that a wider range of discussion might ensue.

The robot is a critical technological improvement that we cannot fail to employ if we are to remain competitive. And we do a disservice to ourselves and to our industry by not pursuing the robot in all manual working environments. In the opinion of the author, we must not continue such a disservice long.

Table I. Comparison of Functions Before and After Robotics

Function	Before robotics (Man/h)	After robotics (Man/h)
1. Release	2.0	2.0
2. Set-up	8.0	8.0
3. Operate	90.0	0.0
4. Inspect	30.0	30.0
5. Load/Handle	7.5	0.0
Total	137.5	40.0

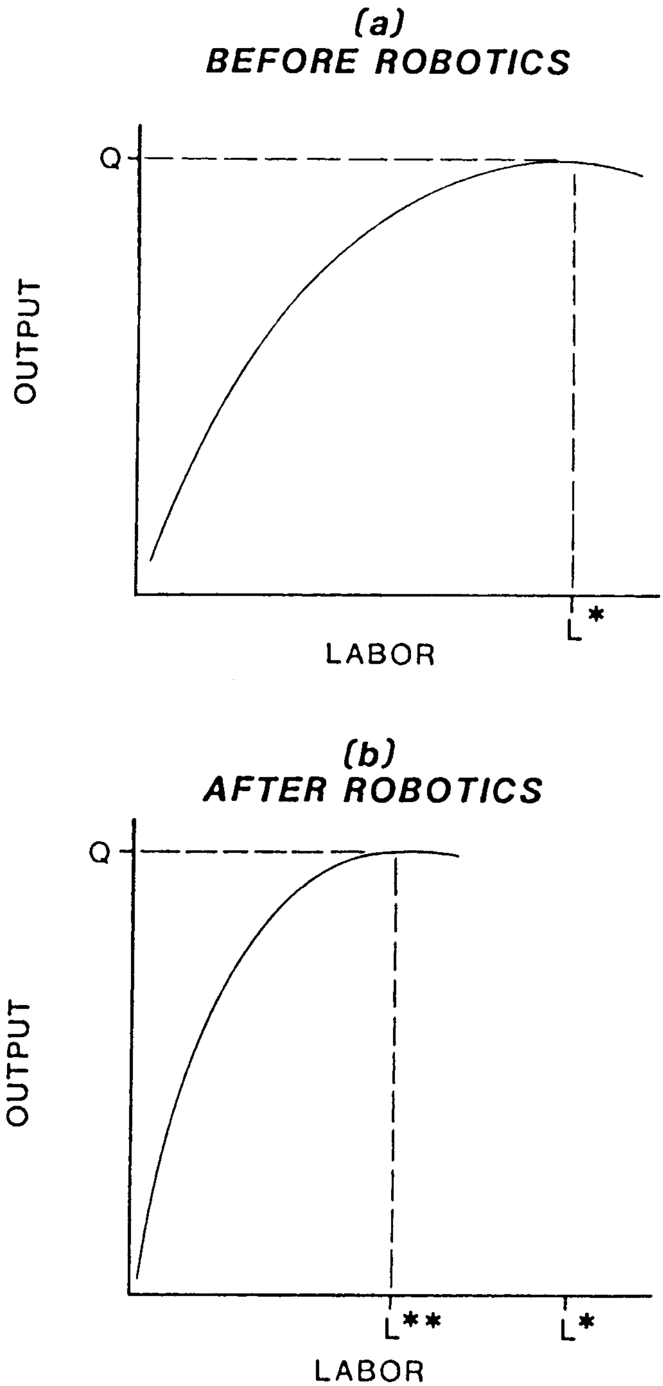

Fig. 1. Output-labor relationship before and after robotics.

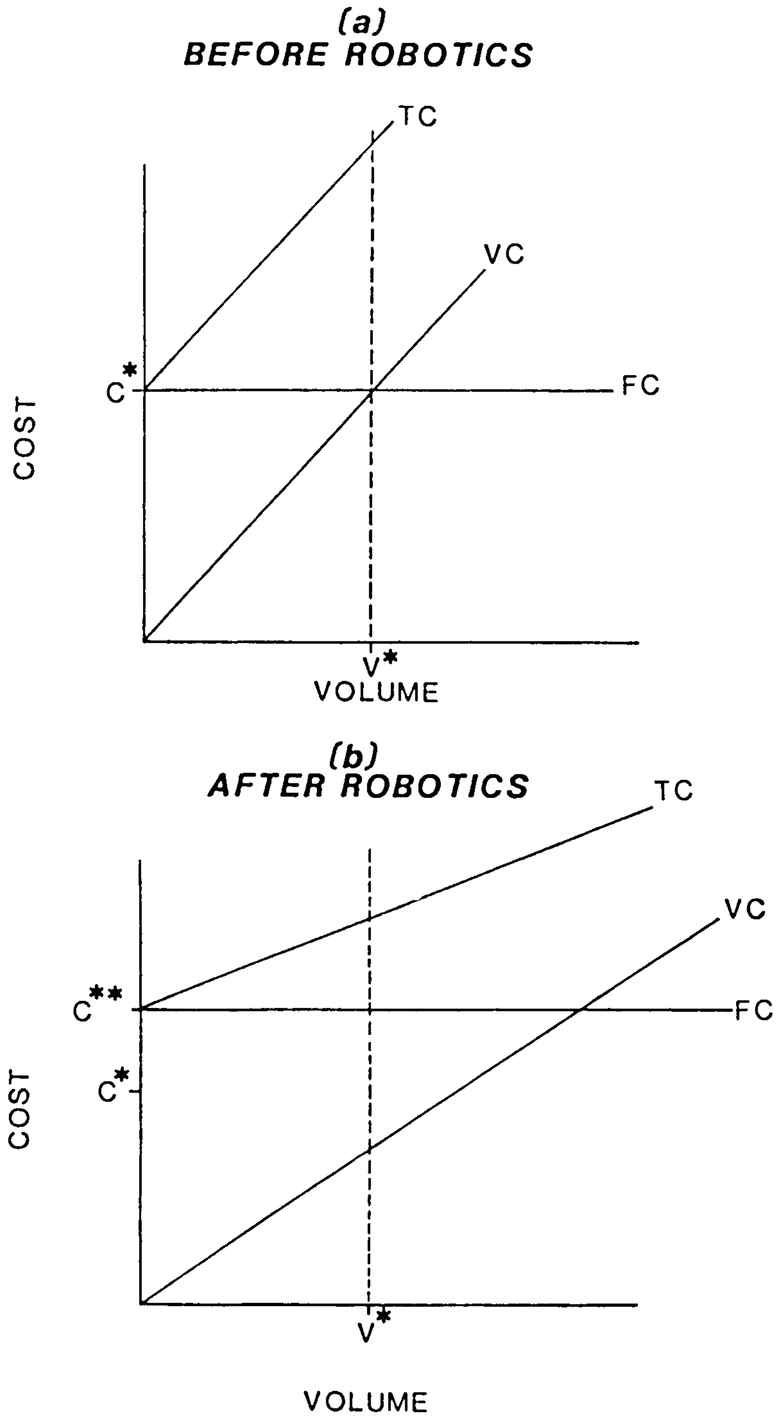

Fig. 2. Cost-volume relationship before and after robotics.

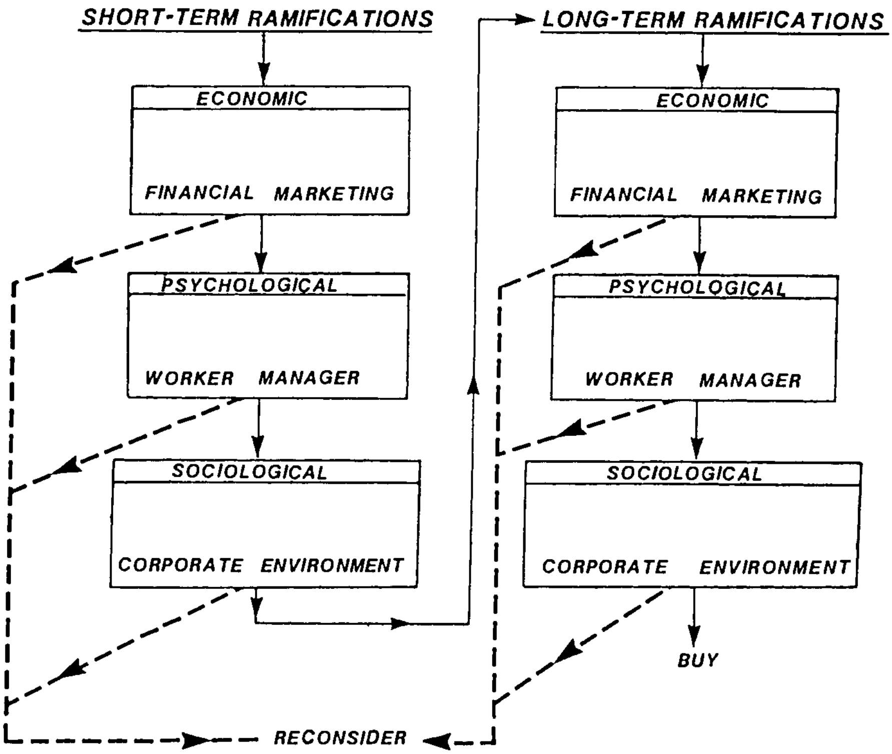

Fig. 3. Flowchart for discussion of justification of use of robots.

Ceramic Engineering and Sciences Proceedings
William J. Smothers

The Real Costs of Microcomputer Utilization

David M. Martin

Iowa State Univ.,
Ames, IA 50011

The use and cost of microcomputers in a ceramic engineering curriculum is discussed. Hardware and software requirements for specific educational goals are given. A cost accounting of local, as opposed to mainframe use shows that the low capital and operating costs characteristic of microcomputer use are at least partially offset by indirect costs for hardware and software maintenance.

Introduction

Today's graduate must be "computer literate," an ill-defined term which varies in meaning from knowing where the on-off switch is to understanding the complexities of assembler codes and operating systems. The public emphasis on computers and computing has increased dramatically in the past few years following the introduction of "Personal Computers" (PCs) into the consumer market. As indicated by Fig. 1, this emphasis is real since the number of computer products shipped has approximately doubled each year for the past few years. The world population of PCs now stands at about four million and continues to grow at an accelerating rate. The popularity of these machines has been a result of an attractive price-to-performance ratio. We can expect the trend of higher performance at a lower price to continue with the integration of sixteen bit and special purpose graphics microprocessors.

The PC has proven to be of great educational value to us at Iowa State University in exposing the student to a wide variety of computer applications using PCs. I'll describe some of the application areas our students are exposed to and discuss the associated costs. The low capital costs of PCs are only a small part of the cost picture and placement, peripheral, operating, and maintenance costs must be considered if one is to make an accurate assessment of the cost of implementing a PC-based computer system. In addition, each hour the student spends working at a computer represents time taken from some other activity and is a cost which, while difficult to quantify, must be considered.

Educational Requirements

Figure 2 shows the approximate direct exposure to computers that a ceramic engineering student now receives at ISU. Notice that only three of these credit hours are devoted to a formal course in computers unless the student elects to take a package of courses in computer engineering. Indirect exposure such as casual use by the student for word processing, problem solving, game playing, etc. would probably more than double the exposure indicated. We have tried to integrate computers into our coursework as tools rather than as objects of study although some instruction on the fundamentals of programming and of computer organization and hardware is unavoidable. We require only one course in a programming language, FORTRAN. This course is taken at the freshman or sophomore level. Our experience is that even though our PCs use a different language, BASIC, the concepts of programming are easily transferred to a new language, at least for scientific programming languages, therefore we give very little formal instruction on the BASIC language. Students are being exposed to computers in high school at an increasing rate. Seventy percent of this year's freshman engineers claim to have some experience and fifty percent classify themselves as expert or advanced! Virtually all of this experience is in BASIC and, like it or not, BASIC is here to stay.

Following the student's initial exposure to programming, we gradually integrate the PCs into coursework. A couple of work stations with good word processing and plotting programs are available and students are encouraged, but not required, to use them. Sophomores are encouraged to write small programs to help in doing homework and in the analysis of laboratory experiments. For example, a sophomore laboratory exercise in freezing point depression involves the determination of the heat of solution of a salt in water as a function of concentration. The second part of the experiment is to determine the freezing point depression of ice by adding the salt to an ice/water mixture. An iterative approach to calculating the quantity of ice melted by the salt addition is required due to the variation of heat of solution with concentration. Solving this problem on the computer is easy while doing it by hand is tedious to say the least.

Upperclassmen are required to write programs to model statistical process as a means to drive home the concepts that underly problems in quality control. Senior students are required to write programs for the analysis of both steady and non-steady heat flow problems. Finite difference methods are used to model one-, two-, and three-dimensional heat flow processes with internal heat generation and a variety of boundary conditions. Students are asked to write these programs rather than use existing, more sophisticated programs which can solve the same problems faster and more accurately to meet an educational goal of understanding both heat flow processes and computer programs to model them. It is easier for students to understand the finite difference models than the partial differential equations on which they are based. The senior students also design and implement computerized experiments which involve data acquisition, control of external devices, such as furnaces, and real-time data analysis. "Hot-wire" and flash-method thermal conductivity experiments were successfully conducted by the senior class this year. Some students get involved with programming at the assembler language level and in the design and construction of special digital circuits in order to perform special tasks with the PCs, but few are involved at this level due to the extensive time and intellectual requirements.

This student involvement is not free. Each hour of computer instruction and use in the classroom is at the expense of some other topic which might be taught. It is hard to decide if a student should learn to do finite difference heat-flow calculations and not learn that the answers to most problems can simply be read off a Heisler chart. Is flipping a coin better than having a computer generate a random sequence of numbers? Only experience will answer these questions, but it is time for the ceramic engineering educational community to begin active discussion of what should be taught.

General Goals and Hardware Requirements

Our educational goals are outlined in Figs. 3 and 4. We first try to develop "computer literacy" through the voluntary use of existing utilities such as word processing and plotting programs. About half of the laboratory reports, etc. are now done using these systems. Large utility and text-oriented programs such as a word processor have the largest memory and mass storage requirements of any of the uses of our PCs as well as tying them up for the greatest length of time. We find that a 32K memory is just adequate for these purposes and that access to floppy disk storage is essential. It is surprising that general purpose programming by students requires little in the way of memory or peripherals, although access to a printer greatly speeds up the debugging process. An 8K user memory and a printer for every half-dozen workstations seems adequate even for finite difference programming. The small memory requirement is a characteristic of most engineering problems since most of our problems require the application of a relatively simple algorithm over and over again. This memory requirement is greatly increased if bit-mapped graphics are used, but few undergraduate level problems require graphics.

Analysis packages, such as general purpose curve fitting, can also be accomplished with relatively small memory machines; around 16K has proved sufficient for our purposes. The device requirements for process control are minimal from the memory standpoint but more stringent as far as hardware is concerned. It is essential that bit-addressable, latching-peripheral interface adapters accessible by the user be included as part of the PC. Very often "game ports" on PCs meet this requirement and can be used for I/O control of furnaces, etc. A lot of miscellaneous hardware, such as buffers, photodiodes, breadboards, etc., are also required. A further requirement, which is met by relatively few PCs, is that the machine should be capable of addressing multiple peripheral devices through a standard communication link such as the IEEE-488 (HP-IB) bus. In addition, the computer's language must support high level commands to communicate with intelligent peripherals such as digital multimeters. It is for this reason that we have made heavy use of the Commodore line of PCs.

Programming at the operating system level requires good software and peripheral support in the form of documentation, symbolic or macroassemblers, floppy disk storage, etc. If programming of single-board or single-chip microcomputers is to be effective, good emulation hardware or software as well as support electronics, must be available.

Equipment and Costs

Figure 5 shows the complement of equipment on hand at ISU. This equipment provides adequate access for about 40 ceramic engineering students, including five graduate students. A separate computational area is reserved for graduate student use due to their heavier demands on both hardware and software.

We began to acquire and integrate PCs into our program about six years ago. The reasons for this move were as follows:

(1) Interested staff,
(2) Low capital & operating costs for PCs, and
(3) Possibilities for control of experiments.

Of these factors the first was the most important since a major time commitment was involved in learning to use the machines. While a direct cost comparison such as that shown in Fig. 6 shows that costs are higher for a central computer system, the data as presented can be misleading. The use rate for the central system tends to be much higher than that of the local system, so the capital cost amortized over the usable lifetime of the system may be quite low. In addition, at least one man-yr of senior staff time was devoted to getting our local PC system operational. On the other hand, our PCs can perform data acquisition and interrupt-type control functions that are out of the question for a time-sharing central system at a low capital and operating cost. The capital cost for a control work station is higher than for a general purpose work station due to the extra peripherals (DMMs, etc.) while the operating costs are higher due to extra demands put on the hardware and software by control programs.

Operating costs for a local system are small and are centered on maintenance. Both software and hardware maintenance are necessary, but probably amount to less than ten percent of the value of the system per yr, although as Fig. 7 indicates, the indirect cost of hardware maintenance can be quite high. If you try local repairs, the learning time involved can be quite high due to the service personnel's being unfamiliar with the devices, while the lost production time can be very expensive if remote maintenance is performed even though the direct cost may be lower. Fortunately, as indicated in Fig. 8, reliability tends to be very good. We experience equipment failure about once every 1000 device h for normal use and about twice that rate for control applications. The fact that there is a failure rate necessitates an investment in backup systems, especially for critical applications.

Locally developed hardware and software tend to be very expensive. The indirect cost associated with writing programs is often ignored, but is usually very high. As is indicated in Fig. 9, even the best programmers take about 15 min per line of debugged code and, if the cost of learning a new language is added to that, the cost can be high even for a modest program. Other indirect costs revolve around misuse of the computer; e.g., computing things which are better handled by other methods, word processing when a simple penciled note will do, doing simple sums, etc. Fortunately, such misuse seems to go through a maximum and taper off as users become more mature.

Cost of Control Applications

Computer control of processes and experiments is attractive as it can result in increases in both precision and productivity. The computer hardware costs associated are usually quite small in comparison with the overall costs as shown in the somewhat extreme example of Fig. 10. In this case, the largest fraction of the hardware cost was in locally designed and constructed devices, while purchase of controllers and other equipment capable of computer interfacing was the second largest cost. The development of software and the debugging of the system was expensive and stretched out over a long time period. This is not unusual, as is indicated in Fig. 11, which shows schematically the cost vs time for development of a typical computer process control application. Notice that the development and maintenance of software tends to be a never-ending process.

Future

It is clear that applications of PCs as intelligent work stations will continue to expand. Much of the added capability implied by the recent developments in hardware will be adsorbed into more user-friendly operating systems and in the support of graphics. Fortunately, standards are being promulgated which will greatly assist in the development of networks of intelligent work stations based on PCs. We at ISU are very actively involved in trying to decide what specific directions we will take in the near future and we anticipate a very widespread network. It is likely that all engineering students will be required to purchase a PC in the near future.

Conclusions

We have found microprocessor-based PCs to be useful in the educational process at Iowa State University and expect both their local and network capabilities to expand in the near future. This utility has not been without cost, and our experience is that capital costs are a small part of the total cost associated with using PCs in the educational environment. The indirect costs of software and hardware development are much higher than either initial investment or routine maintenance.

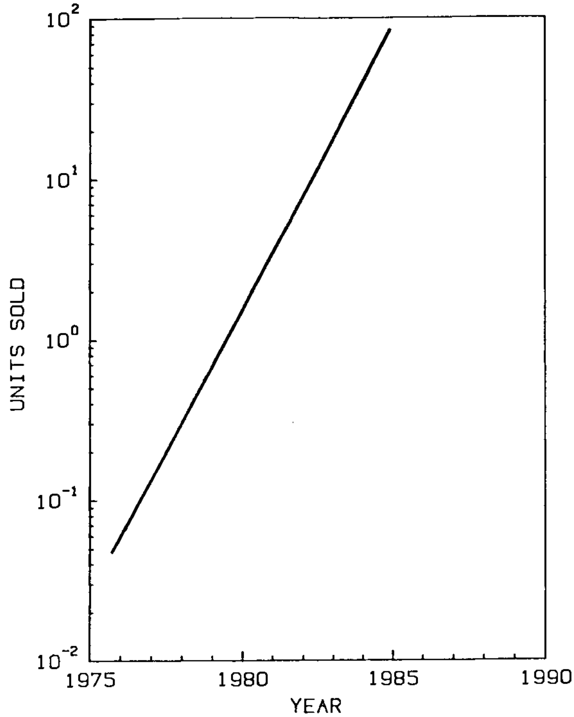

Fig. 1. Computer shipments vs time.

COURSE	CR.	LANGUAGE	COMMENT
Fre Eng	3.0	FORTRAN	VAX/GRAPH
Intro CER	0.4	-	data analysis
CER STAT	0.5	BASIC	PET(modeling)
VIT STATE	0.1	BASIC	PET(CAD)
DESIGN	3.0	BASIC	PET/VAX
			prgm analysis
			modeling
DESIGN	1.5	BASIC	communication
	---		& control
	7.5		

(Cpr. E. optional 6.5 Cr.)

Fig. 2. Iowa State University course requirements.

* "Computer Literacy"
  - wordprocessor
  - graph preparation (32K, shared mass storage, plotter, printer)
  - CAD/CAM/CAE

* Programming instruction
  - iterative solutions (8K)
  - finite difference (8K)
  - modeling (8-16K)

* Analysis
  - curve fitting (16K)
  - finite difference (16K)

* Process control (8K)
  - bit I/O (breadboards, buffers, solid state relays, photodiodes, etc.)
  - Analog input (IEEE-488 meters, multiplexers)
  - robotics
  - communications

* System programming (16K)
  - assembler etc.
  - various microcomputers, support hardware

Fig. 3. Educational goals.

* Dumb Terminals	3
* Personal Computers (12 Commodore, 1 Tek)	13
* Microcomputers	3
* Data acquisition	
Digitizer tablet	1
DMM	8
Power switches	6
Digital 'Scope	2
* Peripheral support	
plotter	3
double disk drive	2
printers	5
modem	3
* Educational Robot	1

Fig. 4. Purchased equipment.

```
* VAX 11/780
  -capital/terminal            $5000
  -operating cost/Khr.         $2700

* PC station
  -capital/terminal            $1250
    (printer,plotter,
     disk, etc. shared)
  -operating cost/Khr.         $ 300
     ( both hardware
       & software )

* Process control station
  -capital/terminal            $2000
    (DMM, misc. hdwe)
  -operating cost/khr.         $ 500
```

Fig. 5. Costs of equipment and operation.

* Home built very costly
* Maintenance

  <u>Local maintenance</u>
  costly due to poor documentation & small numbers of many types of devices.

  <u>Remote maintenance</u>
  costly due to lost production.

Fig. 6. Hardware.

* 1 breakdown/Khr.
* 2 for development.
* Backup systems are a necessity.

Fig. 7. Reliability.

* Software
  - new language 100 hrs.
  - programming is costly
    15% writing
    20% planning
    55% debugging
    1/4 hr. per line
  - maintenance costly
  - lazy computation (i.e. print 2*4)
  - wordprocessing when a pencil will do
  - neglecting math

Fig. 8. Indirect costs.

* Acoustic analysis apparatus

-Hardware

Computer	$1K
Peripherals	$4K
Local Hardware	$20K

-Debug

six man-months

-maintenance

20%

Fig. 9. Cost of computer control.

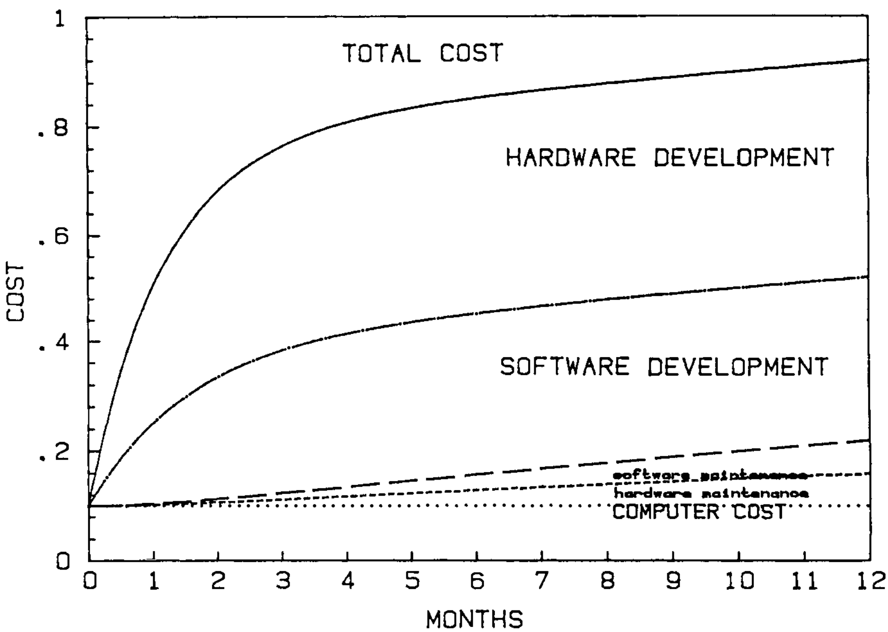

Fig. 10. Costs vs time.

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William J. Smothers

Accessing Remote Databases

JOAN J. SIERECKI

Sierecki's Information Solutions
528 E. Monte Rd., El Cajon, CA 92020

A variety of resources exist which can be accessed by modem over standard telephone lines with a personal computer. Databases specializing in engineering, marketing, business statistics, patents, and legal information are available at reasonable cost. Services such as Dialog, The Source, and Compuserve, among others, are compared.

I am going to discuss the equipment necessary for accessing remote databases, the history of online database development, an example of database use, and comparisons with other vendors.

Many of you already use in-house computer retrieval systems in accounting, research, or electronic mail applications. Many of you also use out-of-house computer retrieval systems which are either hard-wired or phone accessed.

I brought along my chief silent employee who requires juice but no food, maintenance but no salary, and doesn't talk back to the boss. I introduce my modem, a Lexicon-11. It is a simple 300-band (roughly 30 characters in speed) access device to the world of databases. Without my trusty modem, I would be confined to the world of canned programs and single-source databases of my own. A modem plus a telephone and a terminal equals database access. I have used the Hewlett-Packard terminals, the Sinclair ZX81 microcomputer, and the Televideo 950 as terminal access devices. After setting up the computer terminal and modem for receipt of data, the source computer for the databases is dialed. When the computer answers, the phone is placed in the modem for use in working the databases.

Databases are files with information, preferably in a set format that require software to retrieve the records in the files. Database access is sold through vendors. These vendors can be located in books by Cuadra[1] and Van Mayros.[2] Some of the vendors include Dow Jones, General Electric, Lockheed, Pergamon, and System Development Corporation.

Database development began in the early 1960s when the government provided funds to the Library of Congress for the MARC or Machine Readable Character format for cataloging books and eventually other materials. The MARC records were set-up in a specified format using field tags in order to retrieve the information about a publication. In the early 1970s, the government sponsored Lockheed's research to develop software to run the government databases in education (ERIC), government research (NTIS) and agriculture (AGRICOLA). Lockheed rose to the occasion with a system of commands and operators for retrieval of information from those databases. Those few databases have become almost 200 on the Lockheed system which provides access to millions of records.

I used the American Ceramic Society as an illustration of the kinds of information available from the remote databases. I went to the Encyclopedia of Associations file to get a background on the organization. I then went to the master index with the terms "ceramics" and "database" to see where most of the information on this combination of sets is located. I avoided Chemical Abstracts as having too much information and narrowed my search. The master index is useful to novice users and experienced users in new areas. Searchers can check their keywords and search strategies here first in order to narrow or broaden their search. I then looked at the Engineering Meetings database to check and see if anyone had given a similar talk at any engineering meetings but found none. Since I wanted an illustration of a search, I combined "ceramics" and "database" to find nine references. All nine papers deal with the topic of computer use in ceramics.

The Lockheed information databases include engineering, chemistry, art, marketing, law and even non-bibliographic information as the Consumer Price Index with both old and new versions. You only pay for searches you execute in contrast to some other vendors which charge a flat fee per month whether used or not. In the Lockheed system, if the password is unused for four months, it is automatically cancelled and you have to reapply for it. Billing is once a month and breaks down the date, time, minutes, fractions of minutes in each database and the telecommunication charges. The most commonly used vendors of telecommunication are Telenet, Tymnet, and Uninet but some vendors are directly accessible.

The more general public systems include THE SOURCE and COMPUSERVE. Both of these services are geared toward the everyday computerist in providing electronic mail, online shopping, bartering, stock quotations, news as well as computer storage of your private files and statistical packages you can use. Private groups have formed for particular interest areas on these systems, including real estate brokers, writers, and CBers. The search commands are not as uniform from database to database as are the bibliographic database vendors' systems. The menu system of choosing among options gets annoying when trying to move from one database to another especially when the "HELP" command does not extricate you.

The Pergamon and System Development Corporation systems are direct competitors of Lockheed, but each has fewer databases than Lockheed, with many overlapping. Search commands are different for all three which is analogous to learning three different programming languages. All three provide good user support so that each should be compared in light of your individual needs.

Here you have just a glimpse into the world of remote databases.

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[1]Directory of Online Databases, vol. 3, no. 3. Compiled and edited by Ruth N. Cuadra, et al. Published quarterly by Cuadra Associates, Santa Monica, CA, 1982.

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William J. Smothers

Advanced Manufacturing with Robotics

RALPH L. DRATCH

PA Technology
707 Alexander Road, Princeton, NJ 08450

CHARLES S. SKINNER

Booz, Allen & Hamilton, Inc.
8800 E. Pleasant Valley, Cleveland, OH 44131

Basic types of industrial robots are defined from a user's viewpoint. An overview of robot motion characteristics is presented as a means of differentiating currently available robotic systems. Non-servo and servo-controlled robots are defined along with advantages and disadvantages of each. Implementation is discussed from both a technical and economic viewpoint. Implementation costs are broken down into capital, development, and recurring expenses. In closing, a hypothesis is presented for how the factory of the future will develop and the impact this will have on the industrial robot market.

Introduction

This discussion is organized into two parts. The first presents some background information concerning industrial robots from our viewpoint as having worked in the field over the past ten years. The second part addresses the issues that currently face both industrial robot suppliers and users. It represents some of the latest thinking in the field of manufacturing technology at Booz, Allen & Hamilton.

Definition Of A Robot

To begin, let us attempt to define just what an industrial robot is. The Robot Institute of America (RIA), a branch of the Society of Manufacturing Engineers, has published the following definition:

"An industrial robot is a programmable, multifunctional device designed to both manipulate and transport material, parts, tools, or specialized manufacturing implements through variable programmed paths for the performance of specific manufacturing tasks."

This definition is rather lengthy, but it does identify the key elements that distinguish industrial robots from other manufacturing equipment, such as:

- Programmability–By making relatively simple changes to control circuits–either software, hardwire or pneumatic–an industrial robot can be redirected to perform more than one task.
- Manipulate and transport functions–A robot is not a tool. It uses "hand-held" tools and devices to carry out tasks that could be done by humans.
- Manufacturing tasks–Industrial robots operate in production environments.

Although many people are familiar with the configuration of today's industrial robots, it is not always easy to identify a robot by definition alone. Some examples of manufacturing devices which *don't* qualify as industrial robots include:

- NC milling machines–which are not multifunctional, since their only purpose is to remove material.
- Hard automation–such as canning and bottling lines, as they lack programmable features.

Actually, it turns out to be somewhat difficult to come up with an all inclusive/exclusive definition, since with some modification the above devices could qualify, by RIA's definition, as industrial robots. In these circumstances, one is reminded of a quip attributed to J. Engelberger, President of Unimation, "I can't define 'robot' for you, but I know one when I see one."

We might add that the word "robot" entered the English language via a 1922 play by the Czech author K. Capek–"Rossum's Universal Robot." In Czech, the word "robotnik" is synonymous with laborer or serf.

Structural Classification

Industrial robots are composed of a system of several basic components–the controller (brain), a manipulator (arm), and the end effector (hand) which is the device at the end of the arm performing the work. The configuration of manipulators can be used as a means of differentiating the large variety of robots available in today's marketplace. Current robot designs can be segmented into four categories (Fig. 1):

- Rectangular–where all motion is accomplished along perpendicular, linear sliding axes.
- Spherical–which uses a series of rotary joints to position the manipulator. A sliding (telescoping) joint is also included for arm length adjustment.
- Cylindrical–combines rotary and linear motion.
- Anthropomorphic–sometimes referred to as "jointed arm," the motion of this manipulator most resembles that of a human arm.

Each joint in the mechanism corresponds to a controlled variable known as an axis of motion. Generally, the degree of complexity of manipulator motion is governed by the number of controlled axes. Although any point within the robot's envelope of motion can be reached by controlling three axes of motion, it requires six control axes to position an object (such as a welding rod) at an arbitrary orientation. It is not uncommon, however, to encounter robotic systems with over six controlled axes. The added axes provide a convenient means to control complex motions.

Manipulator joints may be equipped with position sensors (encoders) to feed back to the controller data related to position. Typically, encoders measure the relative rotation or linear displacement at each joint. Encoders, as a rule, do not sense the environment outside of the manipulator boundary, as would a more sophisticated vision sensor.

Controls

Robot controllers range from minicomputers equipped with real-time operating systems, to much simpler, pneumatically powered sequence circuits. From a user's viewpoint, robotic controls can be divided into two overall groups–non-servo and servo control. Servo refers to a type of control philosophy whereby the mechanism (manipulator) is under constant supervision by the logic circuitry. Such supervision requires the real-time feedback and analysis of motion data, and as a result, is more complicated and costly than simpler non-servo systems.

Figure 2 illustrates a typical example of a non-servo auto-place robot which uses pneumatic power. The sequence of rotary and linear motions are preset using a pneumatic logic circuit. In operation, motion continues along an axis until the mechanism encounters a stop or limit switch, which is also preset by the user. Tripping the switch signals the controller to begin the next segment of the sequence. Since this is a non-servo system, the controller is "unaware" of the actual position of the arm while it is moving. Typically, each control axis can assume only two positions–start point and end point–once these points have been set by the user. Since the control logic is relatively simple, non-servo robots can move at much faster cycle speeds than servo devices. This characteristic has given rise to the term "bang-bang" as a descriptive reference to the jerkiness of the motion, since axial displacement continues at full speed until a limit switch is encountered. In addition to being fast, non-servo robots are usually less expensive than servo-controlled robots. Prices typically range from $5000 to $25 000. They are simple to use, and the simplicity of design tends to make them very reliable.

Servo-controlled robots utilize a feedback loop to continuously sense the dynamics of manipulator motion. Figure 3 shows a simplified schematic of a servo controller. In this case, the user predefines manipulator motion by establishing set points in the controller memory. The controller compares signals from position sensors with the next point in the motion sequence and generates an "error" signal proportional to the difference between the two. This signal drives the actuators–electric or hydraulic motors–in the required direction of motion. Since sensor data can be sampled at high rates, such as 60 cycles/s, robot motion is controlled, for all intents and purposes, continuously.

Servo-controlled robots are more versatile than non-servo designs, since a much wider range and combination of set points is available. As there are no hard stops imposed by limit switches, motion is smoother, with lower accelerations and less impact load. Powerful logic imbedded in the controller permits the definition of complicated motions, vision inputs, and the convenience of reprogramming by simply switching cassettes. These features add considerably to the cost of the system. Depending on the size, payload, and sophistication of the robot, prices range from $5000 to $150 000 for off-the-shelf, servo-controlled systems.

Motion Characteristics

Control systems determine the nature of manipulator motion. A fundamental type of motion is referred to as point-to-point displacement. Most non-servo and many servo-controlled robots utilize point-to-point motion. In these systems, the user defines a series of points in space that the arm moves to. Each point is committed to memory and the controller determines the displacements along the axes as the arm moves from one point to the next. The user has no control over the path that the robot uses in moving between points. The robot is "taught" tasks by inputting point locations using a terminal or control pendent.

Point-to-point motion is unsuited to spray painting or continuous welding since the path of motion is undefined. For functions where curve following is required, continuous-path control is desirable. Continuous-path robots are "taught" by having an operator physically move the manipulator through the desired trajectory while the controller is in a record mode. During playback, the operator's motion is duplicated with high precision. A disadvantage of this technique is that considerable controller memory is required to record axis positions at the rate of 60 times/s. In this aspect, a point-to-point system is more efficient, since only the end points of motion are recorded, paths are automatically determined by the control logic.

The latest control technology, known as controlled path, combines the best features of point-to-point and continuous path. User defined paths of motion are calculated from input data "on the fly," permitting curve-following motion without requiring undue amounts of memory.

The next step in the evolution of robotic control will be various forms of adaptive controls. Such controls will receive data from outside of the present feedback loop and will alter the motion of the robot to adapt to changes in the environment. The use of vision sensors is an example of one attempt at adaptive control.

Applications

Typical applications for industrial robots include:

- Machine load/unload–die casting, injection molding, lathes, mills,
- Investment casting–dipping of investment molds,
- Welding–spot, continuous arc,
- Palletizing–stacking, unstacking,
- Spraying–paints, coatings,
- Hand tool usage–drilling, riveting, inspection, and
- Assembly–mechanical, electronic.

In each of these applications, the robot is used as a replacement for human labor. However, an analysis of robotic implementations in the United States reveals that although cost savings is an important consideration, quality of worker life is also a deciding factor. Thus the majority of U.S. robots have been implemented in areas that are considered dangerous or unpleasant environments. For example, spot welding on an automotive assembly line–a hot, hazardous job–has been a prime candidate for robotic equipment.

In Japan, an important driver for using robots is product quality. Robots can repeat operations tirelessly and do not forget and require retraining. The Japanese have also recognized the robot as a means of alleviating labor shortages in certain categories.

To date, organized labor has accepted the presence of a moderate number of robots in U.S. factories. Acceptance has been based on a realization of the economies of automation and on the replacement of personnel assigned to hazardous work environments. As robots are developed which can perform more skilled functions, and thus compete with workers for more attractive assignments, labor's position may undergo a change.

In selecting a robot for a particular installation, the following parameters require quantification:

- Payload–weight of the objects the robot will manipulate,
- Reach–extremes of required manipulator travel,
- Accuracy–tolerance and repeatability of required motions,
- Speed–time to perform a complete cycle, and
- Path control–point-to-point, continuous, controlled.

These parameters are used by manufacturing engineers to select the correct robot for the job.

Robot manufacturers typically market their products as if they were machine tools; that is, they are sold as standard items and not customized or adapted to the user's environment. This situation requires the expenditure of considerable time and effort by the user to design the installation. Among the most important steps in the design process are the development of the end effector and the presentation and orientation of work pieces. The end effector is that part of the robot which physically contacts the work. It is typically not sold by the robot supplier and usually is custom designed for the application. End effectors may include grippers, spray guns, drilling heads, and any of a wide variety of work devices.

The vast majority of robots currently in operation have no means of sensing the location or position of the parts they handle. They "expect" the work to always be in the same place. This detail requires careful attention and quite often an additional subsystem must be used to properly orient work pieces. The complexity involved in introducing a robot into a manufacturing operation suggests that users, especially first-time users, develop the application off-line to work out the "bugs."

Once installed and functioning, the flexibility of a robot to work on a variety of tasks is achieved by reprogramming. Currently, new programs are developed on-line, that is, by using the actual robot in the factory environment. This is in contrast to numerical control (NC) programming which is almost always done off-line without having to interfere with production work. Research is continuing on the development of off-line programming capabilities for robots. The difficulty, however, is that unlike an NC machine tool which uses rigid fixturing and precise control to accurately locate tools and work pieces, a robot and its environment is less controlled. Thus, a program developed for one robot may not function on a second identical robot because the work pieces, work-piece orientors and robots are not located in precisely the same relative positions on the shop floor.

To economically justify the introduction of a robot, three factors should be accounted for:

- Purchase price–ranging from $5000 to $150 000
- Implementation expenses–typically 50% or more of purchase price, and
- Operating expenses:
  - —Maintenance (labor and parts): $0.97–$1.94/h
  - —Attendant labor: $1.10–$2.20/h
  - —Power: $0.30–$0.74/h

  Total: $2.37–$4.88/h

In the ranges shown above for operating costs, hydraulically powered robots tend to be more expensive to operate than electric models.

Current Market

The robotic market is in a stage of expansion. New suppliers are entering the marketplace on an almost monthly basis, and the growth of sales has, over the last few years, been an impressive 30% to 50%. Some of the major suppliers are shown below, along with approximate 1980 sales (in millions of U.S. dollars).

Unimation	—	$ 36
Kawasaki	—	$ 25
Cincinnati Milacron	—	$ 24
Kobe	—	$ 21
Hitachi	—	$ 21
ASEA	—	$ 16

Trallfa	—	$ 16
Electrolux	—	$ 10
Fanuc	—	$ 10
Others	—	$ 46
		$223

The category of Others now includes such new entries as Bendix, Siemens, IBM, and General Electric, and such specialized suppliers as Advanced Robotics which builds continuous welding robotic systems.

Statistics on the number of robots in-place worldwide are extremely difficult to interpret due to the problem of defining just what an industrial robot is. Nevertheless, data published by RIA in 1980 shows Japan clearly leading the world in robotic installations (Fig. 4). Note that unlike U.S. manufacturers, the Japanese have made a practice of using less expensive non-servo robots. At the very least, this strategy has given Japanese manufacturers a great deal of experience with operating robotic systems in a production environment.

In the United States, the emphasis is on using more technically advanced servo-controlled robots. The expense associated with these devices has had a negative effect on management decisions to go robotic during the 1960s and 1970s. Figure 5 presents a simple economic argument for why current conditions favor high growth. In 1960, the annual cost of employing two workers per eight-h shift averaged $16 000. A $100 000 robot with $8000 average annual operating costs was not an attractive investment. Now, however, with factory workers' total compensation averaging $15/h, and robot purchase prices remaining constant, the economic advantage is in favor of the robot.

Future Developments

Advanced robotic technology is being developed through the efforts of industrial, institutional, and commercial research programs. Artificial intelligence, adaptive controls, vision and tactile sensors are but a few of the current areas of investigation. Just when these and other developments will enter the marketplace is difficult to predict as it involves the forecasting of technological breakthroughs. Looking at the opportunities for increased demand for industrial robots from a manufacturing viewpoint, however, may provide some insights into how the market may develop.

Assuming that robotic capabilities will be more or less consistent with what is available today, then over the next five- to eight-yr period robots will be used in a "displacement" mode. "Displacement" here refers to the direct substitution of robots for jobs carried out by people. To date, displacement has occurred in relatively easy implementation scenarios and in the so-called "dirty" work areas. However, as these implementation opportunities are fulfilled, increased pressure from labor and inadequacies in robotic capabilities will negatively impact market growth. These negative factors may be neutralized by the adoption of new approaches to manufacturing such as expressed in the concept of the Factory of the Future.

Advanced Manufacturing Systems

The primary attributes of the Factory of the Future are integrated information flow and an increase of automation throughout all areas of the factory. Figure 6 illustrates the concept of a factory-wide data base system for integrating information flow among the three major factory areas–engineering/design, planning and control, and manufacturing. Figure 6 also shows examples of the type of systems that will be used to automate these areas–computer-aided design (CAD), computer-aided engineering (CAE), and computer-based scheduling such as MRP systems. In manufacturing, automated fabrication and assembly has not yet been introduced into the majority of U.S. manufacturing enterprises.

A chronic problem with developing automated manufacturing capabilities has been the wide variety of parts and processes that are fabricated in typical manufacturing facilities. This is especially true in batch and job shop environments, which account for well over half of all manufacturing establishments. Batch production is based on making a large number of different parts in one facility by scheduling production of each part in small- to moderate-sized batches. This mode of manufacturing makes it difficult to design economic automated processes since one part is usually not produced in enough volume to justify the investment in automatic equipment. Recent advances in group technology have indicated that it may be possible to simplify batch manufacturing to the point where automation can be successfully employed.

In many of today's facilities process machinery is organized by function–all milling machines in one section, drills in another, and so forth. Any particular part may be routed back and forth from section to section as each operation in the process is performed. If one developed a matrix of part number vs operation, a fairly random pattern of "hits" (X's) may be expected (Fig. 7), where a "hit" indicates that a particular part is operated on by a specific machine. The principles of group technology point out, however, that there are similarities in part designs which lead to similar manufacturing requirements. By identifying these similarities, one can interchange matrix rows and columns and form clusters of parts that require similar operations. These clusters are referred to as part families.

Given a sufficient number of families, the shop floor can be reorganized into manufacturing cells, where each cell is dedicated to the complete fabrication of a family of parts. Cells would contain a variety of process equipment, such as is shown in the machining cell in Fig. 8, however, the similarity of parts would greatly simplify processing requirements within each cell.

Process equipment would have to be flexible, but not as flexible as in the traditional functional layout. It will also be practical to link the process equipment and provide for automated cell control (Fig. 9). The use of robots may be more feasible under these conditions.

Our view of the Factory of the Future for batch manufacturing is based on the adoption of "cellular" manufacturing. Within each cell, local controllers will be used to schedule material flow and processing. A factory controller, operating in a hierarchical mode, will support the cell controllers and schedule inter-cell material flow (Fig. 10).

To significantly impact manufacturing costs, the Factory of the Future will have to address more than just savings in direct labor. On average, manufacturing costs for U.S. products are accumulated as shown in Fig. 11. Factory labor typically contributes only 10% to manufacturing costs. The revolution in manufacturing must occur in indirect, as well as direct cost areas. If robots can be utilized in a manner which significantly impacts indirect costs, their attraction will increase markedly. Such creative implementations remain to be identified.

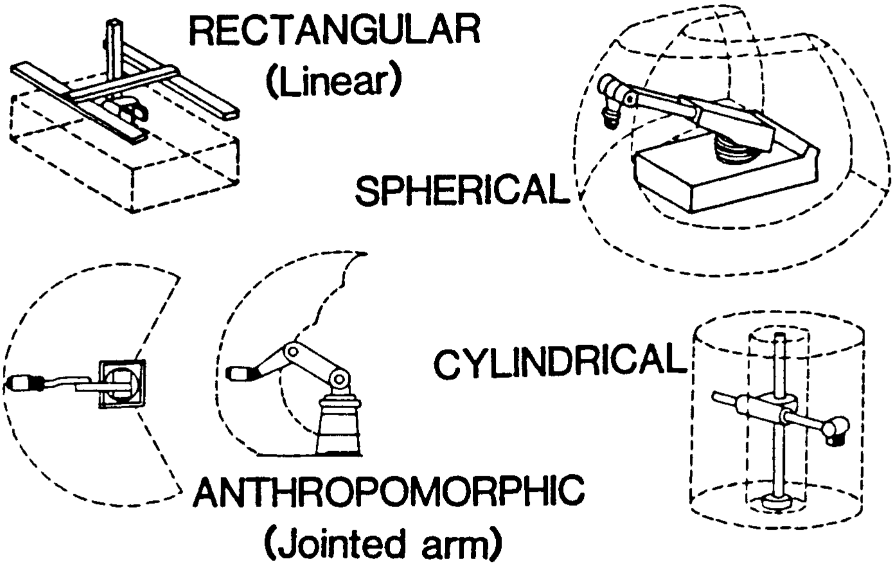

Fig. 1. Four major robot categories - by structure.

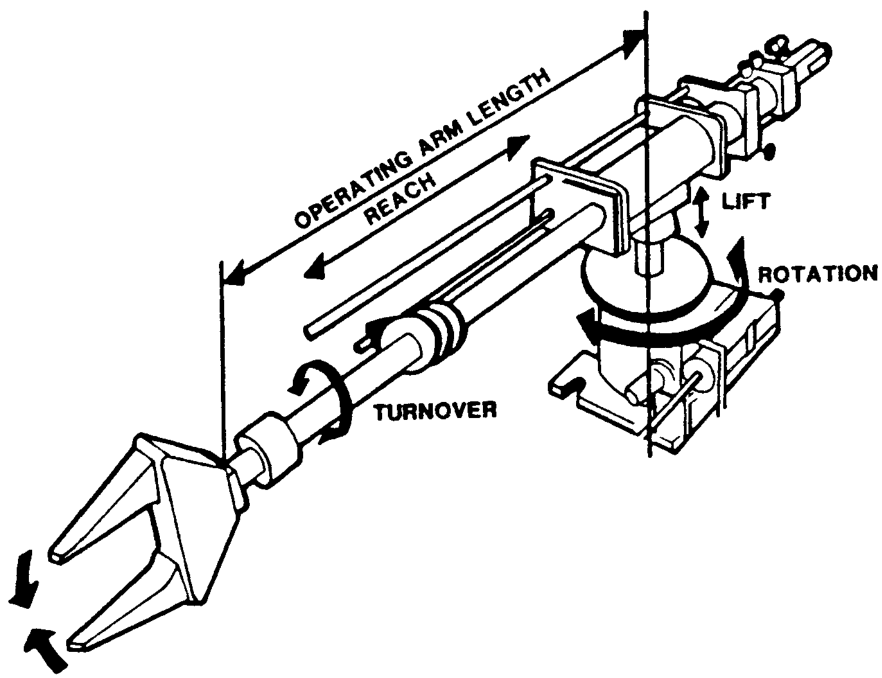

Fig. 2. A typical non-servo robot.

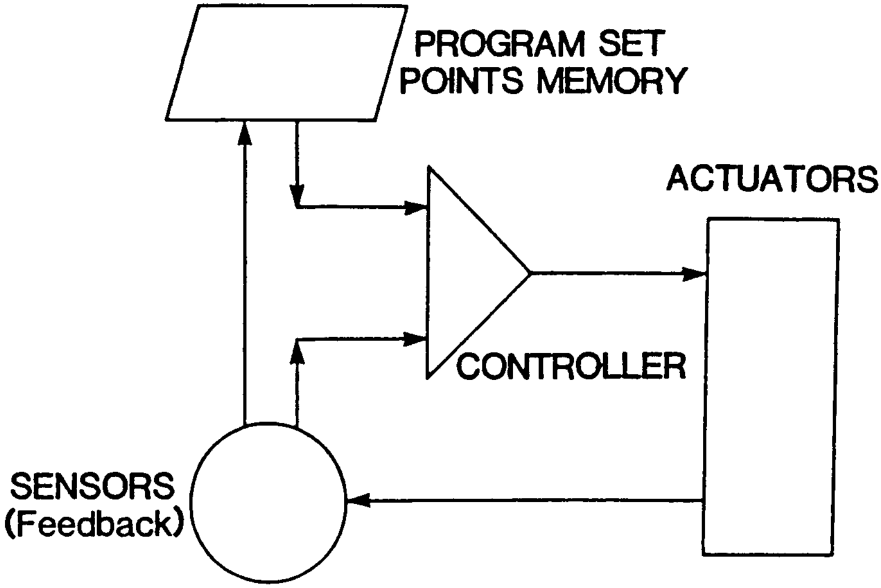

Fig. 3. Servo loop.

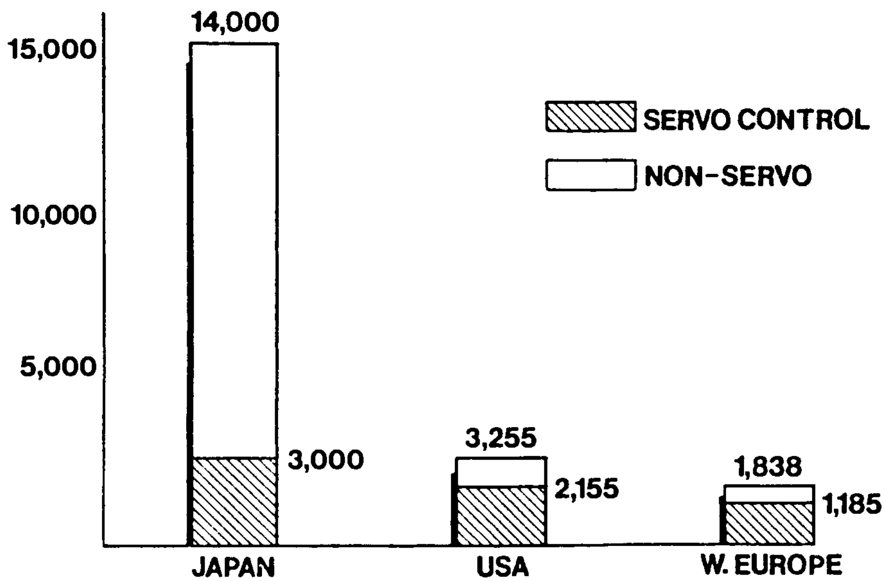

Fig. 4. Robot distribution by major area.

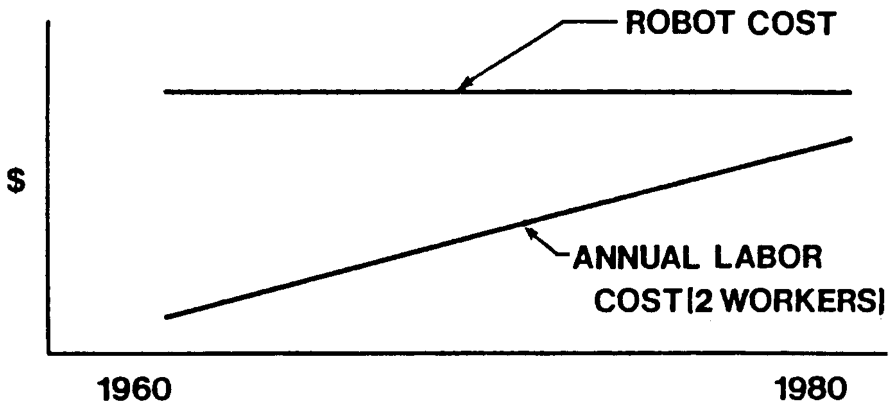

Fig. 5. Capital cost vs potential savings.

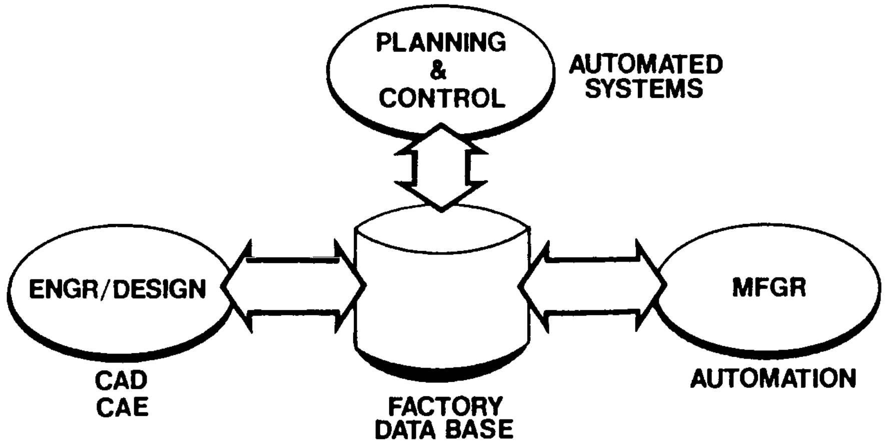

Fig. 6. Integrated factory of the future.

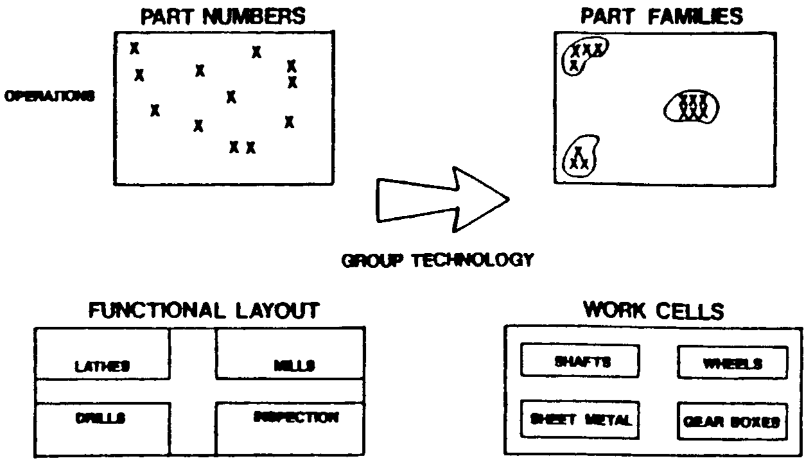

Fig. 7. Group technology/work cells.

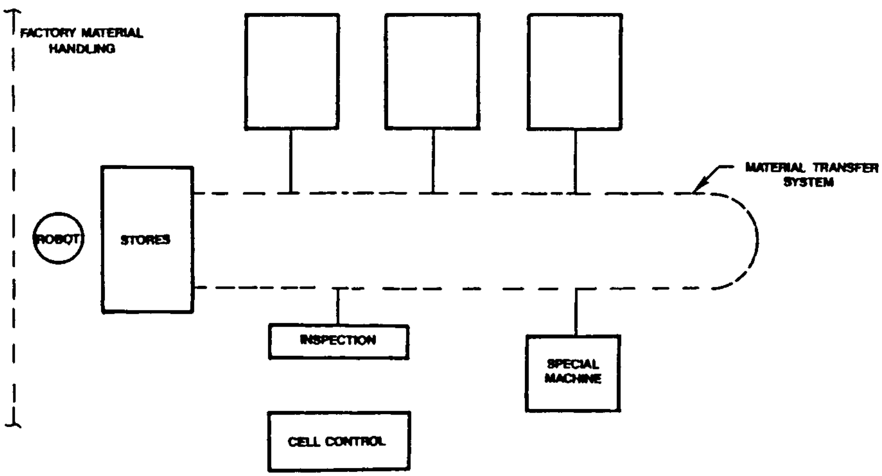

Fig. 8. Conceptual layout of a machining cell.

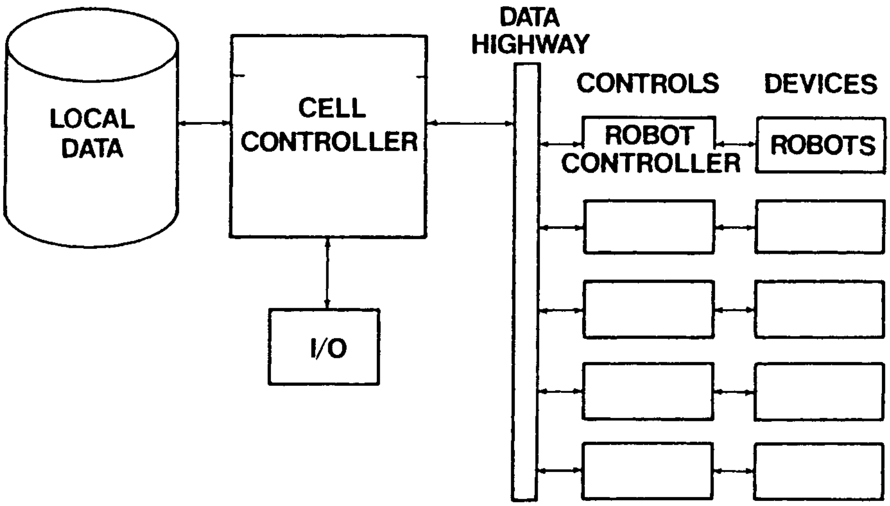

Fig. 9. Automated cell control.

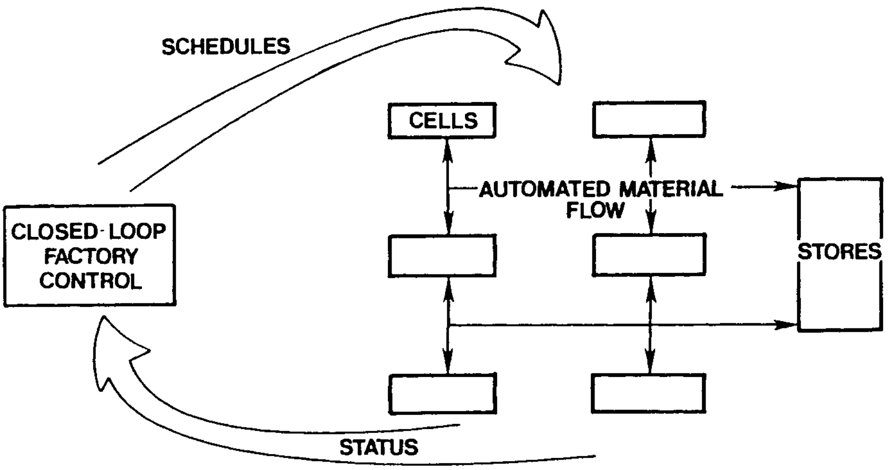

Fig. 10. A concept for batch manufacturing in the future.

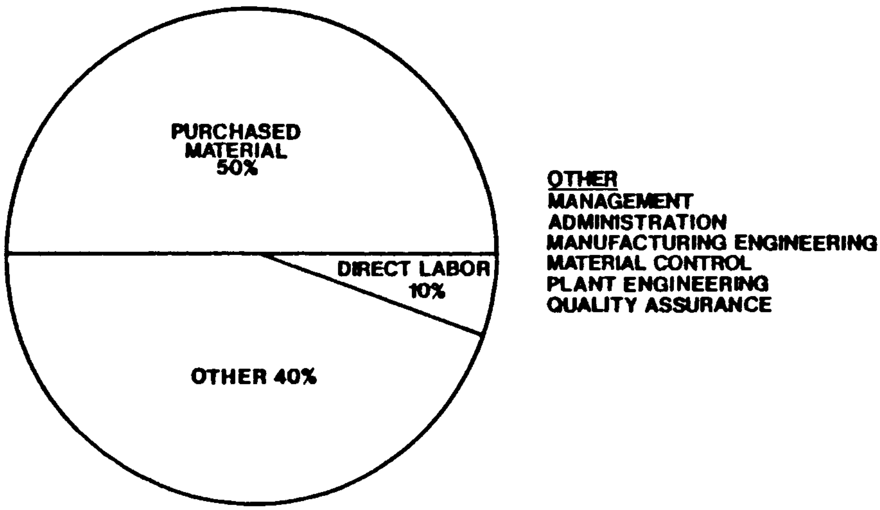

Fig. 11. Components of manufacturing cost.

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William J. Smothers

A Fundamental Examination of Pick-and-Place Robots

JOHN P. MALLOY AND GERALD A. ILSE

Modern Machine Works
5355 S. Kirkwood Ave., Cudahy, WI 53110

Pick-and-place robots are simple, yet widely used. This paper explains what a pick-and-place robot is and why they will be so important during the next decade. It describes the steps necessary to identify their technical and economic feasibility in the manufacturing process. Successful installations are described.

Introduction

During recent years the appearance of robots on the industrial scene has ignited an explosion of interest in the subject. Considerable coverage has been given the topic in the various manufacturing and design engineering technical publications. However, a review of the literature reveals the major emphasis has been focused on the more complex and sophisticated type robots. Relatively little has been published about the simple yet important pick-and-place robot. It is the primary purpose of this article to examine pick-and-place robots particularly the reprogrammable type–Type *C*.

In the sections which follow there will be considered the following major facets of the topic: a definition of pick-and-place robots with their relationship to the larger class of robots; the major importance of pick-and-place robots; the major subsystems which comprise a robot; the particular advantage of pick-and-place robots; the price consideration and economic justifications of pick-and-place robots; and examination of several types of successful applications of pick-and-place robots; finally, the merits of using a turnkey service to avoid costly start-up delays will be reviewed.

Pick-and-Place Robots Defined

Robot manufacturers have developed and are continuing to develop a variety of robotic systems. Some are very simple–some are complex units equipped with sensor feedback units with "intelligence" and "vision." All robots, whatever their type, must conform to the following definition: a robot is a reprogrammable multifunction manipulator designed to move materials, parts, tools, and/or specialized devices through variable programmed motions for the performance of a variety of tasks. In essence, a robot is a system to move objects and perform tasks.

Robots are categorized as non-servo controlled or servo controlled systems depending on the control system used, i.e., the way in which a robot moves from one point to the next and the number of points within its work envelope at which it can stop defines its functional classification.

Non-Servo Robots

Non-servo robots are limited in their axes of motion. They are used where the transfer operations are simple, where high speed is required, and where flexibility is not a high priority. Many non-servo robots are called pick-and-place robots. A pick-and-place non-servo robot is designed to perform a specific task such as loading machine tools. Certain pick-and-place units are equipped with programming capabilities which increase dramatically their flexibility for retooling. It also enables them to be quickly modified for a changed function.

Servo Controlled Robots

Servo controlled robots are either point-to-point or continuous path robots. They contain an information feedback system which monitors the position of appropriate subsystems. They can be programmed to perform a complex sequence of activities. They use tools to work a part as well as to move a part.

Special tooling and material movement systems must often be added. The skills for maintenance are demanding. A major advantage is their relative mobility. The majority of servo robots, however, are dedicated to one task in one location. The lesson here is that there are many types of robots and it is crucial to marry the right robot to the proper task.

In addition to the major classification of servo and non-servo type robots, they have been classified further into types *A,B,C,D,* and *E*. Type *A* robots are designated those which are programmable, are servo controlled and have the capability of operating in a continuous path.

Type *B* are programmable, are servo controlled and operate in a point to point configuration.

Type *C* are programmable, are non-servo, and are general purpose.

Type *D* are programmable, are non-servo, and are used in die casting and molding.

Type *E* are mechanical transfer devices. Although Type *E* are considered as robots in Japan, they do not qualify as robots using the United States definition of robots.

In the remainder of this paper the concentration will be on an examination of Type *C* robots–general purpose pick-and-place robots.

Importance of Pick-and-Place Robots

As one studies the proliferation of types and application of robotic systems the question arises: What is the relative importance of each of the several types of robots and what will be the future importance of each type? Perhaps the best way to answer this is to utilize the collective judgment of "experts" in the field. This is the avowed purpose of the Delphi Study conducted by the University of Michigan and the Society of Manufacturing Engineers.[1]

This comprehensive study was begun in 1980 and the first results were published early in 1982. The number of participants ranged from 36 to 60. Eighty to ninty percent of the various panel participants were from firms using robots.

Over 200 questions were originally submitted to the panel. Three major sections were covered: technological, marketing, and sociological aspects. It is beyond the scope of this paper to present even in summary form the many conclusions reached.

However, several salient results which bear on pick-and-place robots and their relative importance are as follows:

(1) Approximately 10 000 robots will be used in the United States by 1985. Of this group 80% will have been produced by U.S. firms. This is to be contrasted with an estimated 3 000 American-made robots

produced for 1982. Thus, the study projected almost a tripling of the 1982 market by 1985.

(2) The study projects that pick-and-place robots will be the most frequently used robot until 1990. The second most frequent will be machine loading robots.[2]

(3) Among the six major types of robot applications, machine loading is projected as the most popular application between 1982 and 1990. The second most frequently used will be press loading/unloading followed by welding.[3]

A review of this information emphasizes the importance of pick-and-place robots, particularly for machine loading.

After establishing the importance of pick-and-place robots, it is appropriate to understand what constitutes a pick-and-place robot and how they function. Also it is helpful to be aware of the major systems which make up the pick-and-place robots. In this way one can better understand certain of the things which are common or characteristic of this type robot–Type *C*.

Major Subsystems of a Robot

It is important to understand that a robot or a robotic loader is really part of a larger machining system–"machining" used in its most generic sense. The major elements of a machining system include the machine tool itself, the power source, the perishable or consummable tools used, the operator, and the material handling system. The robot typically displaces some or all of the human operators in the system. It also plays an integral part in the material handling system.

Within the robotic system there are three major subsystems:

The "brain" or controller,
The "muscles" or power supply, and
The "hand" or parts gripper.

In a Class *C* or *D* robot several different type controllers can be used. However, because of flexibility, simplicity and cost the most prevalent currently is the programmable controller. It is the purpose of the controller to signal and monitor the activities of the other elements of the system.

The "muscles" or power system can be electrical or hydraulic. The "hand" or gripper in a typical pick-and-place robot is designed specifically for a part or a family of parts.

There are four steps involved in loading and unloading an automatic chucking lathe using a pick-and-place robotic loader. It is necessary only to load the hopper with the parts and to tie the unloaded parts into a material handling system when the machine cycle is completed. The machine's operator is thus eliminated in so far as loading and unloading the machine is concerned. An operator is free then to operate several systems.

An examination of the methodology of the three subsystems described reveals their simplicity, their economy, and their dependability both as regards manufacturing, production and maintenance. This leads to a review of certain of the characteristic advantages of pick-and-place robots.

Advantages of Pick-and-Place Robots

Since pick-and-place robotic systems are engineered for a specific task, they are generally operational almost immediately in the customer's factory. Costly relayout of machine tools is often avoided. Delays in "cutting chips" are avoided. Back-up units are lower priced. Other important characteristics include:

Rapid, accurate loading cycle,
Compact design provides high space efficiency,
Versatile, with a wide variety of applications,
Minimal downtime,
Tooling and chucks are part of system,
Low initial investment,
Maintenance is relatively simple,
No costly start-up delay,
Can be retooled for new parts,
Fast pay back,
High investment return, and
Proven performance in field.

Economic Justification

The financial justification of a robot is no different than a machine tool. The manufacturer substitutes a capitalized asset for variable labor. The new product unit cost must be lower. Reduced total machining cycle time or increased production uptime (or both) must result.

Pick-and-place robots are substantially lower in price than more complicated servo robotic systems. The replacement of one machine operator for two shifts provides cost savings which currently approximate $50 000 annually. Depreciation and maintenance costs must be offset against labor costs. The cost of a pick-and-place robot can often be recovered in one yr. Where several pick-and-place robots are used with modules of machines, return on investment can be spectacular.

A review[4] of the prices of the various types of robots points to a rough grouping of robots by price as follows:

Over $100 000
$55 000–$100 000
$15 000–$50 000
Under $15 000

The more complicated continuous path and point-to-point servo robots generally are in the two higher price categories

The majority of pick-and-place robots will be found in the $15 000–$50 000 category. The complexity of the controller and the gripper system influences price substantially.

A typical but simplified cost justification example may be studied in Table I. A robotic loading system* is depicted replacing two production workers on an automatic chucking lathe application. As can be seen, the payback period for the robot was ¾ yr. The general payback characteristic for robots is discussed in the Delphi study. That study sets the average payback period for a robot at about two yr.[5] It is obvious that paybacks of less than two yr would rank substantially above average for robots in general. This would tend to be characteristic of pick-and-place robots.

Some Applications

The machine tool division of our company specializes in design, manufacture and installation of turnkey automatic machine tool loading systems. Its engineers have developed pick-and-place robots incorporated into turning, boring, milling, and chucking grinding applications. In addition, they build special purpose machines which include robotic loaders. They also link modules of machine tools with transfer applications. This section provides some illustrations of successful pick-and-place robotic installations placed in the field since 1980 by this firm.

In an application of a pick-and-place robot to an automatic lathe, 180 pistons were loaded, machined, and unloaded each hour. In another example, a turning machine was retrofitted with a loader to turn a precombustion chamber part for an automotive supplier. In another case, a pick-and-place robot was incorporated into a four-station dial machine, loading and unloading each station. In this application a piston was rough bored, finish bored and honed. The station produced 360 pieces/h.

Pick-and-place robots also function very successfully in transfer applications. An example is a layout in which two automatic chucking lathes in back-to-front operation are equipped with robotic loaders. A major advantage of this type of transfer application is the economy provided as compared and contrasted with more traditional transfer type approaches. The subsequent retooling of the two machine tools is simplified, thus adding versatility.

Utilizing Turnkey Service in Robotic Installations

A major problem which particularly plagues the first-time robotic buyer is the failure to get the robot up and running after it arrives at the factory. Too often, enthusiasm is high in anticipation of delivery of the first robot. Too often, costly delays occur after the system arrives. This can be the function of numerous factors including lack of the unique start-up technical skills demanded, fear and hostility on the part of worker and supervisor, and lack of maintenance and tool engineering skills.

In essence, a gap can exist caused by failure of the buyer to understand the limited role of the manufacturer where that manufacturer sells the robot but is not committed to getting the system completely up and running.

To a large extent this difficulty can be overcome if the buyer insists on a turnkey purchase. When a full turnkey system is provided, the following services are guaranteed by the supplier:

A study of technical feasibility,
Help in cost justification,
Design of the robotic system,
Manufacture,
A runoff sample lot made to illustrate quality, integrity and productivity rates,
Instruction of customer personnel, operators, supervisors and maintenance,
Installation in customer's factory, and
Field service for parts and labor.

Using a turnkey purchase approach the customer can be well assured that the economic benefits planned for will come to fruition.

Summary

This article is aimed at closing the gap in information which surrounds one type of simple robotic system–pick-and-place robots. The importance of this type robot was examined, and its major subsystems reviewed. Advantages and cost justification of this type robot were presented. Finally, examples of successful installations were presented. The safety of a turnkey type installation to assure anticipated results was described.

References

[1]D. N. Smith and R. C. Wilson, Industrial Robots, a Delphi Forecast of Markets and Technology, Society of Manufacturing Engineers, Ann Arbor, MI, 1982.

[2]*Ibid*, p. 52.

[3]*Ibid*, p. 55.

[4]1982 Robotics Industry Directory, Technical Database Corp., La Canada, CA.

[5]D. N. Smith and R. C. Wilson, Industrial Robots, a Delphi Forecast of Markets, p. 38, Society of Manufacturing Engineers, Ann Arbor, MI, 1982.

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*Piklode K-410, Modern Machine Works, Cudahy, WI.

Table I. Economic Justification Example, Simplified Version

Formula:

$$\frac{\text{cost of the robot}}{\text{wages} + (\text{depreciation (tax rate)}) - \text{maintenance cost of robot} - \text{operating \& programming costs of robot}}$$

Assumptions:

(1) Price of the pick-and-place robotic loading system is $35 000.

(2) Company is running two shifts.

(3) System will replace one operator per shift.

(4) Wages including fringe benefits will be $25 000 per operator or a total of $50 000.

(5) For simplicity, we will assume no savings will be made in either material or operations.

(6) Robot will be depreciated over 5 yr. $\frac{35\,000}{5} = \$7000$

(7) Corporate tax rate is 50%.

(8) Maintenance costs of the robot will be 10% per yr.

$$\frac{35\,000}{50\,000 + (7000 \times .50) - 3500 - 3500} = \frac{35\,000}{46\,500} = .75 \text{ yr}$$

.75 yr = 9 month payback

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William J. Smothers

Automating a Sorption Apparatus

M. D. Rasmussen

E. F. Johnson Co.
299 Johnson Ave., Waseca, MN 56093

M. Akinc

Ames Laboratory, USDOE
Iowa State Univ., Ames, IA 50011

A gravimetric sorption aparatus was automated. The instrumentation used, interfacing involved, and software development technique regarding this apparatus are discussed. Some of the results obtained with this equipment are presented to illustrate the control characteristics and capabilities of the system.

Introduction

There are several ways to measure the sorption of vapor on the surface of powders. Three of the more popular methods are: continuous-flow, volumetric, and gravimetric. Each has its advantages and limitations. [1-3] The continuous flow method is generally limited to surface area determinations. Volumetric techniques are not generally applicable to reactive vapors such as water. Although gravimetric sorption is usually slower and more tedious than the above techniques, it does allow the use of reactive vapors and provides more information about sample surface chemistry and the sorbate-sorbent interaction. It was decided to use the gravimetric technique to measure the surface characteristics of powders obtained from the "Properties and Processing of Ceramics" effort at the Ames Laboratory.

Figure 1 is schematic of the process involved in obtaining an equilibrium sorption isotherm. Vapor is transferred from a reservoir into a closed system. Some of the vapor is adsorbed onto the sample; the amount adsorbed is a function of the relative vapor pressure around the sample. The operator waits for equilibrium to be established, then records the pressure, and, in the case of gravimetric adsorption, the weight change of the sample. This process is repeated 20 to 100 times in going from vacuum to the saturation pressure of the vapor and then back to vacuum in small pressure increments.

Recording the data is tedious. Waiting for equilibrium is time-consuming. In the case of inert vapors, e.g., N_2 or Kr, equilibrium is reached rapidly so the constant attention of the operator is required over the 20–30 h needed to complete the isotherm. With reactive vapors, e.g., H_2O, equilibrium may not be established for several h. While the operator's constant attention isn't necessary, data must be taken at inconvenient times, e.g., 3 or 4 am, to be consistent. For these reasons, it was decided to automate the gravimetric sorption apparatus.

Hardware Used

Figure 2 is schematic of the automated gravimetric sorption system. The sample is suspended from the microbalance* in a hangdown tube which is surrounded by an isothermal liquid to maintain the sample at a constant temperature.

The microcomputer† (PET) is the operator for the system. The PET senses the microbalance output on an IEEE 488 bus. The microbalance electronics unit puts out an analog signal which varies from 0 to 10 mVdc and is proportional to the weight change of the sample. This signal is processed by a digital multimeter‡ and made available to the PET on the IEEE 488 bus.

The PET senses the pressure of the system by use of its 6522 VIA port. This provides eight bits of data which are independently configured for input or output. The manometer§ provides binary code decimal (BCD) output of the pressure. This output is connected to a home-made BCD→PET interface. Each digit is software-selected by the four-bits-out and then read on the four-bits-in. The microcomputer also controls pressure in the system by opening one or the other of the solenoid-operated valves (SOV).

Although not shown in Fig. 2, the data acquired during the sorption process is stored externally using a cassette recorder.

It is recommended that IEEE 488, RS232C, or other standard interfaces be used. The higher first cost of complying with the requirements of the standards is outweighed by simpler, clearer communication and programming. The construction of the BCD interface was required by the BCD output of the manometer and the need to control the solenoid operated valves.

Software Development

The discussion of the software development procedures will be from the viewpoint of the engineer/programmer/user.

These guidelines were followed when developing this program: First, the objectives of the program must be defined. In this case of automating a gravimetric sorption apparatus there were three main objectives to fulfill: (1) control an equilibrium sorption isotherm, (2) be friendly enough for personnel without extensive computer knowledge to operate it, and (3) output the data in a form usable by other analytical programs.

Next, the hardware limitations were identified. These were identified as the instrument accuracy, the conversion or update rate of the meters (0.4 s/conversion) and the solenoid-operated valve open/close cycle. The solenoid-operated valves open/close cycle is limited not only by the physical speed of the valves, but also by the zero-crossing-fired solid-state relays used to control them. These relays have the characteristic of turning on or off only at zero voltage, so they will be open a minimum of one-half cycle ($\approx$8 ms).

The limitations of the software were identified next. The obvious limitation was the speed at which the program could operate. The microcomputer has two language capabilities: BASIC (a high level programming language) and 6502 machine code. Machine level programs operate, in general, about 1000 times faster than BASIC; however, BASIC programs are much easier to write. BASIC was determined to have the required speed and was chosen as the program language. There is some psuedo-machine level BASIC code used for communications with the BCD interface. An added advantage of BASIC is the ability to change the value of variables without complete disruption of the program. If machine level code were used the capability would require additional programming and would be quite complicated to provide.

The controlled variable was then chosen. In this case, there were two possible choices for the controlled variable (the variable used to control and monitor the progress of the experiment): pressure or weight. Pressure was chosen because it is the independent variable of sorption isotherms, is easier to control directly, and has a faster response than the sample weight change.

Next the decision points of the program were identified. These are points where the program must respond in some manner to the conditions of the experiment. In this case, the last transfer (valve opening) was a major action point. It identifies the start or zero for the data taking sequence.

The program also had to decide when equilibrium was reached. To do this, a recursive regression routine[4] was used to determine the time rates of change of both the pressure and weight. Equilibrium was defined to exist when there was an average of less than 1 count/10 min change in the readings. This condition corresponds to the instrument accuracy.

After the objectives have been defined and the limitations of the system have been recognized, a flow chart or algorithm of the proposed program is written. Figure 3 is a flowchart for the program used by the system.

The monitor portion of the program fulfills the friendly objective set forth above. It reads the microbalance and manometer, determines if out of range conditions exist, and displays pertinent information about the experiment. The monitor also provides a timing function which is used to evenly space the data taken for determining if equilibrium has been achieved. The importance of the information display is discussed later.

The control objective is satisfied by the decisions: *P/P_0 in Range*? and *Equilibrium*? The *P/P_0 in Range*? decision determines whether or not the current pressure in the system is greater than the setpoint or target pressure (less than the setpoint for desorption). If the setpoint has not been reached, the appropriate valve is opened and transfers are made until the setpoint pressure is exceeded. From the decision-points explanation given above, recall that the data taking sequence is restarted after each transfer or valve opening.

The decision as to whether or not equilibrium has been reached is also part of the control portion of the program. If equilibrium has not yet been attained, the program returns to the monitor. If the equilibrium conditions are met, the program stores the data externally (on cassette) for use by other analytical programs.

Figure 4 is a photograph of the monitor display. It contains all the pertinent information about the current conditions and progress of the experiment. It is updated continuously, and the user can quickly tell how well everything is working. Messages are displayed in the event of an over/under range condition in the instruments and the appropriate corrective action is shown. Some type of monitor is a great asset to any experiment control program. The operator needs to be able to quickly determine the current status of the experiment. This can be done in many ways–bar graphs, printed video displays, printed material, etc. Out of range (alarm) conditions should be signalled in some manner; audio is usually preferred but flashing lights are also suitable. It is important to use suitable prompts. For example, a question might be asked "Continue?". A better way for the programmer to ask the question would be "Continue (y,n)?" with the appropriate responses included. When equipment is to be used by people unfamiliar with computers, extensive error-checking in the program is recommended and single keystroke responses are preferred.

Results

The program provides what might best be called a stepped setpoint on/off control of the pressure. This is a result of the operating characteristics of the solenoid-operated valves and closed-cycle sorption. Figure 5 shows the result of this type of control under a wide range of conditions.

In Fig. 5 the upper dashed lines represent the response of the weight during the sorption process and the lower solid line of each graph is the pressure response of the systems. All points labelled A or A′ are where conditions have been met for data to be output and the setpoint or target pressure was increased in a stepwise manner. The B and B′ points represent places where additional transfers were required to maintain the pressure above the setpoint. Figure 5(a) is the adsorption of water on a yttria powder, Figure 5(b) is the adsorption of N_2 on yttria. Figure 5(c) is the adsorption of water on a yttrium hydroxynitrate hydrate powder, and Figure 5(d) is the desorption of water from a yttrium hydroxynitrate hydrate powder.

Two modifications have been made to "pure" on-off control. Both are best illustrated in Figure 5(c). In the interest of reducing the total time required for a run, after a certain time, no transfers (and subsequent resets) will be made even if pressure drops below the setpoint. If this modification were not made, the time between A and A′ might increase to 5 or 6 h. Also due to speed considerations, a point will be taken after a certain time (here 2 h) even though equilibrium conditions have not been met.

Figure 6 is a complete sorption isotherm. The isotherm contains $\approx$100 points (each point is equivalent to an A point in Fig. 5 along with the corresponding change in the sample wt.). About 10 d were required to complete the isotherm using the automated system. It is estimated that similar precision would require about one month with manual operation.

Conclusion

The cost of automation for this system over and above the equipment required for manual gravimetric sorption is $2600 for the microcomputer, DMM, solenoid operated valves, and BCD→PET interface. About 40 h were required to develop the software. These costs have been more than offset by being able to perform two isotherms in the time one would take to do manually. Automation also saves the user about 10 h of personal time/run because only an occasional system check is required.

The system performs nicely and can easily be expanded in the future. For example, the replacement of the solenoid-operated valves with motorized metering valves has been considered. This would open the possibility of kinetic studies and more sophisticated control modes.

Two points mentioned earlier deserve restatement for emphasis. (1) The use of standard bus configurations (e.g., IEEE 488, RS232C) is highly recommended. The BCD→PET interface was a construction of last resort. (2) The identification and compliance with hardware and software limitations is imperative in assembling a workable apparatus.

Finally, this observation: programming (the actual line by line writing of the code) is relatively simple. Much more skill and ingenuity is involved in recognizing and working with the limitations of the system and the process control points.

Acknowledgments

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[4]Notes on Recursive Treatment of Filtered Data, D. Martin, unpublished (private communication).

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*Cahn Instruments, Inc., Cerritos, CA.

†Commodore PET, Commodore Business Machines, Inc., Santa Clara, CA.

‡Keithley Model 179, Keithley Instruments, Inc., Cleveland, OH.

§Model 170, MKS Instruments, Inc., Burlington, Mass.

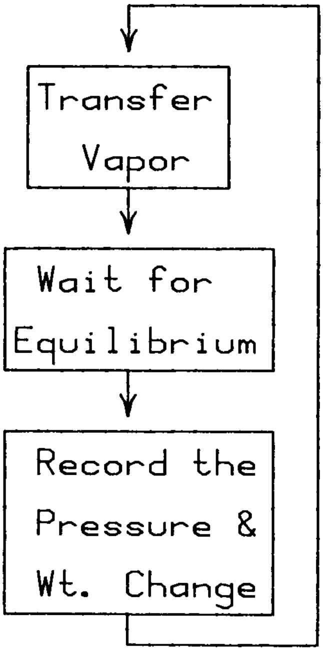

Fig. 1. Schematic sorption process and data taking sequence.

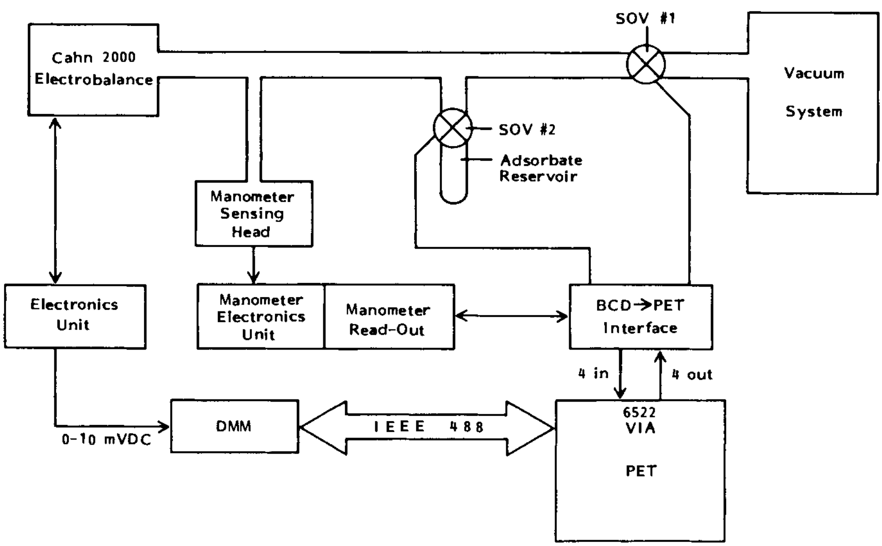

Fig. 2. Schematic of system components.

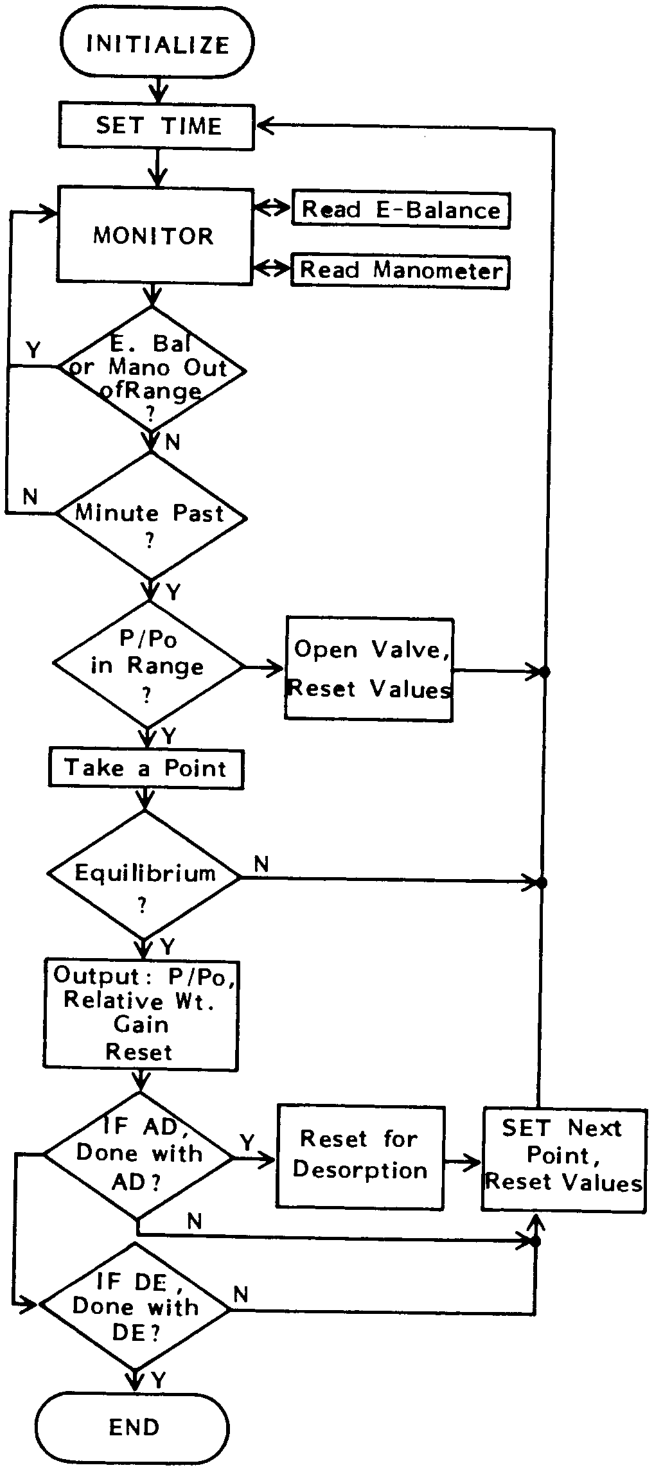

Fig. 3. Sorption control program flow chart.

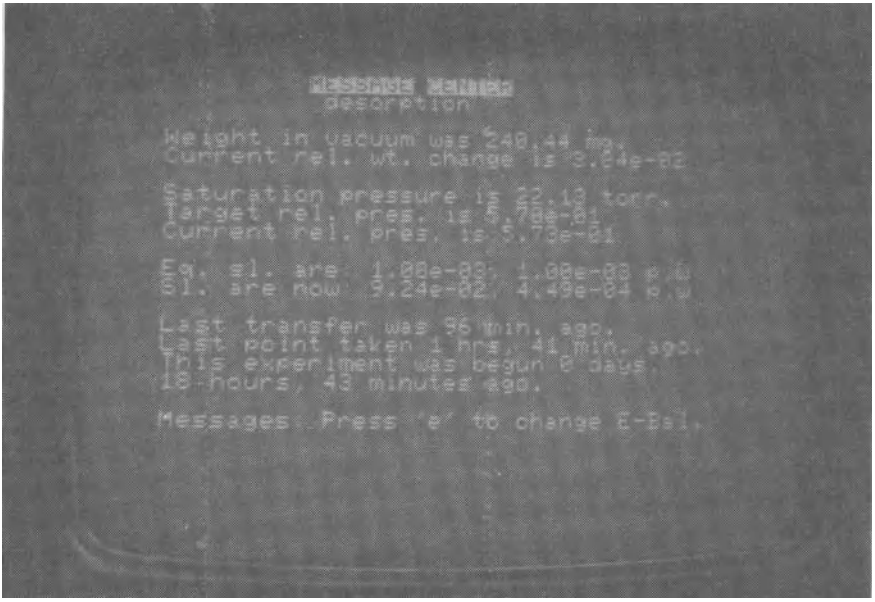

Fig. 4. Monitor display of program while in operations.

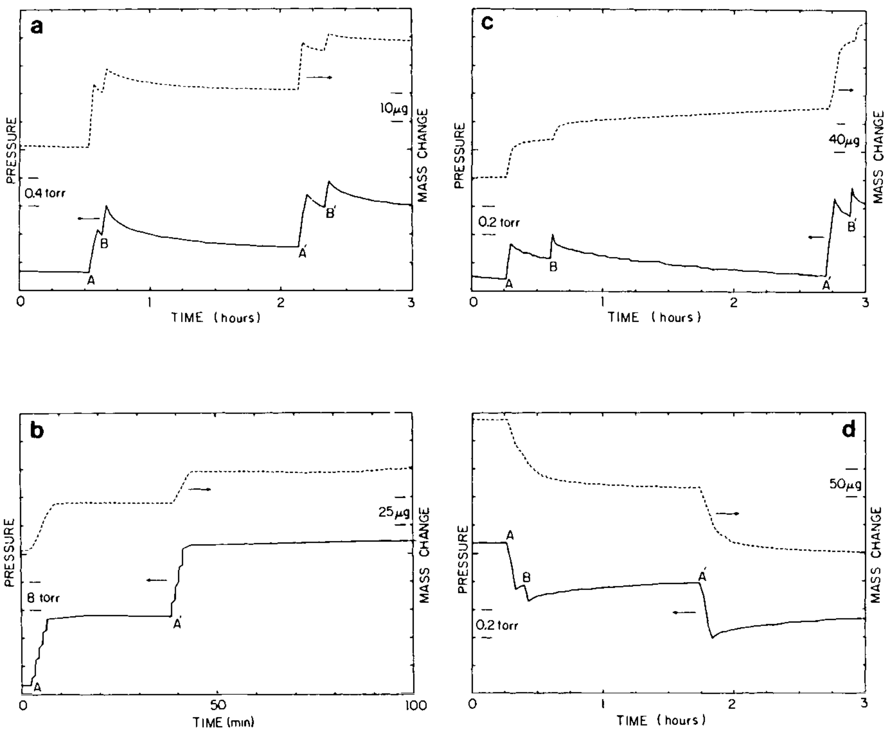

Fig. 5. Illustrations of the system control under various conditions.

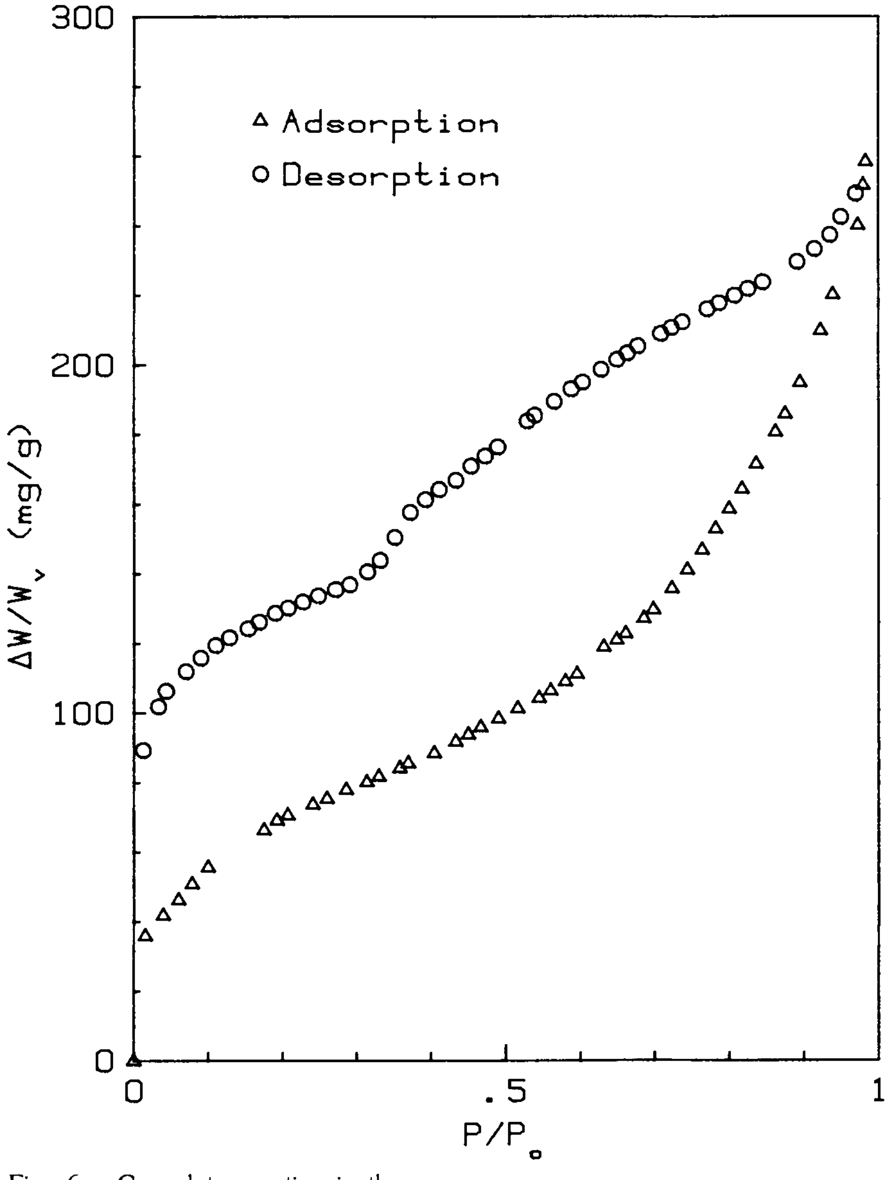

Fig. 6. Complete sorption isotherm.

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Application Basics of Microcomputer and Robotics for Processing Industry

JAYANTA K. GUHA

Westinghouse Electric Co.
400 Media Drive, Pittsburgh, PA 15205

The introduction of microprocessors and robotics in manufacturing operations is increasing at a fast pace. Their application in processing industries could be the answer to low material cost and high product quality. This paper discusses the application engineering fundamentals for implementing this powerful technology on the production floor, allowing manufacturers to stay competitive in the marketplace.

Introduction

The application of microprocessors and computers in manufacturing automation is growing rapidly. It is difficult to envision any cost and productivity improvement efforts in the future without the application of a microcomputer. The application potential of microcomputers has reached deep into every facet of manufacturing know-how as it is being practiced today. The growth in electronics and the computer industry in the past two decades has been astounding. Surprisingly though, computer literacy of the world of industrial automation, has not kept up with its institutional counterparts. This gap is narrowing as more and more applications are implemented. The decade of the 80s will see more computers and robotics in new industries and new phases of factory automation.

When compared to machine tool, fabrication, welding and assembly application, the processing operations often lead to higher levels of factory automation. Use of process control instrumentation is already in place. Further automation can be achieved by integrating the process control with inspection/test and material handling into a robotic processing system (RPS). The purpose of this discussion is to provide a basic understanding of the growing technology of microprocessor and robotics as it applies to robotic processing system (RPS) for automation.

Microcomputers and Process Control

As old processes are improved and new processes are discovered, the process equipment also undergoes dramatic design changes. Today's process equipment is designed for complex processes and requires monitoring of many more parameters than for the early days of simple control devices such as gauges, inspection glasses, hand wheels, and optical pyrometers.

Today the process control involves simultaneous measurement control and computation of multiple parameters such as temperature, pressure, weight, volume, flow rates, density, concentration, acidity and environmental (fire, toxic and radiation) security, etc. The gathering, measurement and control of data synchronously with an ongoing physical process is the function of a "real-time" microcomputer. The ability of a real-time microcomputer to process this information simultaneously provides an efficient solution to many manufacturing and productivity problems.

Real-time may mean different things to different users. If the process parameters need measurement every 30 s, real time is 30 s. For another user who needs measurement and control in 1/30 s, then real-time is 1/30 s. In any event, there are real-time microcomputers for continuous process control as well as for discrete or batch process control. A typical real-time microcomputer for a discrete or batch process is a dedicated, often a fixed function device, with minimum memory capacity, and is required to perform minimum computation. It usually reads only memory (ROM) based and is used in high volume repetitive applications.

On the other hand, a real-time microcomputer for a continuous process may require measurement and control of multiple process data at a high speed. These microcomputers are random-access-memory (RAM) based, are programmable, handle higher data rates, and perform higher level computations.

Closed Loop Control System

A continuous process closed-loop control system is shown in Fig. 1. The system consists of a measurement and a control phase. The measurement phase is initiated by sensors, such as thermocouples, force transducers, etc., generating electrical signals when acted on by various physical phenomenon. These signals are conditioned and processed by a microcomputer into control signals.

The conventional logic relay controllers use analog-to-analog signal conditioning method. A solid state temperature sensor, for example, produces a linear output of 1uA/°K. The resultant output voltage is used to drive a meter or indicator. But in order to simultaneously process multiple process parameters by microcomputer, the analog signals have to be converted into digital format. The procurement and conditioning of the high volume of measurement signals are done by a data acquisition system (DAS) as shown in Fig. 2. The complexity of a DAS and signal conditioning increases with the volume and speed of the input measurement signals. A typical data acquisition system shown in Fig. 2 consists of channel switching or multiplexer, analog-to-digital converter (A/D), input-output (I/O) ports and a bus structure to feed data to dedicated logic or PID (closed loop) algorithm for computation, and a timing system to synchronize all activities. All these could be on a single board in the hardware system. The same board could also have a digital-to-analog converter (D/A) to send out analog control signals to drive actuators, valves and pumps, gates and flow meters recorder, indicator, etc. for physical control of the operation.

Following are the primary functions of microcomputers in industrial automation and control applications.

Control I/0

These devices convert digital signals into signals required for machine control, for example, a programmable logic controller that can replace a relay logic with a standard ladder diagram for a specific application generated on a CRT. This is then automatically converted into appropriate machine language to sense input functions and drive output functions.

The operation control of an individual section (I/S) glass-forming machine is an example of control I/O application.

Proportional Integral Differential (PID)

This is a closed-loop control which automatically controls analog functions using closed-loop algorithms. A microprocessor application replaces traditional analog computing functions with PID algorithms in digital circuitry available in most new equipment today.

The measurement and control of excess oxygen to regulate air to fuel mix ratio in glass tank or other furnaces, are examples of closed-loop control applications.

Coordinate Positioning

This is also a form of PID or closed-loop control, but is used particularly in articulation of a mechanical arm or a tool in manufacturing machinery. It controls the motion and positioning of the tool tip or arm end in multiple axes simultaneously. It also controls the motion of a defined path and velocity.

Examples of applications are in robotics, machine tool, metal punching, cutting, etc.

Other real-time microcomputer applications include: COMMUNICATION, where control functions need distribution over common data communication structure; COMPUTATION, where real-time data is used for statistical analysis such as to maintain "trend analysis" or "efficiency logs" for manufacturing operations; DATA BASE, consisting of local libraries of information needed for higher levels of factory automation such as computer aided manufacturing (CAM).

These real-time microcomputer applications are shown in Fig. 3 and discussed later.

Microcomputer and Robotics

The field of robotics has made quantum leaps with the progress in microcomputer technology. The sensory feedback with application of real-time closed-loop microprocessor control has added new dimensions to the application of robotics in factory automation in recent years.

Robot Control

The brain of a robot system is in its controller. It allows the robot to physically perform a task. The sophistication level of a controller determines the complexity level of the task the robot can perform. Simple tasks, with few sequence of motion, can be performed by an open-loop motion control. Here, the robot motion is controlled by a mechanical stop and no signal is fed back to the controller. Such robots use pneumatic, mechanical (drum control), or simple electrical logic to control motion. These robots are called limited-sequence, non-servo controlled robots and are only a step above dedicated hard automation.

Then there are servo-controlled robots, which have some form of (electric or hydraulic) servo-actuators. Here, the position of each robot axis is controlled by a closed-loop servo system. The axis and joint positions are measured and compared with a set point in the robot controller. If the position is different, the controller will signal the electric or hydraulic joint actuator to move to the correct position. To program a task, the actual values of the joint position encoders at each location on the task trajectory are read and stored in sequence. These values are played back to the robot servo system when asked to perform the task. Many industrial robots today have wire-logic controllers. These robots have certain limitations, such as inability to modify trajectories, limited branching capability to alternate sequence, tedious teaching or programming, and they require accurate and rigidly constrained part positioning. These robots are considered as semi-hard automation.

The most sophisticated and versatile robot controller is a minicomputer-based numeric control (CNC). Such robots are capable of axis transformation. The CNC converts geometric coordinate position data into robot joint-position information. These robots can be programmed on teach-through-mode, and have external program storage capability. Many robots today have a general purpose computer as their controller. These robots have the ability to interface and efficiently process sensory (tactile, vision, etc.) feedback data. The robot is directed to complete a task (combination of many motions) instead of a simple trajectory. The computer control of the robot will be able to receive input commands defining the task to be performed and sensory data describing the environment such as location, accuracy, orientation, etc. By processing the input, the computer directs the robot manipulator to perform an intended task. Such robots are truly flexible automation systems.

Dynamic Properties of Robot

Understanding of certain dynamic performances is critical for selection of industrial robots for an application. A frequently asked question by a prospective robot buyer is "What is the accuracy of the robot?" Some equally important other dynamic properties are repeatability, control resolution, stability, and compliance.

RESOLUTION is the descriptive element of the movement of the robot at the tool tip. It is determined by dividing the stroke of each joint by the number of control increments. It is, therefore, the smallest increment in position that a control measurement system can resolve. This control resolution combined with mechanical inaccuracies of joints give spatial resolution.

The ACCURACY of a robot at tool tip is one-half the distance between adjacent control positions. If the mechanical inaccuracies of the joints are included, robot accuracy decreases.

The REPEATABILITY reflects the ability of the robot to reposition itself to a previously programmed point. The difference between the programmed position and repeated position is, therefore, the measure for robot repeatability.

The STABILITY of the robot is determined by the lack of oscillation of the tool or arm when the robot is in motion. It can cause wear on mechanical and hydraulic components in the arm and also affect other dynamic performances of the robot.

There is often a difference in the positions of the robot manipulator and part/fixture at the point of performance of a task, such as machining gripping, insetting, or assembling, etc. This position differential is a compounding effect of robot component inaccuracies and part/fixture dimension tolerances. The force (torque) generated during the performance of task causes a relative displacement of the manipulator, compared to its natural position. This response of the manipulator to force (torque) is called compliance. Based on the degree of compliance the robot may be termed as stiff or springy.

Figure 4 illustrates the interrelationship of major dynamic properties of a robot. The numerical values of these parameters can be calculated as follows. If the stroke of a robot joint is 24 in. and the control system uses a 12-bit storage for a capacity of 2^{12} or 4096 command increments, then the resolution of the control system is 24 divided by 4096 or 0.006 in. accuracy 0.003 in. and repeatability is something less than 0.003 in.

Physical Characteristics of Robot

Industrial robots come in many configurations. Most robots can be described by one of the four geometric types; cylindrical coordinate, rectilinear or cartesian coordinate, spherical coordinate, and jointed arm. These configurations help define the basic motions of the robot. Each type of robot has certain motion characteristic and work volume coverage that is particularly suited for an application. The number of axes, types of motion, speed, work envelope, and payload capacities generally determine the applicability of an industrial robot. These physical attributes also significantly affect the dynamic performances of a robot, and should be analyzed in detail while selecting a robot.

Sensory Feedback

Sensors play an essential role in robotics. A robot performs various tasks with a variety of parts. In a flexible automation system such as machining center or assembly cell, there are a number of peripheral equipment to monitor and control. The most commonly used sensor types are proximity, range, tactile, and visual. Automatic computer vision adds new dimensions in robotics. Visual feedback often reduces the need for jigs, fixtures and critical importance of part positioning. It eases part tolerance requirements. The small production batches can be run with the same efficiency as longer runs, with minimum production scheduling problems. The visual feedback can control a robot manipulator to work on a moving line, without precisely controlling the line speed. The vision system can perform 100% on line quality inspection and generate process control information. The visual and other sensory feedback with microcomputer control extends the limited capabilities of yesterday's robot into unlimited automation opportunities of the future. The integrated microcomputer control robot and sensory feedback system provide true flexibility to production line automation.

Application in Processing Industry

Various primary and secondary functions of real-time microcomputer applications are shown in Fig. 5. The applications fall into two categories; (A) instrumentation and control, (B) machinery and robotics. Most manufacturing operations may fall into one of three general groups; (1) machinery/fabrication, (2) assembly, or (3) forming/processing. Considerable progress is being made in the area of machining and assembly through the application of automation concepts such as Flexible Machining System or cell (FMS/FMC) and Adaptable Programmable Assembly System (APAS).

A careful analysis of the information in Fig. 5 shows the automation development made in the area of inspection and testing. This can serve to bridge the present gap that exists between the process control automation and robotics. The major beneficiary of such integration would be the processing industry.

Robotic Processing System (RPS)

Manufacturing operations in processing industries such as plastic, composite, glass, electrical, and electronic ceramics, etc., often require 100% on line inspection and testing. The automation concept of a robotic processing system (RPS) is shown in the block diagram in Fig. 6. In the microcomputer control robotic processing system (RPS), the test and inspection measurements are analyzed and fed back in real time to process equipment for corrective control. Simultaneously, the RPS microcomputer control sends decision and/or task signals to robot control to perform necessary materials handling such as, sorting, marking, light machining, packaging, and other secondary operations.

Other applications of RPS include chemical cleaning, coating, glazing, or casting operations. The process control for coat thickness, coating, and/or cleaning duration, solution concentration, or density and part condition (e.g., temperature, surface preparation, etc.) can be controlled by a real time microcomputer. The same microcomputer can also control all inspection and material handling requirements of the system. Forming (glass, plastic, composite), dry or isostatic pressing (electrical insulators, semiconductors, spark plugs, refractories, etc.), and casting and molding (composite, porcelain, whiteware, etc.) operations are some of the other applications.

Machining of ceramics, polishing, cutting, drilling and grinding are precision control operations. The materials requiring such operations are generally expensive or have gone through considerable value-added operation to reach this stage. They are generally cost effective applications for robotic process system (RPS).

Summary

Today, several types of microcomputer control instrumentation are available in the market to monitor and control process parameters. Instead of using them as stand-alone units, efforts should be directed to integrate them with other automation needs in the system such as inspection/testing and material handling, where applicable. The preceeding discussion was intended to provide a basic understanding of the role of the microprocessor to connect these islands of automation, namely the process control, inspection/testing, and robotics. The robotic processing system (RPS), using state-of-the-art technology in microprocessor and robotics, may be the solution to cost effectiveness and productivity in the processing industry.

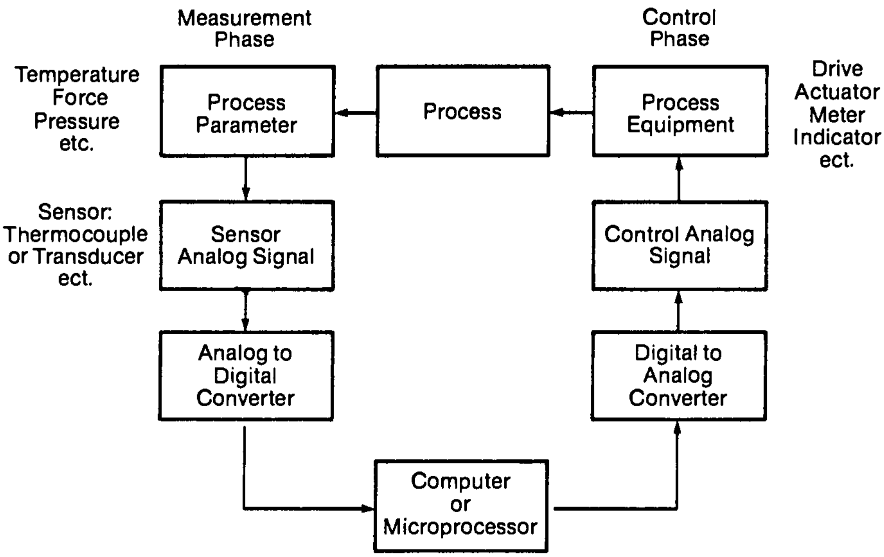

Fig. 1. Closed-loop control system.

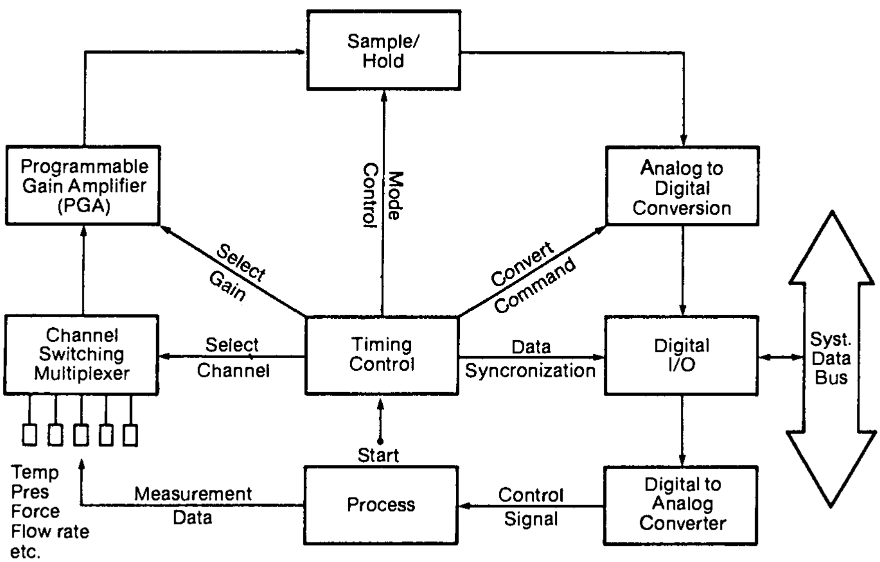

Fig. 2. Process control data acquisition and feedback system.

Wire Logic Control

- Time consuming programming
- Step by step programming
- Robot inactive while programming
- Limited branching capability
- Inability to modify trajectory
- Parts need to be rigidly constrained
- Repeatative high volume production

Computer Numeric Control (CNC)

- Faster teach mode part programming
- Geometric coordinate to joint position axis transformation
- Programs down loaded
- External program storage
- Sensory feedback
- Less expensive tooling for parts
- Low volume—batch production

Fig. 3. Servo-controlled robots.

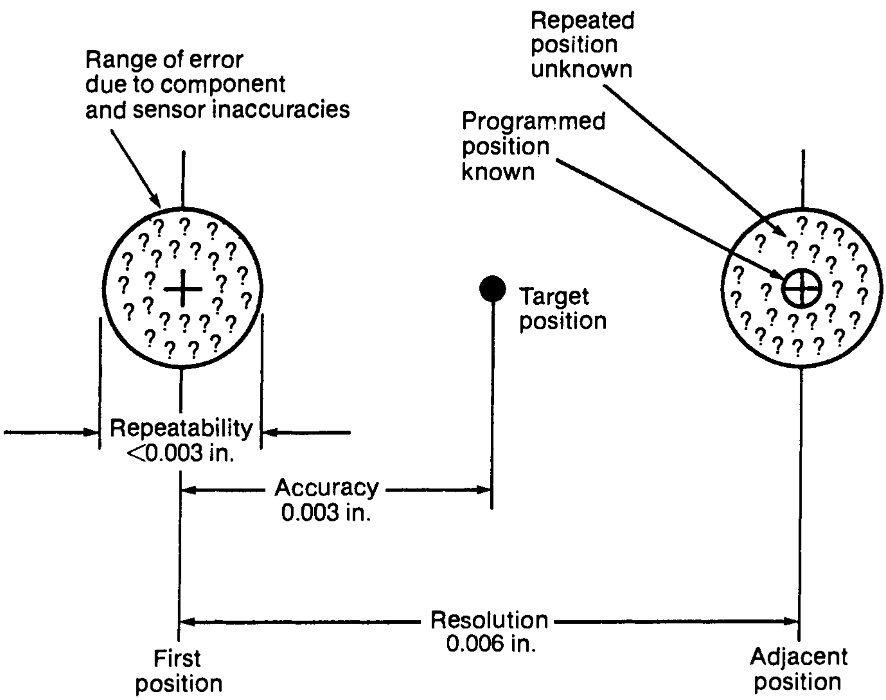

Fig. 4. Interrelation of robot dynamic properties.

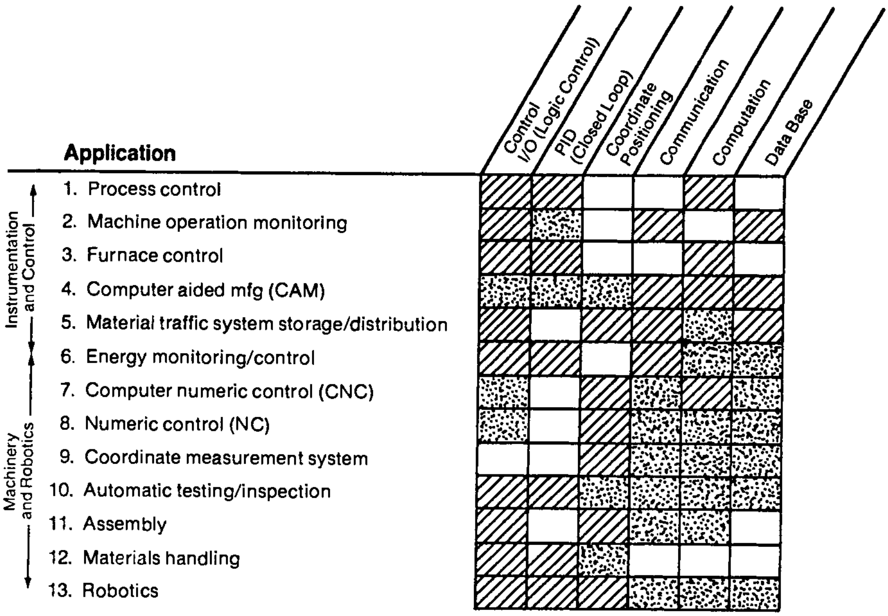

Fig. 5. Application of real-time computer.

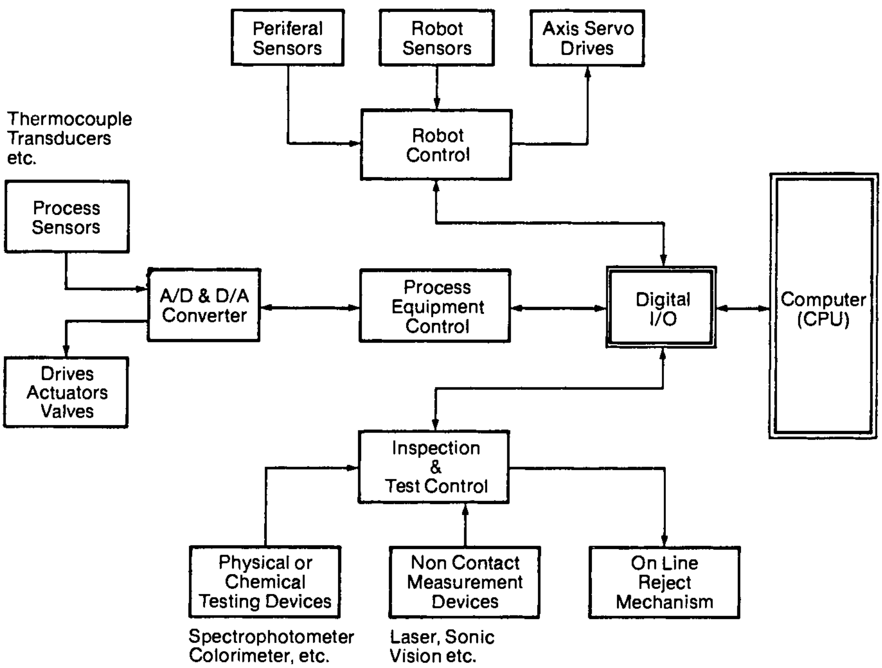

Fig. 6. Control block diagram of robot process system (RPS).

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Robot for Stacking Green Sheets in Multilayer Ceramic Capacitor Fabrication Process

S. KATCHER, I. NOZAKI, Y. TANAKA AND K. WAKINO

Murata Mfg. Co., Ltd.
Nagoaka, Kyoto, Japan

Murata has recently developed a fully-automated monolithic ceramic capacitor assembly machine which has the capability to stack green sheets in the fabrication process using a computer-controlled robot. This machine has contributed to a reduction of production costs and an increase in reliability.

Introduction

Recently, the Murata Manufacturing Company of Kyoto, Japan has met the challenge of increased demand for high reliability components and decreased factory cost by developing an automated system for green sheet stacking used in the production of multilayer ceramic capacitors (MLC).

Multilayer ceramic capacitors are generally manufactured by mixing various ceramic oxide powders together with a combination of organic binders, plasticizers, dispersants, and solvents. The well-dispersed ceramic slurry is cast into thin sheets ranging from 20 μm to about 130 μm using a doctor blade or similar technique. The thin sheet, often called the "green sheet," becomes the actual dielectric layer after being electroded, stacked, laminated, and fired. At present, the process of stacking the individual green sheets is often carried out by hand or by a machine-aided stacking process. Murata has recently developed a system for automating the green sheet stacking process.

The system (called the GSS system) makes use of a robot arm to control transferring and positioning of green sheets during the stacking process. This system has been developed to reduce factory cost and increase product quality and reliability.

Reason for GSS System

Increased demand for MLCs has brought many variations in shapes and values required by the customer. Since each lot requires different procedures and materials, it is difficult to make a machine to automatically stack the part to design. It also becomes very time consuming to set up and produce the many different designs. The ROBOT system controlled by the microcomputer allows each design to be computed and then directly assembled using a supply of materials required for the design. The microcomputer can also instruct the operator on which materials must be used.

Development of GSS System

The method was developed to meet the following criteria:

(1) This process is joined to other processes in the assembly line by a tray carriage system, and

(2) A microcomputer and a ROBOT are used to provide system flexibility. The system is named "GSS" (Green Sheet Stacking).

GSS System Outline

The system has the following stations:

Station	*Function*
#1	Dummy sheet for top of stack,
#2	Printed sheet Type A,
#3	Printed sheet Type B,
#4	Dummy sheet for bottom of stack,
#5	Checking station to verify operation, and
#6	Stacking station.

The system works as follows:

(1) The ROBOT with vacuum pad is positioned in the center of the machine.
(2) The ROBOT arm moves between each station through the checking and stacking stations and stacks the proper sheet in a programmed sequence.
(3) The checking station checks that the arm does transfer the sheet properly to the stacking station.
(4) The microcomputer stores programs for several modes of stacking and daily production schedule.
(5) Stacked sheet blocks are transferred to the next process using tray carriage system.

GSS System Specification

The system must know the kinds of sheet it has available, the quantity, and the design mode that is being used. From this it can take daily production schedule and assemble stacks. It operates at a mean cycle time of 12 s per operation.

The microcomputer has control of the robot program, the stacking program and the daily production plan. The microcomputer can control up to seven GSS systems. It generates the necessary program used by the ROBOT controller. A sequencer is used to control lifts, trays and conveyors used to supply the stations.

The ROBOT is point-to-point mode, horizontal multiarticulation unit with placement accuracy of $\pm .05$mm and maximum speed of 1000mm/s. The articulation has four degrees of freedom and can cover the area shown in Fig. 1. The data memory is 170 points maximum per program.

GSS System Structure

The GSS system is structured as shown in Fig. 2. It is designed to follow a sequence such as shown in Fig. 3. The GSS system consists of the following parts:

(1) ROBOT,
(2) Lift,
(3) Tray-loader,
(4) Stacking conveyor,
(5) Pooling conveyor,
(6) Vacuum pad,

(7) Sheet checker,
(8) System controller, and
(9) Microcomputer.

The ROBOT was developed for stacking multilayer capacitors with the flexibility required to manufacture any type or design by providing the right materials to the operating area. The wide operating area shown in Fig. 3 allows for greater flexibility in capacitor design. The control of the ROBOT is by a program generated in the microcomputer and fed to the ROBOT through a data transmission line.

The lift supplies the sheets to be stacked and the trays to accommodate the stacked sheet blocks.

The tray-loader supplies the trays from the tray carriage system on the lift to the position accessible to the vacuum lift of the ROBOT.

The stacking conveyor loads the stacking tray from the lift to the position of the stacking station.

The pooling conveyor moves the tray full of stacked blocks from the stacking station on to the tray carriage in the lift which will be moved to the next stage of processing.

The vacuum pad on the ROBOT arm picks up the green sheet with the minimum of stress and deposits it onto the stack after verifying that the sheet is in position.

The checking station verifies that a sheet is loaded before stacking and unloaded after stacking.

The system controller is shown in Fig. 2. It must know the stacking mode, the program to be used, and the available materials. It can then calculate and program what stacks it can make that fit into the daily production plan stored in the microcomputer.

Conclusion

This system has allowed the stacking procedure efficiency to increase by 50% to 80%. The incidents of human error in stacking are eliminated. A skilled operator is not needed to interpret and understand stacking routine. An operator is needed to supply tray cartridges to proper stations, but the microcomputer can check and verify all operations affecting the product's requirements.

In addition, the green film can be processed without being touched by human hands in a dust-free environment. This allows an increase in product quality and reliability. The predictable handling characteristics of the vacuum pad has also reduced material losses due to mishandling. This system has indeed reduced factory cost, improved efficiency and product quality, and reliability.

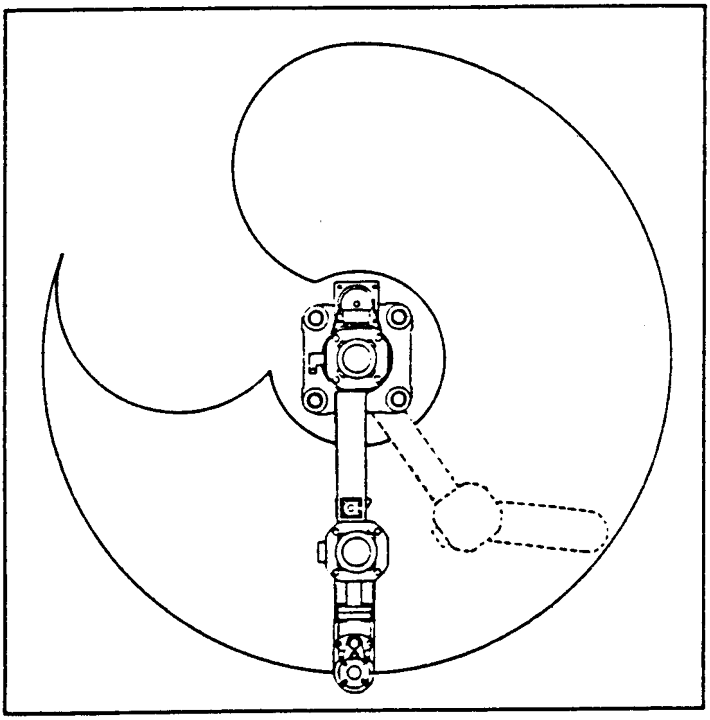

Fig. 1. Robot operating space.

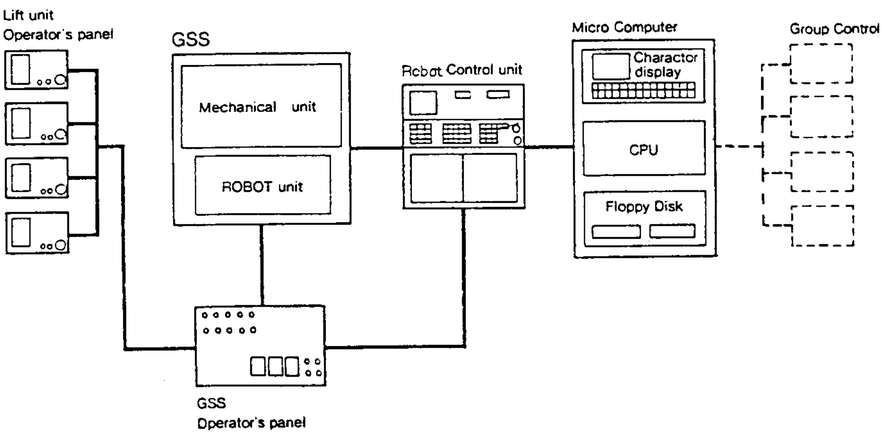

Fig. 2. Block diagram of controls.

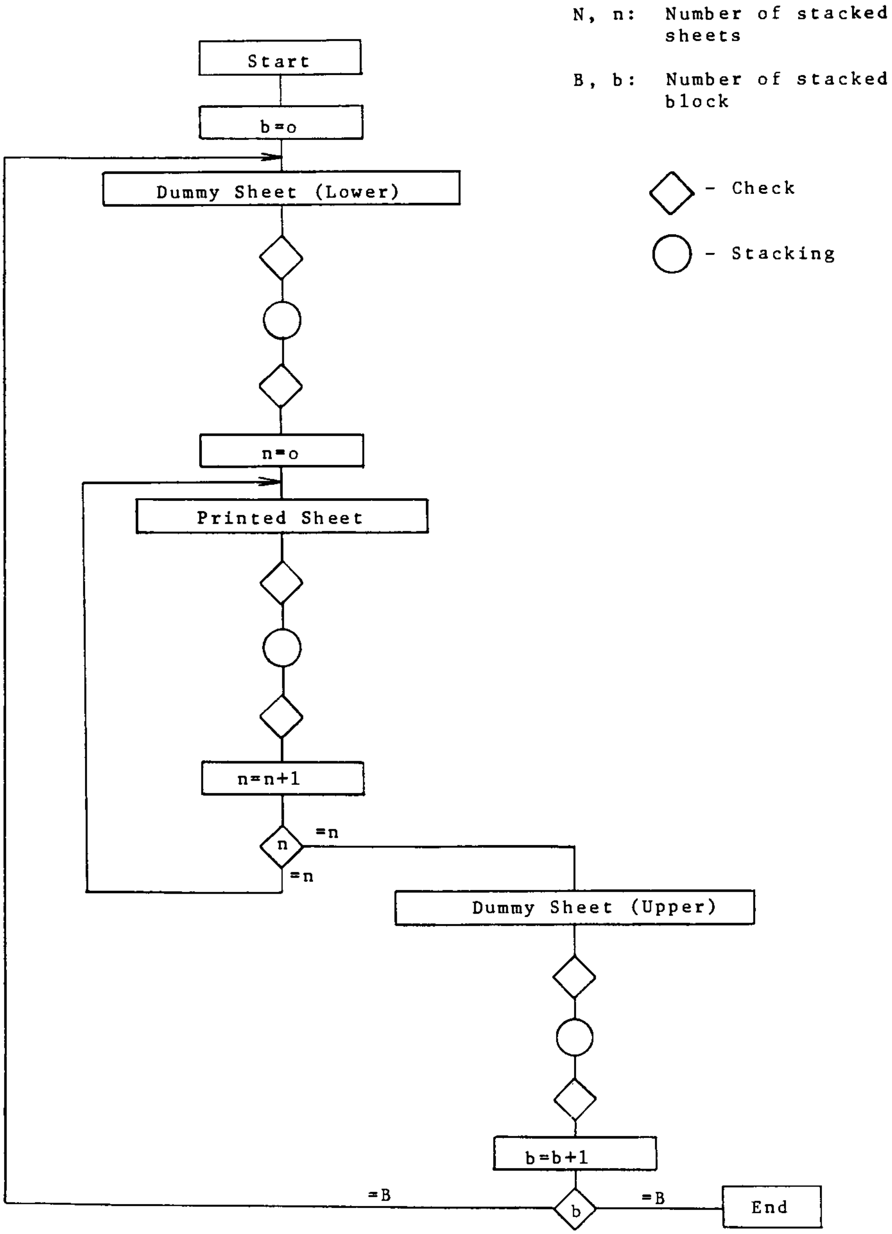

Fig. 3. Stacking process.

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Application of Minicomputers and Microprocessors to Practical Production Problems

FRANK BURHAM

Mepco/Electra, Inc., Cermet Trimmer Facility
11468 Sorrento Valley Rd., San Diego, CA 92121

The hardware, software, and interface equipment required to solve specific production problems for thick film processes are described. The primary system is a minicomputer-controlled probe-head resistance tester. Other applications such as kiln profiles and temperature coefficient tests will be covered briefly.

Introduction

According to the Wall Street Journal, the number of computers and microprocessors now exceeds the number of humans on the planet Earth, i.e., more than 5 billion!

From a manufacturing point of view, we are bombarded with messages like "automate or evaporate" that point out the need for a higher level of automation technology in our factories. Obviously, the explosive advances in computer technology are beneficial to the need for productivity improvement in our factories.

So, we are aware of the need and we are aware of the presence of a technology that can assist in fulfilling the need. The question is, "How do we bring these two together?" My answer is simple, "By starting at some basic level that is readily available and learn by doing."

The objective of this paper is to present some examples of applications in our facility and demonstrate how to design and implement similar systems using readily available personal computers and peripherals.

Mepco/Electra Product Line

Mepco/Electra is a North American Philips company engaged in the manufacture of resistors and capacitors. The San Diego facility produces variable resistors (trimmers), networks, and a specialty fuse. These products are built using cermet thick film processes. The thick film process consists of screen printing, firing, assembly, and test.

Minicomputer and Microprocessor Applications

We utilize two turnkey systems built into purchased equipment, i.e., XY table control for CO_2 lasers used to cut ceramic plates and heater controls for our filing kilns.

This paper deals with the in-house developed systems which are used for:
(1) Resistance testing,
(2) Temperature coefficient testing,
(3) Kiln profile measurement,
(4) Burn-in tests, and
(5) Quality control tests, general.

These production systems read resistance values through a 100-channel scanner. In the substrate mode, a pogo pin "bed of nails" fixture is pressed onto a multielement substrate to obtain the readings. In the tests involving finished product, the scanner is connected to a PC board edge connector which, in turn, accepts test boards loaded with pin sockets. The burn-in fixtures, life-test ovens, etc., are all wired with the card connectors. The test systems are identical for all the resistance measurement applications. The variable lies beyond the 100-channel scanner, using interchangeable cable sets for each application.

The systems read and store resistance values at a rate in excess of two resistors/s. The system is reading at a much faster rate but the two readings/s rate is the effective throughput, including channel switching and logic checks. The readings are first checked for conformance to broad range limits to reject opens and shorts. Then multiple readings are checked for stability. When consecutive readings are equal the reading is accepted. The accepted reading is compared against limits and put into memory.

Most tests consist of two or more resistance measurements taken pre- and post-test. The pre-test data are stored and then recalled for comparison to post-test data. Shift calculations are made and compared to test limits. Rejects are identified and variables data are accumulated as required, including average, maximum, minumum, standard deviation, yields, number tested, etc.

The speed of the computer system allows massive data analysis which is beneficial for product and process trend analysis as well as a yield improvement. So, the system pays off in two ways: first, in improved productivity of the function, then in the yield improvement resulting from data analysis. The automatic data logging also eliminates the human element associated with hand readings. This is particularly important in the quality control tests.

In addition to the production and quality control functions above, we use personal computer systems for engineering data analysis, cost estimates, and capitalization analysis. It may be of interest that we started our computer application activity with the production tests and utilized the computers for business applications later. Reason? It is easier to justify production programs, based on cost savings. Business applications are definitely beneficial, but concrete payback is difficult to prove prior to actual user experience.

System Design

The trade journals are filled with articles and ads using the computer field jargon or "buzzwords." This torrent of unfamiliar jargon can be confusing to the novice who is interested in starting an application.

Fortunately, it is not necessary to completely understand computer technology in order to utilize one. The system design approach I will discuss below will involve very little jargon.

The first step of system design involves selection of the application and the scope of the project. It is extremely important at this stage to reduce the complexity of the task to its lowest level. In essence, you must first crawl, then walk, and finally run.

For example, in a resistance measurement system, the first benchmark should be to establish a capability to measure the resistance and put the data in memory. You can then add the scanning (switching) capability. When on firm ground, add the machine controls and the automatic parts handling. When the system is operational, then you can go back and fine tune it to increase speed and add other embellishments.

When you have selected the application and analyzed the functions required, you are ready to start the system design. First, comes the selection of the computer. I define it as an application machine. It is a computer* that is designed to be ideally suited for many diverse applications. There are many other computers on the market and the field is expanding rapidly. However, it is beyond the scope of this paper to deal with comparative merits of the various systems.

I selected the computer approximately three years ago, due to its low cost, ready availability, ready service, and the broad availability of peripherals and software. One major feature is the seven expansion slots which accept a wide variety of plug in cards.

The input and output (I/O) capability is excellent. The obvious first level input is the keyboard. The game control ports offer three push button inputs and three analog (potentiometer) inputs. Outputs to the operator include the screen, printer, plotter, and speaker. For machine control outputs, the game control port offers three switches (TTL annunciators), and a strobe (pulse). In addition, plug-in boards are available for multiple-channel relay-type inputs and outputs.

Instrument Bus

The plug-in board that adds tremendous application capability is the instrument bus card. The instrument bus approach was developed† and it was later adopted as an industry standard designated as IEEE-488. Most instruments on the market today use this standard.

This instrument bus allows a computer to control instruments using a 16-conductor cable. There are eight data lines and eight control lines. The bus can accommodate up to 14 instruments using up to 66 feet of cable. Communications take place at a rate of 1 megabyte/s.

The computer is designated as the controller, and communication with the instrument uses a "talker-listener-handshake" protocol. In essence, the controller addresses an instrument and says, "I'm going to be the talker, you listen." The instrument says, "OK I'm listening, go." The controller sends the message, then designates the instrument as talker, and the controller becomes the listener to accept the instrument data.

The standard functions include: enable remote (become controlled by the computer), lockout panel (panel switches are inactive), clear (establish initial conditions), setup (instal parameters such as range, number of digits, etc.), poll (check for status of interrupt flags, etc.), trigger (start reading) and, of course, measure (take the reading and send back the data).

The instruments with IEEE-488 capability available on the market today include digital voltmeters, signal generators, signal analyzers, oscilloscopes, counters, power supplies, etc. In addition, for switching purposes, there are many choices of scanners. Various relays are available: small signal, thermocouple or strain gage compensation, digital coding and power. Also, there are solid state switching systems for high-speed multiple-point analysis such as required to probe a functioning printed circuit board.

In essence, all the basic instrumentation required for almost any application is available. Many manufacturers offer the bus capability as standard equipment. Some offer the bus as an option.

Hardware

For the systems described earlier, I selected a data acquisition/control unit.[‡] This unit contains a built in digital voltmeter and current source, a real time clock and accepts up to five 20-channel relay cards for 100-channel switching capability. It has excellent speed and accuracy plus an internal memory capable of storing 60 to 100 readings, depending on data format. Many other systems are available but this one has the advantage of multiple instrument capability in one physical unit.

Additional hardware was required, including the probe cards, to access the substrates and the interconnecting cables. Since there were several geometries, the cable set was brought out to a universal header. The various probe sets are plugged in as required using zero insertion force connectors.

Software

The concept of software development can be a constraint to the novice. I recommend the use of BASIC since it is an easily understood language of approximately 150 meaningful words. In addition, a math capability in algebra is required. The programmer must be able to write the necessary equations and in particular, be able to create the necessary comparisons. Most logic flow requires comparison of value for equality, greater than, or lesser than. All programming can be done in decimal. As experience is gained, the number systems for binary and hexadecimal can be helpful, but knowledge of these systems is not required for BASIC programming.

Flow charting techniques are helpful. An understanding of three logic flows are required: sequential flow, where operations occur in a fixed sequence; loop flow, where an operation or set of operations is performed repetitively for a specified number of times; and conditional flow, where the sequence is directed based on a condition being true or false.

With these three skills developed, BASIC language, algebraic logic, and logic flow, one can program. The skills are easily developed and proficiency comes rapidly with practice. There is a wealth of literature on the market to assist in programming. Plus, there are many utility subroutines available at a very low cost or free through the various magazines.

One extremely important feature of software for production applications is to make it "user friendly." This commonly-heard term means simply to provide clear statements of what you want the user to input and how the input should be made. A common example in many packages is the use of a question followed by (Y/N). The programmer expects the user to press Y for yes and N for no. A production operator may have three problems here. What does Y/N mean? Where are Y and N on the keyboard (not being a typist) and do I follow Y or N with the return key? A good user-friendly program will explain the notation to be used in a beginning introduction section and may even show a picture of the keyboard. Most often, menu selection programs are easiest to follow. For these, the user is given a list of selections designated clearly and followed by an instruction on how to make the entry.

Error handling routines are also very important. Anticipate the types of errors likely to be encountered and set up routines to handle them and return to the normal program flow. Operators will not know how to handle a "hung" program.

Cost

The primary cost element of a production application will be the instrumentation and hardware for the measurement system. The computer is likely to be the least costly item.

The example below is for general information of the approximate cost of the 100-channel resistor measurement system. It is intended to provide a "ball-park" only and may or may not accurately reflect what could be required for your system. There is a tremendous selection of computers, peripherals, and instruments in the marketplace, and it pays to shop for value. Keep service in mind and buy locally from reputable dealers.

Do not get overly concerned about obsolescence or future price declines. In most cases, the delay in the productivity improvement to be gained cannot be offset by price declines. If you have a bona fide need, do it now!

EXAMPLE: 100-CHANNEL RESISTANCE MEASUREMENT

ITEM	APPROXIMATE COST
CONTROLLER	
COMPUTER WITH MONITOR DISK, DRIVE AND PRINTER	$ 2 500
IEEE-488 BUS CARD	500
	$ 3 000
HARDWARE	
INSTRUMENTATION—DVM, 100-CHANNEL SCANNER	$ 7 500
FIXTURES	$ 4 500
	$12 000
SOFTWARE	
100 HOURS AT $30/h	$ 3 000
TOTAL SYSTEM COST	$18 000

Future Applications

In keeping with the message used earlier about crawl, walk, run, I am presently developing prototypes for expanded machine controls, primarily in stepper motor controls for robotics applications. Voice systems and visual recognition systems will follow.

The application process is a progressive one. Success in an application leads to development of enhancements. One idea leads to another, etc.

If you have not engaged in a computer application for a production problem, I encourage you to do so now. There is no better time than today to plunge in and enjoy the experience. In addition to the obvious benefits, the biggest reward of all may well be the survival of your business!

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*Apple Computer, Inc., Cupertino, CA.
†Hewlett-Packard, Palo Alto, CA.
‡Hewlett-Packard HP3497A.

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A Microprocessor-Controlled Lignite Gasifier

EARL JONES

Elgin-Butler Brick Co.
Elgin, TX 78621

E.P. HAMILTON, III

E.P. Hamilton Engineering
Austin, TX 78766

This paper discusses the controls for a lignite gasifier at Elgin-Butler Brick Company. The control system employs analog proportional control loops with supervisory setpoint control via a programmable digital controller. The programmable controller employs preset ramping, startup, and abort algorithms to automatically change setpoint.

Introduction

A control system is easier to understand if the manufacturing process principles are known. The following is a brief background of Elgin-Butler's lignite gasification project and a description of the gasification process.

Clay brick manufacturing requires large amounts of energy. Natural gas is the most desirable source of this energy because it is an easily controlled, clean burning fuel. However, the escalating price of natural gas dictates the adaptation of lower price fuels for firing brick. Some brick manufacturers have converted to solid fuels such as coal or sawdust.

In Texas, the most abundant low-cost fuel is lignite, found either near or immediately adjacent to surface mineable clay seams suitable for brickmaking. Gasification of this lignite with the removal of all sulfur, ash, and tars from the gas will provide Elgin-Butler with an ideal low-cost fuel for firing brick.

A unique 8.8 MW (30 MBtu/h) traveling-bed sawdust gasifier design has been modified to gasify on-site lignite at Elgin-Butler's brickplant east of Austin, Texas. There on a 2000-acre site, the company mines brick clay to a depth of 18.2m (60 ft) in open pit mines. A lignite overburden overlies the clay at a depth of 4.6m (15 ft).

Elgin-Butler is currently completing the construction of this $1.5 million project that will convert the lignite overburden into a low energy gas that will fire two existing brick kilns to 1204°C (2200°F) at $2.95/GJ ($3.10/MBtu). The current cost of natural gas is $4.28/GJ ($4.50/MBtu) and these two kilns consume enough natural gas to fuel a city of 10 000 population.

Both state and federal air permits have been granted for this unit which is designed to gasify 81 647 kg/d (81 tonne/d) of 3.33, kc/gm (6000 Btu/lb) stockpile lignite containing 50% fines and up to 30% moisture. Sulfur in the lignite reacts with the alkaline ash, resulting in a clean low Btu gas and non-hazardous ash with no waste water discharge. The brick kiln emissions of particulates from firing low-Btu gas will be approximately 9 072 kg/yr (9 tonne/yr) and sulfur dioxide emissions will be below 453 953 kg/yr (450 tonne/

yr), or less than one-half the allowable increment without use of scrubbers, baghouses, or precipitators.

The unit accomplishes gasification by a three-stage process consisting of (1) drying and pyrolysis; (2) cracking of tars and other volatiles in a cyclonic combustor; (3) and gasification of the remaining char. The low Btu gas then passes through a series of cyclone separators and heat exchangers where particulates are removed and the gas temperature is reduced from 871°C (1600°F) to 316°C (600°F). The low Btu gas is pressurized to 71 gm/ml (28 in. water) and piped to kiln burners.

One kiln modification is completed for firing low Btu gas as the preferred fuel and natural gas as a back-up fuel. High velocity, mixing burners were installed for modification to dual gas. These burners were selected because of their successful adaptation to low Btu gas at a brick plant in Driefontein, South Africa in 1975.

Description of Lignite Gasification Process

Figure 1 shows a schematic of the lignite gasifier. Lignite and air go into the gasifier with ash and low energy gas coming out. A variable speed rotolock feeds lignite into the gasifier. The lignite and subsequent ash are conveyed thru the gasifier by variable speed augers. A bed depth of fuel and ash is maintained in the system with a specific material flow rate required for complete gasification. The ash is discharged from the gasifier through the intermittent operation of a constant speed auger/rotolock combination.

Hot air is injected into the gasifier under pressure from a combustion air fan. The gasifier operates under negative pressure from the downstream gas fan. The final temperature of the low energy gas is determined by the flow rate of combustion air through the air/gas heat exchanger and the excess hot air is dumped into the atmosphere. Particulates, separated from the low energy gas, are recycled through the gasifier system.

The auger shafts are cooled by a closed loop water system which includes a pump, a fan-coil unit, and a water tower.

The gasifier system must provide a varying quantity of low energy gas at constant pressure. The low energy gas quantity is assumed to be directly proportional to both the combustion air quantity and the total carbon quantity of the input fuel. The second assumption is that the combustion air, required for optimum gas production, is directly proportional to the total carbon in the input fuel. A change in the moisture content of the input fuel will require a change in the air to fuel ratio.

The drying auger tubes are to operate at 70% full, based on cross-sectional area. This dictates a direct rpm ratio between the rotolock feeder and the drying augers. This rpm ratio must be determined by field experimentation.

The third assumption is that the input fuel will flow thru the drying augers at a maximum rate of 3.4 m^3/h (120 ft^3/h).

The fuel-ash level in both the first stage and the third stage are to be maintained at 61 cm (24 in.) above the grate.

The fourth assumption is that the fuel-ash flow through the first stage at a maximum rate of 3.4 m^3/h (120 ft^3/h) and will decrease in volume by 70% during its third stage residence.

The gas valves downstream from the gas fan contain Teflon seals with a maximum operating temperature of 260°C (500°F); therefore the low energy gas must not exceed this temperature.

Water flow must continue thru the grate auger shafts during power failure.

The atmosphere in the first stage is to be maintained above 871°C (1600°F). The atmosphere in the third stage is to be maintained above 927°C (1700°F). The temperature of the combustion air leaving the heat exchanger is to be maintained above 538°C (1000°F).

The firing zone immediately above the grate in the first and third stage must not exceed 1149°C (2100°F). This temperature can be varied by the flow rate of combustion air, the grate auger rpm, or the amount of steam in the combustion air. The effects of these three inputs on the firing zone temperature must be determined experimentally.

The low energy gas pressure on the discharge side of the gas fan is to be maintained at 71gm/cm^3 (28 in. water).

These process functions and associated functions require over one dozen proportional control feedback loops plus an excess of 30 discrete controls. A central control unit directs and coordinates this complexity of control.*

Computer Controller

Initially, computer control of the gasifier system was considered undesirable for the following reasons.

(1) Too complex for the kiln operators,
(2) Too complex for brickyard maintenance,
(3) Not suited for brickyard conditions.
(4) Too complex for management, and
(5) Who would develop the software control program?

Elgin-Butler designed the gasifier control system using familiar proportional controllers and relays but could not fully justify the design over computer control. A review of current company use of computers and/or microprocessors revealed the following:

(1) All calculators were microprocessors,
(2) The copiers were microprocessor controlled,
(3) Some typewriters contained microprocessors, and
(4) Accounting and payroll accomplished by computer.

Who operated these electronic devices?

Elgin-Butler brickyard personnel operated them and maintenance has not been a problem. The offices were computerized for efficiency. It was determined that computer controls on the gasifier system would automate a complex control system to the extent that the current kiln operators could operate the gasifier in addition to their kiln duties.

Once the concept of process computer control was accepted then the various aspects of operation, programming, and maintenance were studied and the following three approaches to process computer control were considered:

(1) Operator only,
(2) Operator and programming, and
(3) Operator, programming and maintenance.

Operator Only

Kiln operators can be trained to operate the gasifier using the computer controller. This approach requires the software control programming to be provided by the manufacturer of the computer, and/or the manufacturer of the gasifier, or a professional software company. The company that provides the software programming must then train the operator. Also the computer manufacturer or a professional elecronics repair company must be contracted to maintain the computer controller system.

This operator only approach functions satisfactorily in accounting where federal accounting standards provide a common base of similarity for software programming. Unfortunately such a commonality does not exist for the multiple variations of manufacturing processes and controls. Successful computer control of a complex chemical reactor, such as the gasifier, requires intimate knowledge of the process requirements, instrumentation, computer operation and software programming. This is the operator/programmer approach to the process computer control.

Operator/Programmer

The kiln operators can be trained to operate a computer controlled gasifier but programming the software for the computer controller requires specialty knowledge. The gasifier control system must be compatible with the brick kiln system, requiring Elgin-Butler personnel to be cognizant of both processes and their instrumentation regardless of the control system selected. Since Elgin-Butler is currently operating and controlling the kilns and was involved in the engineering of the lignite gasifier, the decision was made to provide training for in-house software programming of the computer controller.

The operator/programmer approach to computer control requires the following:

(1) Intimate knowledge of the process,
(2) Instrumentation and control design capability,
(3) Computer software programming capability,
(4) Operator training, and
(5) Maintenance by manufacturer or electronics company.

The plant engineer is normally the one to be selected for computer controller training. The plant engineer must know the manufacturing processes for both lignite gasification and kiln firing. He must know all the process variables and possible disturbances. He must have a basic knowledge of control theory and techniques in order to effectively use and maintain the control systems for these processes. He must know control theory in order to understand the system's dynamic properties and capabilities. Control settings can then be made experimentally by knowing how changes in these settings will affect the process. Analytical determination of control settings is difficult and time consuming due to problems in setting up a model of the process.

In setting up many control systems a standard procedure is followed. The controller settings are adjusted until the measured variable has a steady oscillation. The system is then on the verge of instability (wild swings). Next, the controller settings are backed off so that the system operates in a stable region. The tendency is to back off so much that the system is very stable and disturbances have little effect on the quantity controlled, such as fluid flow. With this type of setting any deviation of the controlled substance takes a long time for correction. This stable system will have a large safety margin but product quality and quantity will not be optimum. Understanding the controls and process thoroughly, allows for a tighter control and more efficient production.

An efficient plant operation must have the preceding capabilities either in one person or a team. In addition, plant operations should acquire the capabilities of software programming of the computer controller. This is simple user programming (giving instructions to the computer) and not the complex programming required in the computer industry for the read only memory functions which dictate computer internal operations. User or software programming is the logic sequencing of input/output information in relation to the computer internal instructions placed there by the computer manufacturer.

The computer control selected for the lignite gasification system includes a number of different electronic modules and is designed for controlling small manufacturing processes that require both digital and analog control. Simply stated, it can perform on/off control and feedback loop control.

The basic component of a computer is a microprocessor. A microprocessor is a digital integrated circuit, better known as a silicon chip, that contains the digital functions necessary to be a central processing unit (CPU). The chip processes input information, step by step, in a prescribed fashion which results in an answer or output. The microprocessor's inputs and outputs are in the form of increased or decreased dc voltage and must be translated. Translation into numbers (digits), zero thru nine, result in a digital computer which can perform mathematics and other logic functions. Translation into varying control voltage or current results in a proportional or analog computer.

The system used contains both a digital computer and an analog computer with corresponding input, output, and memory functions. The digital computer can be user programmed in ladder logic which is based on standard schematic electrical wiring diagrams for switching, timing, counting, and relay controls (on-off controlling). The analog computer is programmed for the more complex proportional controls (PID) by keyboard operator response to computer generated prompting messages flashed on the screen in typewritten English. The analog computer asks questions and the keyboard operator answers, thus programming the PID feedback loop.

Proportional-Integral-Derivative (PID) refers to the standard proportional control. An example is crown temperature control in a tunel kiln where a thermocouple generates a voltage that varies directly with crown temperature change. This changing voltage is transmitted to a controller which compares it to a setpoint setting and causes a fuel valve to modulate proportionally to correct the difference between the actual crown temperature and the setpoint temperature.

Programming the computer requires a minimal knowledge of binary numbers, Boolean algebra, and computer language. It is necessary to know all parts of the equipment and their functions. The controller start up procedure and keyboard functions are quickly memorized and short practice sessions, following the instructions carefully, result in a readily acquired programming capability.

Elgin-Butler's training for in-house computer programming has proceeded apace with the gasification construction plus the initial software programming by the gasifier manufacturer.

Operator/Programmer/Maintenance

Installation and maintenance of a computer controller requires a change in plant maintenance as well as a change in plant engineering. If a computer controller is installed, then maintenance of these electronics must be provided on an outside maintenance contract basis or in-house personnel must be trained. Elgin-Butler elected to provide their own in-house maintenance because they have an electrician who is electronics oriented. Electronics maintenance of the computer controller may be provided by the computer manufacturer, an electronics repair company or in-house electronics technician. Maintenance by the manufacturer is the least desirable while in-house electronics technician is the most desirable. If Elgin-Butler did not already have an electrician with excellent electronic capability then an electrician would be sent to electronics school or an electronics technician would be hired. Timely repair and maintenance is required in production operations which dictates a sufficient inventory of printed circuit boards, sensors, and transmitters. Possibly, the most important maintenance capability is to have a manual control option with personnel trained for this function.

Control Summary

Microprocessor control of Elgin-Butler's lignite gasifier will allow current kiln operators to monitor the automatically controlled system, eliminating the need for four additional gasifier operators and will provide optimum control.

The computer will monitor the gasification operation and will make operational decisions which will include:

(1) A quick response to gas demand by the kiln,
(2) Change the lignite feed as the gas demand changes,
(3) Provide a timed sequence ash dump, and
(4) Provide automatic start-up after power failure.

Project Status

The lignite gasifier components were received in March 1983. Elgin-Butler's construction crew completed assembly of these components, as shown in Fig. 2, in August 1983. At that time testing, calibration and programming of the control system was initiated.

Conclusion

Stockpile lignite is a trash fuel by coal standards but Elgin-Butler has large quantities of it and we intend to gasify it. In 1911 there were 26 gasification units operating in Texas that were fueled by lignite. It is reasonable to assume that lignite gasification for industrial application can again be achieved. It is Elgin-Butler's intention to revive this technology.

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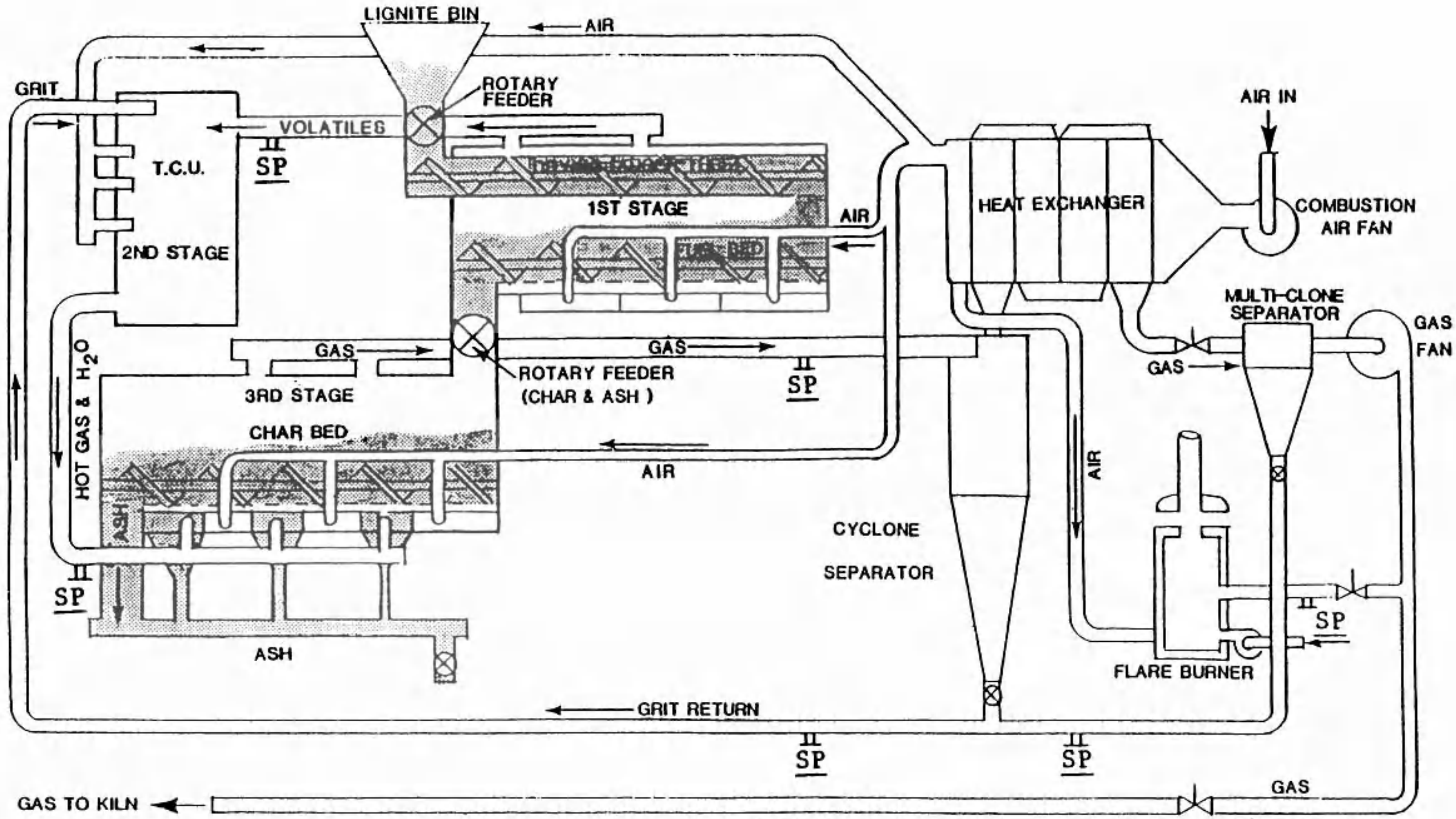

Fig. 1. Schematic design of Elgin-Butler Brick Co. traveling-bed gasifier. SP = sample port for combined gas-particulate sampling.

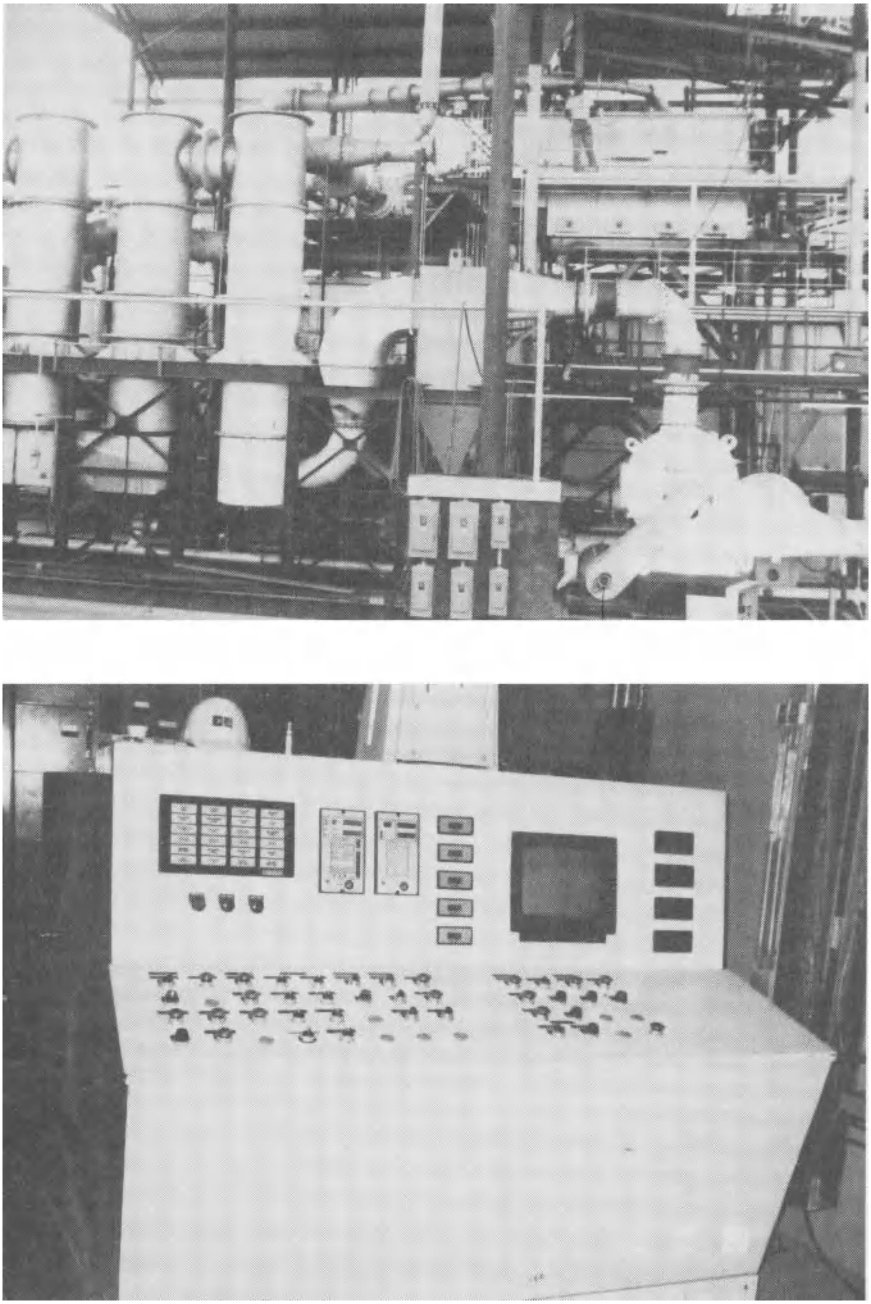

Fig. 2. Lignite gasifier being constructed at Elgin-Butler Brick Co.

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William J. Smothers

Microprocessor Application in a Refractory Plant

KENNETH R. JONES

Globe Refractories
Newell, WV 26050

The application of microprocessors to very accurately controlled material handling and processing is discussed. Control of all mechanical functions of presses, automatic setting equipment and the quality control of both density and size of various products is described.

Microprocessor-based programmable controllers have the speed, intelligence, flexibility, and durability to control processing on refractory presses. With the appropriate auxiliary equipment and sensors a high level of control and accuracy is now available that just a few years ago would have been impractical.

Programmable controllers (PC) are controlling 720 tonne (800 ton) toggle presses and 135 tonne (150 ton) hydraulic presses at Globe Refractories. Both types of presses are run by 8K memory word PCs which control raw material feed, press cycle functions, conveyor belts, and automatic setting equipment. There are 96 inputs and 64 outputs for 110V controls. A series of 24 three-digit thumb wheel switches are used to input timer values, counter presets, and other operator controllable functions.

The PCs will also accept 0–10 V dc analog signal and drive 16 three-digit digital displays. These digital displays provide the operator with real-time information required to efficiently operate the presses and quickly diagnose any problems.

Sizing accuracy on the toggle presses can be held to ±0.03 cm (±0.010 in.) for a brick 8cm (3 in.) thick. This is accomplished by epoxying strain gages to the two side bars of the press and measuring the strain produced during the pressing cycle. The PC reads the individual strain gages, checks for a valid reading, compensates for temperature, then adds the two values and compares this total to the setpoint pressure value. If the error is greater than 9 tonne (10 tons) a correction is made in the raw material fill cavity before the next cycle begins. The correction made is proportional to the error, so the larger the error the more the fill cavity is adjusted.

Alarm functions for the toggles presses are also monitored by the PC. The most important function being monitored is the total press strain gage reading. If the pressure exceeds the press load limit, the PC immediately halts the press cycle to prevent damage to the press frame.

The sizing control on the hydraulic presses is accomplished by direct measurement. The position of the top and bottom hydraulic cylinders are measured, using linear position sensors, at the end of the pressing cycle. The two measurements are added to give the size of the finished piece. If the piece is too long, the hydraulic pressure is increased up to 6% above the pressure setpoint in an attempt to compress the piece to proper size.

The final length of the piece is compared to the length setpoint. If the error is greater than 0.09 cm (0.035 in.) a fill correction is made. Correction of the fill cavity is proportional to the magnitude of the error. The length setpoint is adjusted using a three-digit thumb wheel switch in incremental steps of 0.02 cm (0.007 in.).

Programmable controllers have enabled Globe to substantially increase product quality by automatic size controlling. The PC also produces reduced downtime and faster repair with PC-prompted trouble-shooting aids.

Ceramic Engineering and Sciences Proceedings
William J. Smothers

Use of Computers and Microprocessors to Control Kilns and Dryers

FRANCIS V. PIXLEY

Pixley and Associates
2000 W. Union Ave., Englewood, CO 80110

A review of the most up-to-date computer and microprocessor installation in the brick industry is presented. This will include interfacing of computers and microprocessors to provide total control of kilns and dryers and supply management with daily progress reports. A description of the kiln and dryer control logic along with the problems incurred with sensing the environment is explored.

Introduction

The use of microprocessors and programmable controllers has become the accepted system for controlling the majority of new automated equipment now supplied to the ceramic industry. Over the past six years CERIC/PIXLEY have developed logic systems for the use of microprocessors to control our kilns and dryers. In our most recent plant in the United States we have moved ahead to a new level of control which provides management with the ultimate in plant supervision and control. This is done with a computer to manage the programmable controllers or microprocessors.

The paper will cover the following:

(1) Description of the functions of programmable controllers and computers,
(2) Description and illustration of the logic for controlling kilns and dryers,
(3) Discussion of the problem areas with these systems, and
(4) Discussion of the role of the computer and how it improves management's control of the plant and pays for itself.

Microprocessors and Programmable Controllers

These are terms with which we have become familiar. This equipment* to a large part has replaced the old stepping switches and relay control systems for automatic equipment. In their various configurations they can take input signals, process the information through a program, activate an output to start or stop motors, open valves, and perform other tasks. The main limitation of this equipment is that it can handle only one program at a time *with a limit of variables.* In most cases the units can be easily reprogrammed manually if changes are required. This equipment does not have a large memory bank and usually provides no way to store information.

Computers

The computers[†] provide a whole new level of control possibilities. They do not take the place of the programmable controllers which must be used to carry out the switching functions and gather information but it does extend the capability and power of the programmable controller.

The computer's real *importance* is its memory. This allows more programs and more complex analytical programs to be written. It permits the storage of vast amounts of data that can be recalled in a variety of forms to aid in the operation of the plant. The computer is the brains and the programmable controller is the arms and legs of the system.

As we proceed to describe the new system currently being installed on the Denver Brick Company's new kiln and dryer and handling system, the role of each unit will become clear.

Control System

A block diagram of the system being installed at Denver Brick is shown in Fig. 1.

The first level is the kiln/dryer/handling system which is to be controlled.

The second level is represented by the programmable controllers. For simplicity, one controller is shown for the dryer, one for the kiln, and one for the handling system. In actual practice the geometry of the plant and economics will dictate the size of the programmable controllers and where they are located. These systems have a basic program and data to function independently of the computer.

The third level is the computer array which is linked to the programmable controllers through a data highway system. Starting on the left side of Fig. 1, we have the CPU or the central processing unit with a hard disk memory system and two eight in. floppy disk drives. Coupled to this system is a printer with a keyboard and a video terminal with a keyboard. These two units are used entirely for programming purposes and are normally accessible only by the designated programmers.

The next unit is a video terminal with a keyboard and graphics capability which is the main console for the plant operator. The data available on this screen is also displayed on a large color display video screen that is mounted in the control room so that the data is easily visible to a group of people.

The main control console at the touch of a button will display the temperature curves in the kiln indicating the desired curve and any deviation from the desired curve. Information concerning the setting of the burners, damper openings, etc., can be pulled up and displayed on these screens.

This screen will also reproduce a replica of the track and haulage systems and indicate the position of every car in the circuit. In essence, this screen and terminal will supply the current information and status of all the systems throughout the plant.

On the right side is another video terminal and keyboard with a printer. This unit is on line at all times and acts as an alarm terminal and an events terminal. This means that when there are any failures in the system it is through this screen and terminal that the data will be indicated and automatically recorded by the printer. It is also on this system that commands can be given to withdraw the information and make permanent copies from the main hard memory system. For example, a command can be given that at every push, the push time and the condition of the kiln and the status of the system can be recorded. Or the events can be recorded on an hourly basis such as a kiln fireman would do.

If there are any failures or down time, this will also be recorded to indicate when the failures occurred, the duration of the failure, and the time of startup. The reason for the three basic systems is:

(1) The hardware on the left provides the primary CPU, memory system, and programming capabilities. It will be possible while the system is under operation to write new programs, put them into the memory, and have them ready to go without disrupting the normal operation of the plant.
(2) The main video terminal allows management to monitor on a continuous basis all the functions within the operation.
(3) The right side of the system is for recording current events. That means that one man can be programming, one man can be looking at the operation; and if there is a failure, or an event is happening, it can still be recorded without interrupting the other processes.

To fully understand the impact of this system over the old methods of operation it is necessary to take a moment and review the various stages of kiln control.

Kiln Control Logic

Figure 2 shows a typical kiln that has seven controlled firing zones, the burners are designed with automatic spark ignition, uv flame supervision, individual throttling control on both the air and gas lines. There is a rapid cooling section, waste heat off-take to the dryers, cooling air, supply fans mounted in the doors, or as we like to refer to them, over-pressure fans. At the entrance end is an exhaust stack system plus a short recirculation system between the exhaust and burner zone. At the lower right is an undercar cooling fan which blows air underneath the car and is exhausted at the entrance end. This air is used with the waste heat recovery for the dryer. The final system under control is the pusher system for the cars.

The following brief description of the control system will give some idea of what is being tried to achieve with the programmable controllers, and ultimately the computer.

Starting at the exit end of the dryer it is wished to hold an exit temperature on the cars of approximately 6°–11°C (10°–20°F) above ambient. When this temperature exceeds the control point, the waste heat damper opens to draw off more air which lowers the pressure in the entrance end of the kiln. This causes the over-pressure fans to increase the volume of air entering the kiln at the exit door which increases the cooling rate and restores the pressure conditions throughout the kiln.

The temperature of the quartz conversion is also considered a critical point and this is coupled to the rapid cooling zone jets. The temperatures at the jets are controlled by modulating the rapid-cooling fan dampers. Each set of jets can be individually adjusted. As the cars move under the thermocouple recording the temperature of the quartz inversion point, if the temperature is still too hot, the exhaust fan increases to allow more air to flow up the tunnel to bring that parameter back in line. Again, we have changed the pressure at the front end of the kiln, and the programmable controller scanning the system then makes the appropriate correction with the overpressure fans and the waste heat cooling fans to bring the system totally back into control parameters.

The next controlled section on the firing curve will be the firing zone which is controlled primarily through the thermocouples and the burner zones to shape the actual firing curve. Again, as the gas and air are modified, corrections are continually being made to maintain all the other parameters within the kiln. If the stack temperature is above the desired set point, the programmable controller will begin to shut down the early preheat burners or bring them on as required. There is also a program that selectively chooses which burner should be turned on or off. It may not always be the first group. It may be the second, third or fourth, depending upon an analysis of the system at that moment.

The next system which is under control is the undercar cooling system. This system was designed to provide counter pressure to the pressure in the tunnel, to cool the cars and recover the heat that is normally lost beneath the kiln to use it for the preheater or dryers. As the pressure in the kiln varies, the programmable controller will modify the dampers on the undercar cooling supply fan and exhaust fan to maintain a fixed pressure differential between the top and bottom of the cars.

At the front end of the kiln is the exhaust fan which has been, as said before, tied into the kiln through several logic points and is continually adjustable through its variable speed motor. The programmable controller also has control of the pusher and, depending upon the conditions, the computer can modify the push rate without outside intervention. This feature is used in case there is a power failure, and the system has been off for several hours, the kiln can go into a start-up mode, which is a separate program from a running mode. The pusher may start at a 50% speed rate while the temperatures are being increased and the cooling curves are being re-established, and when the computer indicates that the system is approaching normal operating parameters, it will switch over to a full push rate and a normal operating program.

The above is an overview of the type of control logic and functions that the programmable controller is doing on the current system and it will be shown how the computer is further increasing these capabilities.

Dryer Control

Figure 3 shows a new dryer which is a three-section dryer. The sections are:

(1) The exit end, the high temperature section, provides whatever temperature is necessary for the final drying of the brick before it enters the kiln,
(2) The intermediate section, or the tempering section, recirculates and tempers the air to the desired temperature prior to it passing back into the rhythm or shrinkage section, and
(3) The final section is the rhythm fan section which coincides to the shrinkage water segment of the drying cycle.

Following the same philosophy as used on the kiln, all the parameters are controlled during the drying cycle and maintained with constant surveillance.

The temperature, say 180°C (350°F), is controlled with a thermocouple at point A. The booster burner or the fresh air damper maintains the required temperatures at this point. At point B, at the end of the second zone, a temperature of 95°C (200°F) is held by using hot air from the main supply fan or ambient air. At Point C in the rhythm section, the same capabilities of maintaining the temperature at the exit end of the dryer by inducing more hot air if necessary to the rhythm fans is applied. The relative humidity is sensed in the exhaust stack and it is modified by increasing the overall air flow through the dryer. As the overall air flow in the dryers increases, the pressure change is sensed, and the exhaust volume is adjusted to bring the whole system back into balance.

Since both the kiln and the dryer are under full automatic control, and the one link between them is the waste heat from the kiln supplying the dryer, a mixing box is used so that the kiln cannot affect the dryer, or the dryer affect the kiln. This is of utmost importance in maintaining a reliable and independent system.

Car Handling System

The car handling system is also controlled by the programmable controllers. The basic functions, such as starting and stopping the cars, running the haulage systems, opening and closing the dryer doors, and the kiln doors, are typical of current technology. It is the addition of the computer to this system that makes it unique.

The above descriptions indicate how the programmable controllers function and the type of logic that is used to control the kilns, dryers and car movement.

The following will show what the computer is adding to the overall system.

Starting with the car moving system, a binary counting system is put on the kiln cars with detectors on the transfer car so that any of 70 cars can be identified. With this system, and the memory within the main computer, when a car is loaded the operator tells the computer what product is on the car, this immediately begins an inventory program and also a method for tracking the product through the rest of the process until it is shipped. Every time the car is moved, the computer can verify its position and track it through the dryer, kiln, and unloading stations. It is possible with this system to call up a specific brick and find out where and how many are in the system, which storage tracks they are on, or what position they are in in the kiln. It is possible to write a software program so that when the cars are unloaded and the finished packaged brick are counted, the difference between the car load and the packaged brick will represent the waste for the day. So one of the functions that the computer brings to the system is a full inventory base system.

When the car enters the dryer or the kiln, the computer can modify the curve and conditions within the kiln and dryer as required for that particular product. For instance, at the Denver Brick plant they will be firing red clays at 1065°C (1950°F) to buffs, and fire clays in the 1175°C (2150°F) range. It is possible to have a car entering the kiln at 4 am and the kiln will automatically begin to increase the burners and modify the curve to fire that particular brick without the interference of the kiln fireman or the plant supervisor. This may take the form also of slowing the kiln down or speeding it up, depending upon whether solid brick, large shapes, or light shapes are being fired. The computer has the memory and capability of modifying these functions based on predetermined information.

Management Function

The computer becomes a full management tool. As indicated, it will maintain the inventory and tell management precisely where the brick are in the process, what has been shipped, or in stock; it can totalize, accumulate and remember what has been made since the beginning of the operation. As mentioned earlier, the computer has the capability of turning out a hard copy of every event or function that takes place during the day. This means that management has at its fingertips, when it walks in at 8 am, a complete record of the kiln, dryer, holding room–whether the parameters were being held or if there were any problems that happened during the night. They do not have to trust the memory or veracity of their fireman as to what was done.

How many people have come in and found bad product on the line and immediately blamed the kiln or the dryer? They probably spent several days resetting the kiln and dryer for the assumed problem and eventually found out that it was the raw material or manufacturing that was the real trouble. Having the exact facts in hand immediately allows management to go to the source of the problem.

Maintenance Control

It is possible to put a software program into the computer that acts as a reminder to the maintenance department as to when fans, bearings, car wheels, etc., should be greased, repaired or replaced. When the work is done the information can also be put into the computer via the terminal so that there is a permanent record as to when the work was being done. It is also possible for the computer to bring up on to the screen every morning the work that should be done based on a predetermined greasing and maintenance schedule.

Probably the biggest unanswered question is how do we pay for a system like this. What is the justification for installing a kiln of this type with programmable controllers, computer system on top of it, and make it pay for itself. The answer comes in three areas:

(1) The improved recovery the system will allow. Management will have at its hands all the information it needs to make sound decisions when there is a shift in the product quality. The system also will maintain the parameter much more accurately than any human could do, thereby assuring that when quality product is being produced it will continue to be produced since the drying and firing functions are not allowed to vary.

(2) Manpower–The current kilns in Europe and the new one in the United States will essentially operate with no fireman, and no off-duty personnel. This alone represents a minimum of \$60 000 to \$100 000/yr in payrolls. The current systems are designed to have a three-level alarm system:

The first level–if the event does not stop the process for over 15 min, or is within certain preset parameters, the computer will simply indicate the event for correction on Monday morning or during working hours.

Level 2–is an event which would stop the operation and requires immediate attention such as a failure of a switch, transfer car motor, door closure/opening system. At this point, the computer will dial a predetermined sequence of numbers which would call up the maintenance department and the supervisors until someone is found to come out and make the correction.

Level 3–notification would be a major shutdown or disaster condition, at which time not only will the above personnel be notified, but both the police and fire department would be automatically called.

(3) The third area in which these systems justify themselves is in the energy saving. The kiln is always operated at an optimum condition. Mass gas flow is maintained at predetermined levels, exhaust temperatures are maintained as closely as possible to predetermined requirements so, as the product shifts and the load weight changes as

the density of the product in the kiln shifts, the air flow and fuel consumption are maintained at their optimum conditions. All of this enhances and ensures that the kiln will operate with a minimum energy consumption.

Summary

The programmable controllers' first function is to take information in, process it, and activate the output such as the motors and control devices. Putting programmable controllers on the kilns is only the first step. It is what you do with the programmable controller, the sophistication of the programs that are installed on it, that determine whether you are just replacing traditional control equipment with a programmable controller or whether you are going to the next stage to develop a fully integrated project system.

The addition of the computer above the programmable controller provides the memory system. We have just touched briefly on some of the systems which we are currently installing, but with some imagination, it is apparent that once the information has been put into a permanent memory form and the correct programs are written, a mass of useful data will be available to management. We are just beginning to scratch the surface of the use of the computer in the ceramic plant operation. It is our intention and Denver Brick Company's intention to eventually tie the computer back into the manufacturing and grinding operation so that management will have at their fingertips a complete history of the operation on an hourly and daily basis so that the decisions they make will be more accurate because of the quality of the information.

About 25 yr ago I was making speeches on mechanization and automation when we were talking about setting machines and automatic handling systems. My final warning in every speech was (1) don't be afraid; (2) yes, it will take more sophisticated personnel to handle these systems; and (3) you will not survive if you don't begin moving in this direction.

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*Typical suppliers are Allen-Bradley, Highland Heights, OH; Texas Instruments, Richardson, TX; Modecon, Div. Gould, Inc., Rolling Meadows, IL; and Barber Colman, Rockford, IL.

†Of the type, IBM, Armonk, NY; Digital Equipment, Maynard, MA; Hewlett-Packard, Palo Alto, CA; and Apple-TR80, Apple Computer, Cupertineo, CA.

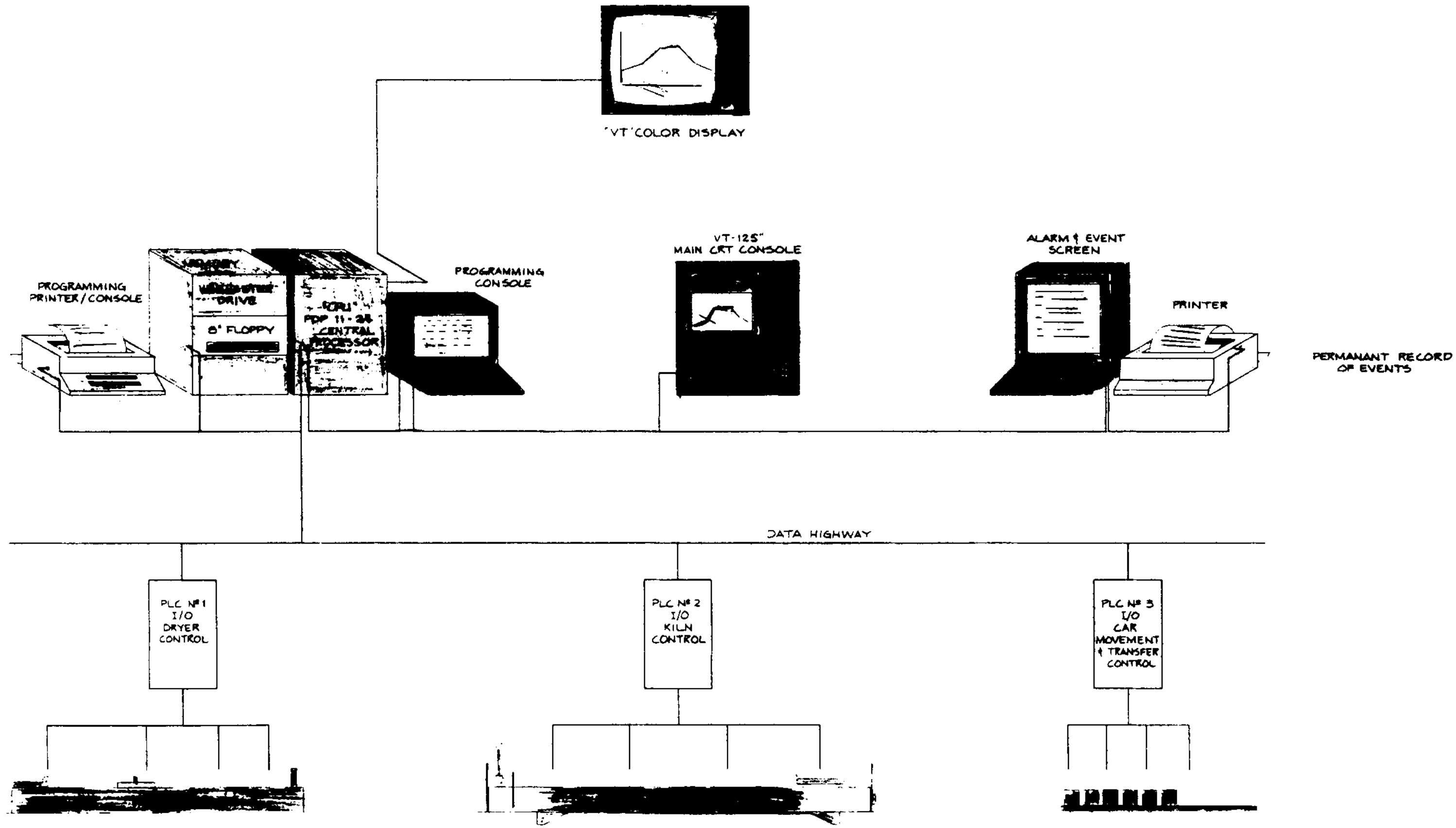

Fig. 1. Block diagram of system being installed at Denver Brick.

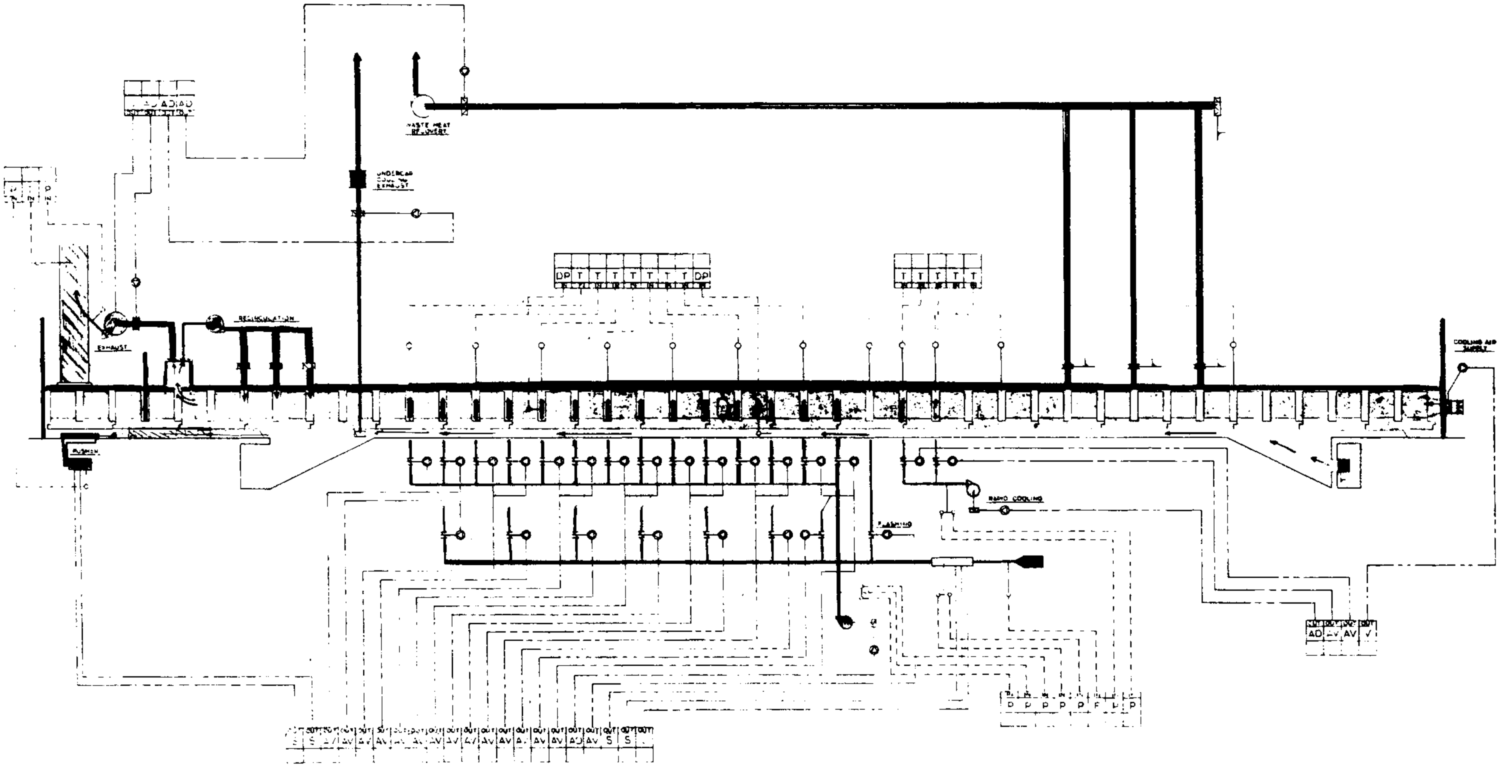

Fig. 2. Typical tunnel kiln system with programmable control showing I/O functions.

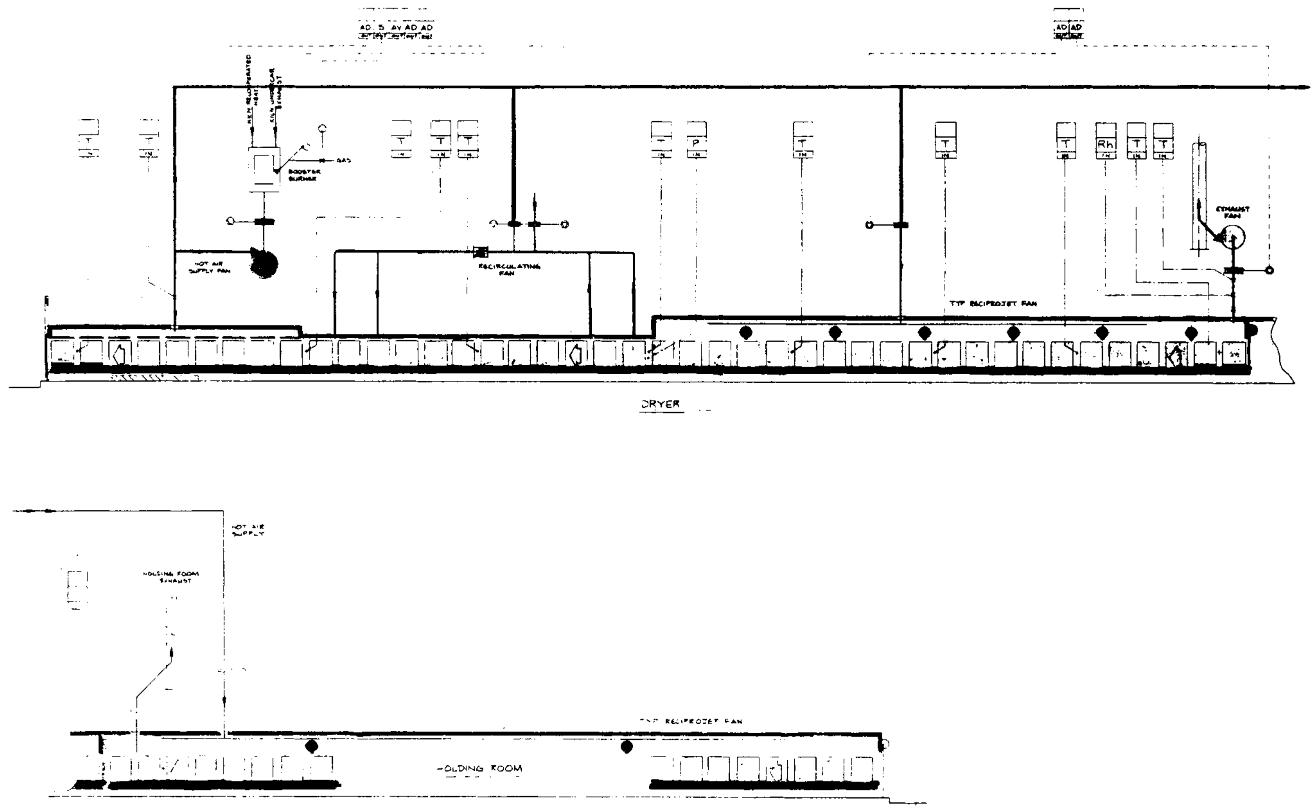

Fig. 3. Dryer and holding room system with programmable control showing I/O functions.

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William J. Smothers

Application of Microprocessors to Kilns and Ceramic Manufacturing

MARIO MORI

Mori s.p.a.
Via Sallustio 41100
Modena, Italy

CARLO GAMAGGIO

Lamco
506 Terrace Hill Dr.
Temple Terrace, FL 33617

The TCU microprocessor system that we are presently using with our roller hearth kilns summarizes all the developments derived from the experiences we have achieved in the course of time with application of microprocessor systems to the process control for ceramic products of fast firing kilns.

By examining the main technical functions and features of the microprocessing TCU system, the type of development that the application of such systems has about in the last twelve months will be underlined.

One year ago we presented the first applications of the microprocessing system for the control of rapid firing ceramic kilns, and had concentrated our attention on the selfregulation and control of the kiln temperature. Even today, one should repeat that if these systems are right by the kiln's side, it is due to their absolutely superior precision, which was not found in the traditional systems, that they act as self-regulators for the material firing curve. This superior precision is revealed in the quantity and quality increase of the fired product, especially since it is applied to the regulation of rapid firing cycles.

We know that with a certain type of product to be fired, the inherent chemical and physical characteristics determine a limited firing curve which corresponds to the shortest firing cycle to obtain a worthy product. For such a firing cycle there exists one, and only one, temperature for every instant that allows one to obtain a worthy product. To obtain the maximum production it is therefore necessary to make the firing curve of the kiln correspond to such a limited curve of the product. In other words, to increase to the maximum the production, it is necessary to limit the oscillation of the curve of the internal temperature of the kiln to the minimum limit possible for the firing curve. Therefore even in the TCU system the self-regulation is the most important and most accurate function. In every individual area the chosen temperature is predetermined by a group of rotating counter-meters with 1°C resolution. The temperature survey taken with 10% thermocouples is done with a 1°C resolution and a 0.5°C precision. The temperature control program brings the burners to the minimum point when the surveyed temperature is 1°C higher than the set-point, and it brings it to the maximum point when the temperature is 1 °C lower than the set-point. Generally, in the critical firing curve zones, the temperature oscillation can be kept within a range of $+0-1°$ from the set-point. The firing curve oscillation therefore can range within a maximum of 3–4 °C. This precision is obtained in two ways: the use of very high quality components, mainly amplifying converters, and the use of particular program procedures. Both are designed to eliminate the disturbing effects in the industrial environment at the warning of the thermocouple. The amplifying converter, the most precious element in this system, carries out a first substantial filtration of the signal and it transmits it, amplified 1000 times and converted into digital signals, to the microprocessor which is able to read the signal that has arrived, with a resolution of 10°. Afterwards it carries out every 13 cm (5 in.) sixteen averages from 256 readings in order to extract the values which correspond to the interferences. The decimal point is extracted from the gathered temperature, and it is the temperature which is read by the microprocessor. The comparison with the set-points is carried out by the microprocessor by a digital system and not by the analog comparator as was done in the traditional systems. The correctness and the precision of the signal, which is read by the thermocouple, in comparison with the set-point and resulting regulation, have proven during laboratory and production tests that they are incomparably superior to the traditional analog control systems which, incidentally, are still in use.

The other functions of the system can be placed into four main groups: (1) cycle control and automatic procedures, (2) data collection, (3) alarm warning, and (4) visualization and printing of the data pertaining to the three preceding groups.

Cycle Control and Automatic Procedures

Fine control by using the second set-point: Because of the preciseness of the control it is convenient even in view of a larger fuel saving to limit the difference in gas supply to the burners between the maximum and the minimum during the control phases. The maximum and the minimum points in this new control process are very much closer to one another. The minimum point which was used in the traditional procedures begins at a second set-point predetermined at 2–4°, or in other words above the main set-point. Evidently it is the precision of this system that allows two correctly functioning set-points within a range of only 2 °C.

Firing curve control in case of "voids" in the feeding of materials: Because of the low thermal inertia due to the rapid firing, and, consequently, the presence of the firing material on the thermal scale of a given section, the absence of material moving through a given section can lead to excessive or insufficient temperature variations, called "voids." They are determined by the length of absence of travel, the thermodynamic features of the section in which the "void" is moving and the derivative of the firing curve in that section.

The alteration of the firing curve which follows causes substantial damage to the material immediately following the "void." If the material is subjected to overheating, it may reach such a softened state that the advance of the material in the kiln is interrupted. This generates the so-called "overlapping," with damages that affect more than the surface of the material that is temporarily overheated. The TCU system detects the emerging of a "void" in the kiln and it follows it along its route, section by section, changing the set-point of the section into which it is entering by one temperature interval and anticipating the arrival of the "void" in the next section by using a control procedure that makes the sections follow through the increase and decrease at the right time and with the roller level.

With this operation one merely re-enacts that which is generally manually performed by the kiln operator. In the event that the kiln operator prefers to manually perform the duties, the system visualizes the position of the "void" advancing within the kiln and, section by section, outlines very efficiently the variations in the firing curve, making this a great help for the operator.

Cold joint temperature compensation: Even though this operation pertains to the true temperature control, it is shown apart because of its independent structure, the absolute correction precision, and the manifest efficiency of the finished product.

TCU system's auto-diagnosis operation: The auto-diagnosis operation serves to verify the correction functioning of the TCU system. It is performed only in the event of possible malfunctions of the installation and allows one to distinguish the possible internal causes.

By repeatedly pressing a button, the auto-diagnosis goes through five phases:

Phase 1: memory test–the positive result shows that the system's internal memories are working correctly; the opposite shows that there is a damage inside the system.

Phase 2: rotating meter test–allows the system to control on video-surveyed values of the temperatures which appear on the meters.

Phase 3: output test–allows one to manually operate each output of the control system's solenoid valves. The actual output is visualized by the flashing of a corresponding rectangle on the video.

Phase 4: converter test–the positive signal confirms that the surveyed temperatures are exact; the opposite causes a damage to one or more conductors of the thermocouples.

Phase 5: print-out test–this test activates the in-succession print-out of all the alphanumeric characters of the printer.

Data Collection

The second group of TCU system functions consists of the data collection. It is a function whose implementation into our system has almost exclusively been requested by our clients. They consist of the indications of date and time, the speed of the rollers, and the option to project onto the video screen the pictures coming from a video camera. In addition, twelve inputs are provided on the TCU system for the piece count or the 12-point counting possibilities scattered along the production line. Inputs for analog measurement indications are also provided, that is, twelve input possibilities for variable electric signals coming from instruments along the production line can be transducers of pressure, temperature, and supply.

This group of functions, and particularly the counting of pieces, and the input of analog measurements are a potential for accumulated data that is put to our service in order to control or to periodically analyze the points of the kiln or the entire production line.

Alarm Conditions Warning

The alarm conditions which are signaled by the TCU system are divided into three fundamental groups. In the first group we find the warning of nonimmediate danger conditions. The system calls the operator's attention by showing on the right side of the video the flashing abbreviation "MES" (message); by pressing the appropriate switch the message appears on a specific yellow-background video screen.

The messages belonging to this group may include, for example, "enter date and hour," which appears during the manual feeding phase; "temperature entered is higher than the maximum value," which appears when a temperature is higher than the maximum permitted for the safety of the installation, is registered on the rotating meters.

"Section out of control" is the third message which is accompanied by the flashing into the video screen of a histogram of the out-of-control section. It appears when the temperature recorded by the thermocouples differs by more than 10°C from the determined value on the rotating meters. It means that in such a section there exists an abnormal condition which prohibits the correct section control by the system. It may be, for example, the presence of a "void" in the section or the malfunction of a control element of the installation. The three warnings mentioned above remain on until the disappearance of the causes which have brought them about. They produce neither acoustic nor visual alarms.

The second group provides the alarm warnings which are caused by internal conditions of the systems.

The third group provides the alarm warnings for external causes.

The four alarms and their corresponding messages are:

(1) "overlapping," which signals the presence of blocks in the movement inside the kiln,
(2) "motors off,"
(3) "temperature higher than the maximum value on the recorder," and
(4) "gas valve disconnected."

In addition to these four messages, which are always present, 16 other possibilities for alarm messages or indications chosen by the user are provided.

Visualization and Print-out

The fourth function of the TCU system consists in the visualization and print-out of the data related to the three groups of functions previously mentioned. The printing on rolls of normal calculator paper is periodic or on request.

The values of the set-point and measures of each control section of the TCU system are printed on request or periodically. Each print also indicates the date and the hour of such operation.

The visualization function is performed on a three-page color monitor. The first page is dedicated to the autocontrol; the second to the warning messages, to the indication of the recordings, and to the readings of other analog measures. The third page is used for the system's four autotest function. The page used for the visualization of the autocontrol operation contains pictures produced by color histograms of the temperatures which have been reached in each section and also the positioning of the related set-points. This allows an immediate visual control of the kiln's thermal curve. On the same page, the temperature for each section is given in °C. In addition, the position of the "voids," which are travelling through the kiln and speed of the rollers and the materials is identified.

The effects of the adoption of the TCU system can be quantified as follows: The quality improvement corresponds to a 3% increase in the first quality products. In the 3%, 1.5% is a direct result of the more precise system control. The second 1.5% derives from the possibility given to the operator by the system to react, within a short lapse of time, to correct the abnormal functioning.

The increase in production is calculated to be 2.5%; an increase of 1.5% can be recorded after a short period as a direct consequence of the shortening of the firing cycles, while the other 1% is recorded during a long period as the result of a more continuous and stable condition where occasional incidents do not occur. For example, on all the installed systems there has been an almost total disappearance of "overlappings" due to the overheating and the softening of the materials. This allows additional savings in the maintenance; the spare parts costs of the rollers, for example, are reduced by about 4%.

The fuel consumption also profits from the more precise control and thus decreases by 3.5%.

As a consequence of the adoption of the TCU system, the dimensions are more difficult and less likely to be quantified by the personnel. The system allows the complete check of the kiln condition in a period that is drastically less than those of the traditional systems, mainly for the clarity and the preciseness with which it gives the data to the operator. For example, periodic surveys of the firing curve are possible by simply pressing a button and obtaining a print-out of the kiln temperature at that moment.

The recording and the calculation of the temperatures in digital values allow a greater precision than that provided by the traditional instruments, whereby the various possible errors were due to an inadequate defining of the reading scale, or to errors of parallax due to the reading angle of the instrument.

The new system allows a quicker intervention because the system is more sensitive to variations of the firing curve and instantly recognizes it, but also because it is the system itself that calls the operator's attention by means of a flashing of the histogram of the section out of control, or by the sending of video messages.

For curiosity's sake, we are also studying the adoption of a talking CIP which would give verbal messages. Unfortunately, the vocabulary used by these talking CIP is mainly in English even today. In other words, there is a better kiln operating conditions control with a smaller employment of time and direct attention by the operator. This signifies that the operator tires less and wastes less time, dedicating instead the time he is allowed to other control operations or performing small preventive maintenance.

By limiting the valuation of the data to those which are most easily assessed (quality increase, quantity of products, reduction in maintenance and consumption costs), bearing in mind that the raw materials and the finished products differ, and that the different installation conditions cannot be found together or grouped with the above mentioned values, the investment recovery time for the TCU system varies between 12–15 months but does not exceed 18 months.

During the past two yr, the cost did not increase, as did, on the contrary, the functions of the system. Therefore, the cost percentage for a standard 66 m single firing kiln for 1500 mq ca. of red body decreased from an average value of 9.5 to about 8%. The first system is close to two yr old and the maintenance costs can be considered insignificant. The only stumbling block was the first type of printer used; evidently it was better suited for office instead of industrial use, because, left unprotected and exposed to the ceramic dusts, it required periodic cleaning and maintenance.

The latest systems have adopted cabinet-protected printers, thus eliminating the previous type of inconvenience. The only elements which are delicate for contact with the ceramic industrial environment are the rotating meters, among which a certain number have been substituted after 20 months of operation.

The most precise, but also the most frequent control reactions, involve the control relays of the combustion system's solenoid valves. The consumption of these relays remains high (15 per yr). In other regards, the TCU system has not shown signs of incompatibility with the ceramic industrial environment, except for the fact that it requires a monophase voltage that must not shift away from the 220 V nominal value by more than 10%.

Although the working conditions state that the environmental temperature surrounding the system installation must not be higher than 35°C, the system has an excellent temperature tolerance.

Signs of malfunctions due to high temperatures have been detected only in one instance where the processor had been subjected to short-range radiation from high temperature tubing, and its temperature had risen to 50°C. No further precautions are needed besides the standard electric panel board.

The TCU system, as we have seen, in addition to the main functions which are rigorously defined, offers a fair exploitable potential, left to the user's discretion, in regards to the countings, measures, messages and warning signals. We believe that by placing ourselves in the user's position and encouraging the ceramic technicians to use these possibilities to the maximum, other simple operations can be found, critical points in a production line can be kept under control, and ultimately provide other means far more secure and peaceful for the operator responsible for a kiln or production line.

As a result of the experiments conducted thus far (14 systems are installed today and four others will be within the year), other future ways of applying this system and cycle control system in general, have emerged.

The microprocessing systems have a limited capacity and potential. For example, although the TCU system is provided with a large number of functions and although there exist openings for further applications, it is nonetheless operated at 75–80% of its total potential. It is therefore a product for which variations and optimizations can be explored and from which a greater assistance can be sought; however, it will be progressively more difficult to implement and expand to a larger number of control units.

It is a product then that is well on its way to complete maturity. The most recent ceramic technology and the automated systems which were adopted as a result of these new technologies, have proven that there are favorable conditions for the implementation of these systems. Their concrete realization depends nonetheless on the possibilities of combining into one project effort the specialized experience of machine users, machine constructors, and microprocessing system constructors of these machines.

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