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Fluid Power Goals and Trends for the 1990's

Abstract

Every important activity must have a goal and a stimulus. To be realistic, a goal must be based on achievable endeavors. Thus to formulate an effective plan for coping with problems in the future, fluid power must have rational goals that reflect the available knowledge base, attitude consensus of industry, and the prevailing direction of technology application. Such goals must be natural extensions of industrial trends.

This paper proposes a broad spectrum of goals for fluid power, which if successfully attained, will ensure its continued progress and growth well into the next century. These goals can be categorized in seven activity areas as follows:

- Energy Conservation
- Leakage Control
- Fluid Stability Control
- Proactive Maintenance
- Contamination Control
- Computer Aided Engineering
- Microcomputer Control

Industrial trends reveal not only the industry-wide direction of focus, but also the expressed level of activity being applied. These technological trends provide evidence that specific goals are being pursued. Trends are confirmation of the general consensus of industry and should be reviewed and studied carefully. The technological trends presented in this paper provide a strong basis for assigning research subjects both in academe and industry. The trends also provide unusual insight for industry regarding "what is new" and "what is passe."

Introduction

Technological innovation is a major factor that is spurring industrial development and economic growth. Our standard of living and our hopes for the future are well rooted in past decades of technological advances. It is recognized by economists that technical innovations account for from one-third to two-thirds of our improvement in productivity. Hence, the application of advanced technology leads to the ability to compete in the world marketplace.

The problem which we face today is that we must become aware of technical innovations which are candidates for product inclusion and to know the trends and impacting factors which can affect the adoption of a given alternative. The rate that new knowledge and technological innovations are being advanced and diffused is astounding.

Our security and sustained success in today's global marketplace depends upon our alertness and skill in recognizing and dealing with technological change, and of course relating such changes to the trends and impacts of the market and our society.

Indeed, change is inevitable but the results of change can be a disaster or an inviting and profitable opportunity. We must be able to perceive change (trends and possible impacts) and to recognize timely opportunities. Having goals and knowing trends give us warning of impending problems and provide us with the valuable time needed to conduct orderly searches and explore new knowledge and applicable innovations. Change-causing factors must be recognized and studied in order to make effective decisions and to have a basis for truly assessing, selecting, and pursuing technological innovations.

It should be obvious that there is no better way to prepare for the future than to establish meaningful goals and to know the trends of our industry. Both provide the required stimulus for achieving a highly innovative position upon which to mount a successful competitive program. Hence, the goals and trends presented here may prove to be the critical factors needed to foster growth and achieve prosperity not only in the present decade, but in the century to come.

Goals for Fluid Power

The goals being promoted for fluid power today are not spectacular, mind boggling subjects. On the contrary, they are realistic extensions of our current trends and the foreseeable needs of our industry. In other words, goals should never be surprises but affirmation and revelation of peer opinion. The goals presented here are categorized as follows:

- Energy Conservation
- Leakage Control
- Fluid Stability Control
- Proactive Maintenance
- Contamination Control
- Computer Aided Engineering
- Microcomputer Control

Energy Conservation

Great strides have been made over the past half century in transforming mechanical energy into pressure energy and back to mechanical energy. Such transformation has not been achieved without a penalty. Unfortunately, it has been accompanied by energy losses that are reflected in the mechanical and volumetric efficiencies of the system. Pressure energy is the energy needed to push a volume of fluid into or out of the high pressure region of a fluid power system. If this pressure energy could be conserved, the efficiency of the transformation process would jump to almost the level of perfection.

To conserve pressure energy, several conditions must be accomplished:

- Minimize the loss of pressurized fluid not contributing to shaft power—for example, reduce both internal slippage and external leakage.
- Reduce or eliminate fluid throttling processes within the system—that is, flow from relief valve operations (non-safety related) and/or flow/pressure control through throttling.
- Minimize the volume of fluid under compression to reduce the loss of compression energy—for example, reduce the high volumes of pressurized fluid being exhausted periodically to the reservoir in response to the duty cycle of the system.

Since the transformation of energy in a fluid power and transmission system is required to obtain useful shaft work and this transformation is an imperfect energy conversion process, inherent volumetric and mechanical inefficiencies result. Such energy losses result in the generation of thermal energy rather than mechanical energy. What is obviously needed is a converter capable of transforming thermal energy to shaft work. Theoretically, there is no reason why heat cannot be utilized to achieve useful shaft work. Perhaps, the energy conscious era ahead will foster innovations capable of satisfying this need—maybe it has already been created in the form of the Freon-motor concept or the heat pump.

Leakage Control

The subject of leakage control encompasses two aspects—preventing pressurized fluid from escaping to the environment and conversely protecting the system from environmental hostility. Fluid escapes from pressurized chambers of the system wherever interacting elements are separated by a clearance space. Such elements might be the mating threads of a conduit joint, the wear plate and fluid displacing elements of a pump, the control surfaces of a valve (bore and spool), or the piston or rod of a cylinder together with its companion seal and associated mating bore. These critical interfaces must receive more and more attention until solutions are found. The trend toward higher and higher pressures as well as temperatures makes it absolutely necessary that substantially more creative thought be given to this area.

Environmental exclusion is another critical area of concern and remains a high priority item in most organizations. The need for hermetically sealed fluid power systems has never been greater than it is today and will continue to be in the future. Wear of interacting surfaces cannot be avoided without exclusion of environmental contaminants—dust, dirt, moisture, and chemicals. Methods must be investigated and developed to achieve hermetically sealed systems—perhaps

through reservoir isolation techniques, cylinder rod boots, and new conduit fittings.

Fluid Stability Control

Hydraulic fluid is a critical system component, and its chemical and physical properties are significant indicators of possible material and performance degradation of the system. Unfortunately, these fluid properties cannot be maintained in "like new" condition indefinitely. The reason for this is that fluid in storage or service is not necessarily stable but is constantly degrading due to exposure to system stresses and the perils of the environment.

The goal for hydraulic fluids should be to achieve fluid stability—that is, the fluid should be formulated to resist chemical decomposition and physical change in storage and service. Fluids must be formulated such that they exhibit greater resistance to the four basic degradation factors—chemical, thermal, mechanical (agitation), and contamination (air, water, catalysts, etc.). As the severity of service conditions continues to rise, the rate and extent of fluid degradation increases. Service tolerant fluids must be made available to keep pace with the ever increasing severity of operating conditions.

Proactive Maintenance

Over the past quarter century, the fluid power industry has progressed from a breakdown ("fix when broken") maintenance philosophy, to a preventive interlude of simply forestalling failure, to a predictive activity of warning of failure in progress, and finally to a proactive strategy of a pre-alert to failure. Proactive is defined as an event which occurs prior to a critical change. Hence a pre-alert activity is performed prior to any system damage taking place and is designed to identify and correct aberrant root causes of failure before failure actually occurs.

A proactive maintenance strategy is the maintenance goal of the future. It alone offers a formidable deterrent to failure and provides the basis for self-compensation—that is, self-adjusting, self-lubrication, self-limiting, and self-correcting type of an operation. The goal is to identify the aberrant root causes of failure and achieve self-compensation.

Contamination Control

There can be little doubt that contamination is an enemy of almost all components and systems. In the past, efforts were concentrated on the control of particulate contaminants and slight attention was focused on such contaminants as water, air, products of oxidation, etc. In the last few years, however, that situation has slowly changed, now technology recognizes the deleterious influence of all contaminants.

Contamination control encompasses a broad scope of activities, from contaminant detection and analysis, to exclusion and filtration, and finally to component tolerance and system compatibility. One of the goals already presented must be achieved if this enemy—contamination—is to be brought under control. That goal is the development of hermetically sealed fluid power systems. If the ingress of dust, dirt, moisture, air, and chemicals can be prevented there will be no need to filter them out of the system or find ways for components to survive in their presence. Contaminants can also enter fluid power systems from the residual material left in components during manufacturing and

assembly. Component cleanliness specifications are emerging and must become commonplace in the future.

Filtration is another critical area in contamination control where the focus must be redirected. It is now possible to produce filtration components which exhibit extraordinary particle separation characteristics. However, much more attention must be placed upon the capacity of these super filters. The life cycle costs of a high efficiency filter with less than adequate capacity is far too great. Ways of gaining more capacity or dirt holding characteristics with high efficiency filters must be found and developed. In addition, the effect of system dynamics upon filter performance must be overcome. Any filter which exhibits excessive desorption in the face of unsteady flow must be avoided.

Component contaminant tolerance is the third critical aspect of contamination control which must be addressed. Wear and seizure of fluid power components have always been a reality. However, few have established an objective in their research and development efforts to discover the design requirements of highly tolerant fluid power components and apply this knowledge in component development. The design configurations which permit a fluid power component and therefore a system to resist the attack of all types of contaminations must be found and implemented in the future.

The effect of contamination upon the life and reliability of fluid power system is a major concern in every maintenance strategy. That is why an on-going fluid analysis program to determine the contamination levels present in a fluid power system is becoming wide spread. However, there is a considerable lag time in our current ability to detect the presence of excessive contaminant levels. We must firmly establish a goal to measure contamination in-line on the machine if the time lag is to be eliminated. It must be eliminated since many times great damage is done before anyone becomes aware of the real problem.

Computer-Aided Engineering

For decades, fluid power designers have been asked to accurately and quickly specify a system along with the proper components for a desired application. For a simple system, the designer may be able to accomplish this task using a trial and error approach or his experience. However, if it is a very complex system, the task becomes dramatically more difficult. To tackle today's highly demanding applications, the engineer must have more powerful tools. It is totally unacceptable from a cost standpoint to permit the design factors of a hydraulic system to be estimated and then fabricate the system to see if it works. The best tool available, and one which is becoming more useful very quickly, is the personal computer with an effective software package.

Personal computers have unique features over main frame computers, such as low cost, high mobility, easy hardware interfacing, wide availability, etc. However, like the main frame, a personal computer cannot be applied without proper software for simulation, analysis, and design. Consequently, the goals for computer aided engineering for fluid power are as follows:

- Implement fluid power design principles and hardware interfacing procedures onto the personal computer to avoid verifying design concepts by cutting metal, and allow the designer to accomplish design tasks more efficiently, accurately and economically.
- Integrate PC simulation with real time control. That is, a "soft" prototype (model) must be incorporated into a "hard" system

(physical) such that the prototype's characteristics can be tuned at the software level to optimally specify design parameters before fabricating the prototype.

- Establish a total knowledge base information system which integrates the talents of fluid power professionals together. This system will complete the design-manufacturing-sale-application-design cycle.

Microcomputer Control

One of the most magnificent contributions of microcomputers to fluid power applications is the opportunity it offers to implement sophisticated control and data analysis algorithms on the computer. It was a dream in the 1970's but now it is a reality. However, with many fluid power applications, the problems of 1) having only a limited number of measurable variables, 2) dealing with unreliable measurements, 3) operating environments hostile to delicate electronic components, 4) system compatibility and non-linearities, and 5) high power demand of conventional fluid power control elements have significantly degraded the practicability of employing microcomputers in high level real time condition control.

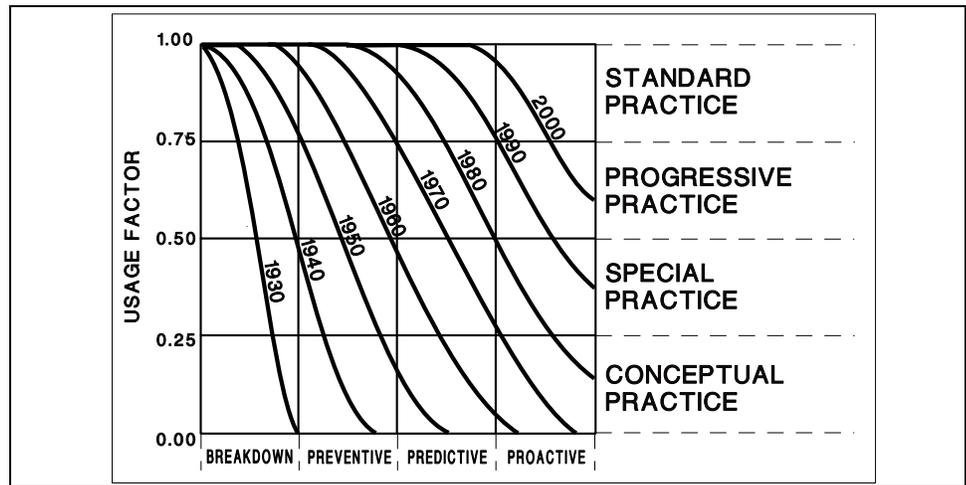
Condition control is an interactive process of condition monitoring, condition analysis, and condition response. As a closed-loop system, condition control assesses system states and then identifies, prescribes, and administers the response requirement. It has been the ultimate objective of applying microcomputers to achieve complete condition control in industry. However, it is obvious that to achieve the objective, smarter sensors are required to acquire reliable data. In addition, more intelligent analysis algorithms are needed to interpret vague and uncertain information, more robust control strategies to adapt to system non-linearities and environmental variations, less cost, and less power required for control elements. Therefore, the needs for microcomputer control are:

- Implement distributed intelligence networks for process systematization and automation.
- Develop low power, low cost terminal control elements that can be integrated into the distributed networks practically and economically.
- Develop remote sensing devices and data interpretation techniques to avoid using signal lines.
- Establish adaptive control algorithms with self-learning and self-calibration capability which can compensate environment changes and tribological degradation.
- Incorporate fuzzy logic and neural networks for processing the unavoidable vague conditions and uncertain information in real time condition control.

Trends in Fluid Power

Need is not only the mother of invention, but also the pacesetter of change as reflected by the trends in industry. Fifteen years ago, great concern was expressed by the so-called leaders of the fluid power industry regarding the threat by the electrical industry. What they feared was that fluid power was rapidly becoming "mature" and the rate of innovative progress was expected to be slow, technological advances favored electric and/or electromechanical ball-screw

Figure 2
Maintenance Strategy Trends



Contamination Control

Today, greater attention is being given to component and system service life and reliability than ever before. Foremost in the minds of equipment users is an awareness of the importance of fluid contamination control—a situation that has been a long time coming. The Beta and Epsilon ratings of filters are no longer buzz words used by the "chosen-few" but are terms used in equipment specifications to which suppliers are expected to comply. The Omega ratings for fluid power components are lagging filter ratings by a few years but there is every indication that contaminant sensitivity ratings for components will eventually be standard practice throughout world-wide industry.

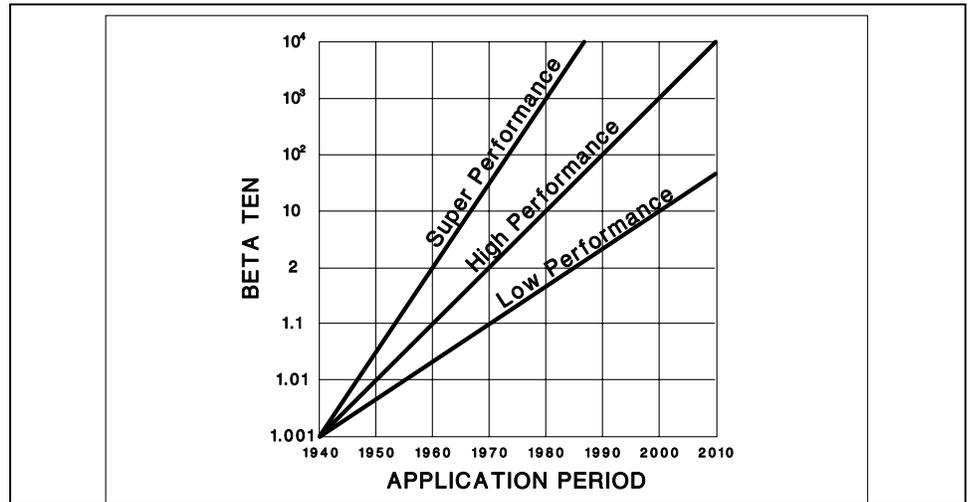
The trends in contaminant exclusion are as impressive as those in filtration. Reservoir breathers which prevent the entrance of at least some of the particulate contaminants are becoming more common place. Some of these breathers also address the age old problem of water contamination. In addition, much more attention is being given to the wiper seals on fluid power cylinders. However, all of these techniques fall somewhat short. The goal of hermetically sealed fluid power system has yet to be realistically achieved. Component cleanliness specifications are being formulated and applied to prevent the inclusion of contaminants during assembly. It would be counter-productive to use dirty components to assemble a hermetically sealed system.

The Omega rating of fluid power components has been, indeed, a giant step forward. However, in recent years, a trend of back sliding has occurred. Laboratory evaluations which only produce information useful in categorizing the contaminant sensitivity of components will not permit service life estimation. Data must be produced in such a manner as to allow the development of service life algorithms. In this way, not only can the components be rated and categorized but a truly realistic estimation of service life and protection levels can be attained.

The traditional trade-off between filter efficiency, dirt holding capacity, and pressure drop is still "alive and well" in the approach used by many fluid power designers. However, trends toward greater dirt holding capacity and lower pressure drop in high efficient filters are emerging. The use of new synthetic fibers with controlled parameters has permitted a rigorous analytical treatment of the entire subject of filtration mechanics. With proven filter models it is only a question of time before truly amazing things are accomplished in the area of filtration. In addition, the use of these new synthetic fibers brings excellent

chemical and temperature characteristics. The fibers also have more resistance to deformation which will lead to effective pore shaping as well as pleat shaping. The progress in hydraulic filtration over the years can best be illustrated as shown in Fig. 3. The filtration ratio for particles greater than 10 micrometers was approximately two for what in the 1970's was considered high performance systems. Today, even low performance systems use filters which exhibit a Beta Ten greater than two. There is every reason to believe that the trend shown in Fig. 3 will continue well into the next decade.

Figure 3
Filtration Trends in Fluid Power



Contaminant monitoring is a large part of every maintenance scenario. The analysis and measurement of particulate contamination have been brought out of the clean room and into the field by the use of effective portable contaminant monitors. Work is progressing on in-line real time monitoring to measure not only particulate contamination but water and chemical debris as well. The future holds great promise in this area.

Fluid Antiwear Protection

Of all the components in a fluid power system, the fluid has been given the least attention in the research and development activities of our industry. It is true, however, that formulators and blenders of high performance liquids have produced a trend toward better antiwear protection. A fluid power system must effectively operate over a broad range of conditions. Therefore, it is not possible to adequately protect and lubricate high performance fluid power components strictly through fluid mechanics' techniques. This is the incentive for the development and inclusion of antiwear additives in our hydraulic fluids.

Since the development of hydraulic fluid is a complex technology in itself, the burden is on the fluid power industry not to actually develop the hydraulic fluid but to properly inform those fluid development companies of our unique requirements. In the past much of our fluid specification information came directly from the automotive industry. Certainly some of the fluid needs of the automotive technology overlap many of the requirements of the fluid power industry. However, the need to transform, transmit and control energy through the use of a fluid medium places different requirements on our fluids.

The assessment of the degree of antiwear protection provided by hydraulic fluids has made good progress in the last few years. The development of the Gamma test has effectively demonstrated that not all hydraulic fluids are "created

equal.” In addition, this technology has provided a useful method for antiwear additive degradation assessment. Through the use of the Gamma rating for hydraulic fluids, it is now possible to not only select a fluid which will adequately protect system components, but also ascertain the degradation of that fluid and pin point fluid change periods.

Leakage Control

Increased attention is being paid to the internal leakage of components. For example, the neutral position leakage of a valve is becoming an important criterion in valve design and selection. Also the use of self compensating wear plates in hydraulic pumps is becoming almost commonplace—an attempt of course to counteract the effects of fluid contamination and abrasive wear.

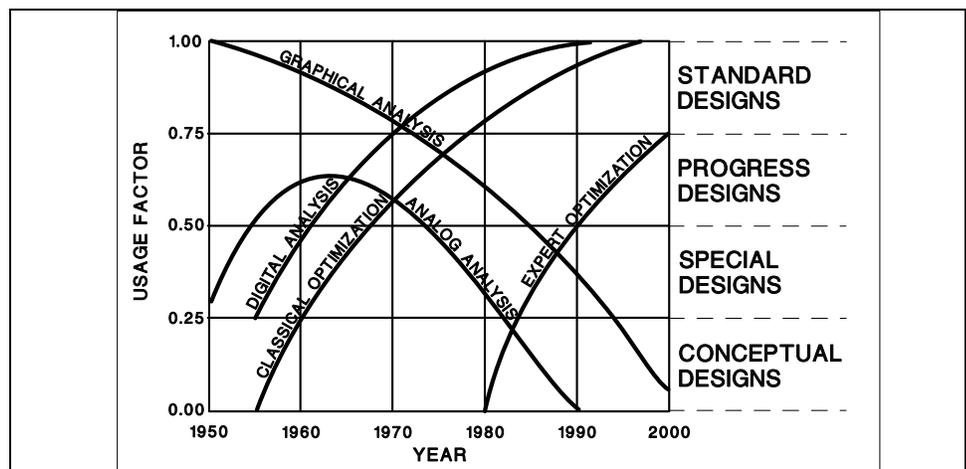
The importance of installing wear rings on heavy, horizontally mounted cylinders is receiving broad application with great success. The switch from pipe threads to straight threads is becoming more complete each year. In a similar fashion, flared fittings on vibrating equipment is giving way to O-ring type fittings that can withstand line stresses and vibration.

Computer-Aided Engineering

Growing numbers of fluid power designers are developing software and using computers to solve problems that were once attacked by simplified analysis and rule of thumb type procedures. In the early days of computer modeling and simulation, the design engineer had to not only be intimately familiar with fluid power components and systems, but he needed to be a mathematical whiz and a proficient computer programmer. Obviously, this combination is very unique. This dilemma became the driving force for the development of increasingly powerful computer aided engineering tools.

The trends in modeling and simulation as shown in Fig. 4 are quite interesting when one starts at about 1950. Analysis using analog methods started sometime in the 1940's and peaked with only marginal success in the early 1960's. Digital analysis began sometime in the 50's and grew until today it must be considered common practice. Graphical analysis which was the mainstay in the 50's and 60's is virtually a thing of the past today. Along with digital analysis came optimization using what is termed classical methods. Classical optimization is now at its peak. Expert optimization using fuzzy logic and neural networking is showing rapid growth.

Figure 4
Modeling and Simulation Trends



The current thrust in modeling and simulation is to switch from 1) the classical approach using specialized models to the unified energy approach using performance models; 2) a dedicated system approach to the new integrated system methodology that combines hydraulic, pneumatic, mechanical, and electrical components; and 3) drafting board dimensional techniques for achieving data base analytical designs and finally to accomplishing knowledge base expert design. The trend is to provide designers with powerful PC-based software to aid in their design missions. They need only to know what software does and are not required to know how it does it.

In industry, there is ever increasing interest in developing "Knowledge Base Electronic Catalogs (KBEC)" for products and applications. The trend is to establish a technical data base which possesses design specifications, application requirements, and information to aid in making system design marketing decisions. The purpose being to narrow the gap of technical understanding and requirements between designers, manufacturers, distributors, and users in order to provide a precise and effective communication channel. Several KBEC software packages are available today to meet a variety of fluid power application needs. For example, a contamination control dedicated KBEC software allows the distributors to specify a filter or component from their data bank to meet user requirements. A more sophisticated KBEC software which is available allows the distributor to design a system, analyze its performance, select components, provide circuit and element drawings, issue quotations, and adjust inventory—all on a PC. No doubt, the industry is marching toward the development of KBEC software to integrate the drawing room, machine shop, sale office, and application together.

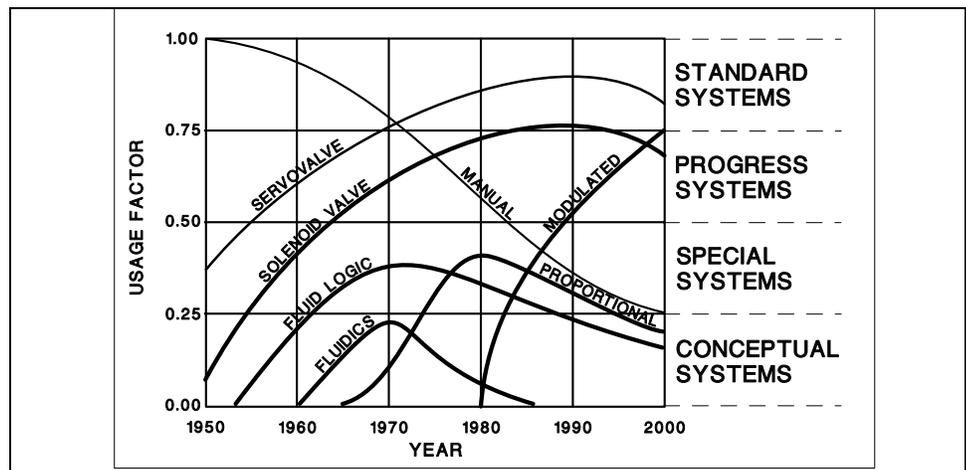
Microcomputer Control

While the microcomputer has gained increasing attention in today's engineering applications, fluid power researchers are concentrating on technologies that integrate the electronic brain with fluid power brawn. Although the dramatic progress in microelectronics will continue to make future microcomputers more powerful and less expensive, these devices are still too far away from having a "brain" without extracting critical intelligence from human experts.

The trends in the types of control elements used in fluid power systems reflects the electronic impact. The use of manual control has essentially given way to the servo control and solenoid control elements as shown in Fig. 5. However, the advent of powerful microcomputers is rapidly leading to the use of modulated control elements. Other electronic control elements, such as servo valves and solenoid type elements, will fade as the modulated valves become more and more prevalent.

The 1980's was an exciting decade for fluid power engineers in microcomputer control and system automation. They were knowingly (or unknowingly) working toward establishing a real time condition control system which detects, analyses, and responds to the operating data acquired. This tendency is the landmark of replacing traditional control with a more powerful and reliable microcomputer control.

Figure 5
Trends in Control Elements



The increasing complexity of today's fluid power system motivates designers to seriously consider a distributed control system for their applications. However, the most troublesome factors which restrain the progress of adapting distributed control systems in fluid power is that it requires a large number of sensors and control elements which might exceed physical (power, size, etc.) and economical (cost, marketing) limits. To overcome these difficulties, in the past decade, scientists have devised terminal elements to integrate distributed control networks and enhance system intelligence. A terminal element possesses the capability of sensing, analysis, and issuing control commands to achieve dedicated local control. It dramatically reduces the number of sensors required and significantly improves control reliability.

The rapid growth in the development and application of electrically modulated valves indicates the need for replacing conventional servo valves with less costly valves for many modern applications. The family of electrically modulated valves, colloquially called the "poor man's servos," includes Pulse Width Modulation (PWM), Pulse Frequency Modulation (PFM), Pulse Number Modulation (PNM), Pulse Amplitude Modulation (PAM), and Pulse Code Modulation (PCM). Although much of this development is still in its early stages, it promises to have a profound effect on the future of fluid power controls.

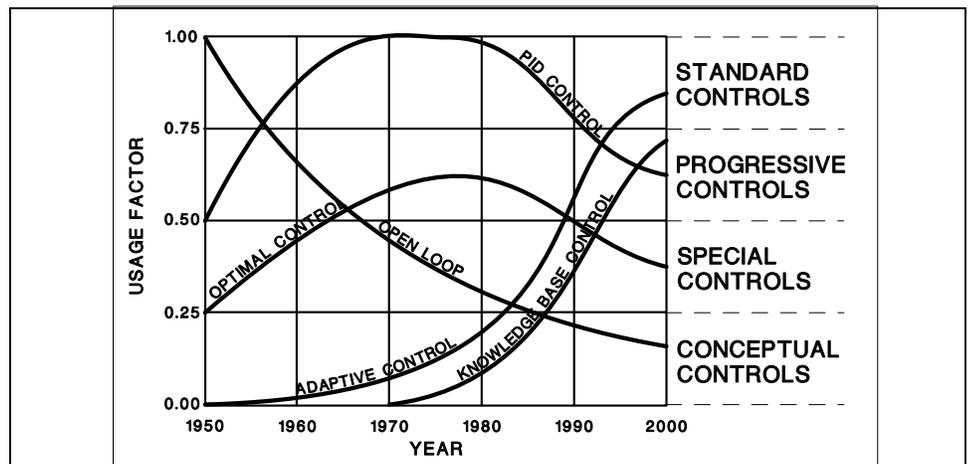
High power consumption and inherent non-linearities are the critical drawbacks of electrically modulated valves over conventional servo valves. In recent years, research has been focused on the use of software to overcome these non-linearity problems, both drawbacks are due to the component structure and system characteristics. The use of fuzzy logic and neural networks has been utilized by some researchers in resolving control non-linearities successfully.

In reducing the power consumption of control elements, engineers are working in different directions such as mechanical mechanism amplification, new materials for solenoids, more tolerant contamination and tribological lock designs, less internal and external leakage, etc. Primary efforts in this area achieved a limited level of success but are auspicious.

The use of microcomputers for data acquisition has been overwhelming in most fluid power laboratories. The major function of the microcomputer tends to be nothing but a monitor for multiple sensors and a data logger. The trend is in extending its use to do diagnosis and troubleshooting which are parts of real time condition control. The kernel of diagnosis and troubleshooting is to have an inference engine which can analyze and interpret data acquired from the system. Researchers are concentrating on the development of an inference engine which

combines the analytical models, statistical data and/or expert opinions. The direction is advancing from a deterministic decision making process to an experimental/statistical forecasting approach and now to more realistic knowledge based failure prediction technology. The increasing amount of commercial software available for aiding in maintenance management is a major trend and is needed in this area. It has been found that the use of neural network principles for sensing and interpreting non-definable parameters along with fuzzy logic for processing expert knowledge is an important new trend offering great promise. As can be seen in Fig. 6, control strategy trends reveal that the open loop control system is rapidly giving way to the many types of closed loop control. The use of PID control has begun to decline as is the optimal control strategy. The hot new control system follows the adaptive and expert knowledge base strategy. The trend to a smarter and more responsive control strategy will continue long into the future.

Figure 6
Control Strategy Trends



Pressure and Temperature

No paper on fluid power trends would be complete without addressing the ever increasing levels of pressure and temperature at which fluid power systems are now operating and what those parameters are likely to be in the future. When one looks back over the history of fluid power, it is truly amazing to see the trends of systems operating pressure and temperature. From a beginning of 200-500 psi, system operating pressure has climbed until today there are 8000-10000 psi special design systems in existence. While it is true that the majority of the fluid power systems operate between 2500-6000, technologists are hiding their collective heads in the sand if they do not believe that the high pressure systems being developed today will not become the normal systems of the future.

System operating temperatures have also shown an amazing upward spiral. Not very many years ago, a system temperature in excess of 140°F would have been considered quite hot. Today, however, the vast majority of the hydraulic systems exceed 140°F with some as high as 210° to 250°F. With the development of synthetic hydraulic fluids, the main obstacle to higher temperature has been removed and temperatures can be expected to continue to climb. The safety aspects of high pressure hydraulic systems are important; however, those of high temperature hydraulic systems are absolutely critical.

The trends in pressure levels used in fluid power systems are shown graphically in Fig. 7. As new materials, better designs, and more effective contamination control become a reality, the pressure levels will climb. The temperature

trends are shown in Fig. 8. Sealing materials and fluids are the primary limitations in temperature levels. Safety is also becoming a major consideration. System designs are moving toward operator protection from such high temperature systems.

Figure 7
Fluid Power System
Pressure Trends

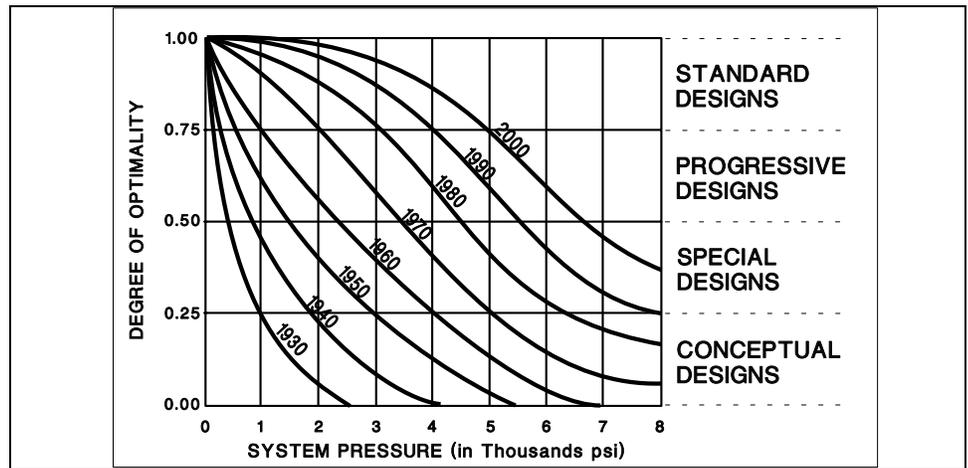
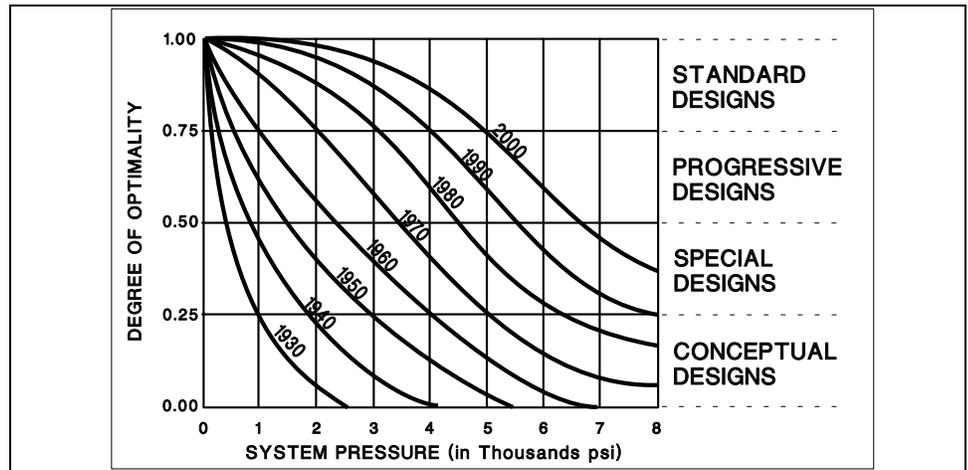


Figure 8
Fluid Power Systems
Temperature Trends



Conclusion

The past has been exciting for the fluid power industry, but the future looks even brighter. Fortunately, very few creative technologists listened to the doom sayers of yesteryear who predicted the demise of the fluid power world. It is a difficult task to sit at a desk and propose goals for an industry like ours. It takes a great deal of intestinal fortitude. However, the authors feel strongly that the success of our world depends upon the establishment of goals and recognition of trends. There may be other goals which are important and certainly development is under way in other areas. However, if we, as an industry, can achieve the goals presented here, we will insure our future.

The goals which have been established in this paper, although they are ambitious, are realistic and achievable. One could agree that the trends are more or less as delineated here. However, there can be no doubt that these goals are critical to our continued success. Energy, reliability, and life are foremost in the minds of equipment manufacturers. The incorporation of electronics in our fluid power systems and the use of analytical tools to spur design innovation are the way to the future. Our future is indeed bright and all we need to do is think rationally, work hard, and channel our creativity in the best direction.