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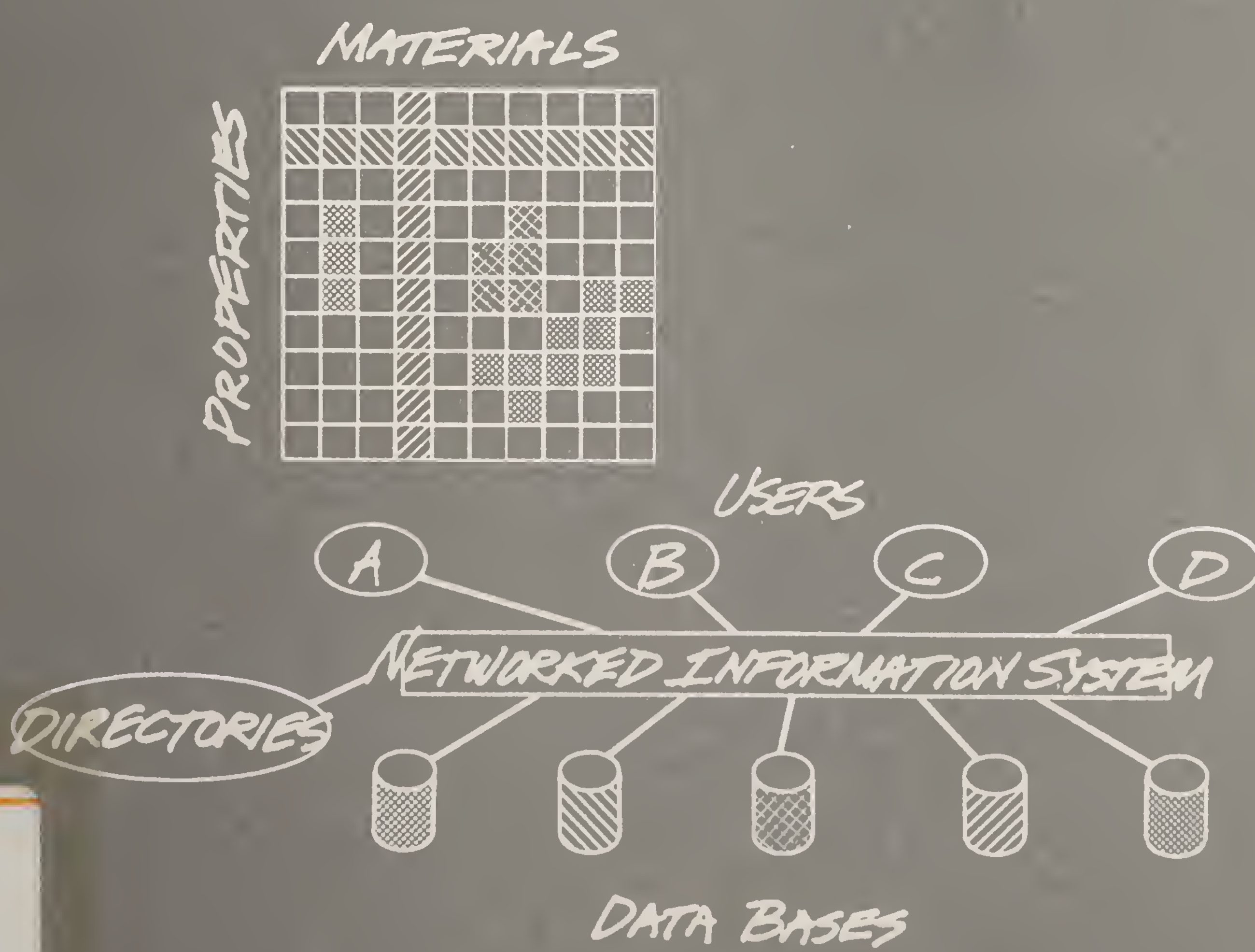
Computerization of Welding Data — Proceedings of the Conference and Workshop October 19-21, 1988

T. A. Siewert, J. E. Jones, and H. G. Ziegenfuss, Editors



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ABSTRACT

This publication comprises the proceedings of an October 1988 conference on computerization of welding data. A written summary of each speaker's presentation is included in its appropriate conference session:

- Overview of computers and databases,
- Welding applications software, and
- Welding case studies.

This publication also includes the proceedings of a workshop which listed future computerization needs in the welding industry and an informal survey of the registrants' usage of computers on the job, both of which occurred at the conference.

Key words: computerization; database; mechanical properties; procedure qualification records; welding information; welding procedures

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ABBREVIATIONS

AI	=	artificial intelligence
ASME	=	American Society of Mechanical Engineers
ASTM	=	American Society for Testing and Materials
AWI	=	American Welding Institute
AWS	=	American Welding Society
CAD	=	computer aided design
CEGB	=	Central Electricity Generating Board (of Great Britan)
CGA	=	color graphics adaptor
CVN	=	Charpy V notch
DOD	=	Department of Defense
DOE	=	Department of Energy
DOS	=	disk-operating system
EGA	=	enhanced graphics adaptor
FCAW	=	flux-cored arc welding
GMAW	=	gas metal arc welding
HAZ	=	heat affected zone
JTIC	=	Joining Technology Information Center
MIST	=	Materials Information for Science and Technology
MPD	=	Materials Property Data
MMA	=	manual metal arc
NACE	=	National Association of Corrision Engineers
NASA	=	National Aeronautics and Space Administration
NBS	=	National Bureau of Standards (now NIST)
NIST	=	National Institute of Standards and Technology
NMPDN	=	National Materials Property Data Network
NNS	=	neural network system
P groups	=	classification system within ASME B&PV code
PC	=	personal computer
PEPCO	=	Potomac Electric Power Company
PQR	=	procedure qualification record
RAM	=	random access memory
SAW	=	submerged arc welding
SMAW	=	shielded metal arc welding
TWI	=	The Welding Institute (of Great Britain)
VGA	=	video graphics array
WIC	=	Welding Institute of Canada
WIN™	=	Welding Information Network (trade mark)
WPS	=	welding procedure specification
WRC	=	Welding Research Council

CONTENTS

INTRODUCTION

The first workshop on computerization of welding data was held in 1986. It produced a list of national welding data needs to guide software developers and other computer professionals.[1] Since then, substantial improvements have occurred in software, hardware, and the acceptance of database technology. In the spring of 1988, the National Institute of Standards and Technology, the American Welding Institute, and the American Welding Society decided to plan another workshop to assess the progress. After further discussion, they decided to organize (1) a conference to present the latest developments, (2) a subsequent workshop to produce a new list of needs, and (3) a preconference tutorial to give novices a background on common computer applications, such as word processing and database management.

The conference, workshop, and tutorial were held October 19 through 21, 1988, in New Orleans, Louisiana. Sixty-one managers, welding engineers, and computer professionals attended. The list of participants is included in Appendix A. This report is a chronological record of the conference and workshop.

[1] *Computerization of Welding Information—A Workshop Report,* T.A. Siewert and J.E. Jones, eds., National Bureau of Standards (U.S.) Special Publication 742, National Bureau of Standards, Boulder, Colorado, 1988.

SURVEY OF PARTICIPANTS

To provide additional information for the conference planners, all registrants were asked to complete a survey form (Appendix B). Those whose forms had not been received by the start of the conference were asked to complete a form at the beginning of the conference.

The survey was designed by the conference committee to determine the size of the room, the number of computers needed for the preconference tutorial, and which welding industry groups would be represented at the workshop. The tabulated data are included in this report (Appendix C) because they provide a measure of the use of computers in the welding industry and perceived needs for the future.

Results of the survey were surprising. The organizers expected that only a small number of the participants would feel the need for the tutorial in basic computer capabilities. About ninety percent of the participants were interested in attending the tutorial, even though their survey replies indicated considerable knowledge of computer capabilities. The obvious conclusion was that, in spite of their experience, they wanted to take advantage of this opportunity to review their skills and possibly learn about recent advances.

Most of those surveyed have access to personal computers, from 8088 chip-based machines to 80386 chip-based machines and work stations. Although participants at the 1986 workshop were not polled, it seemed that less than half had access to a personal computer. This tremendous increase in computer availability indicates an influx of computers into the welding industry (and so the value of this conference). Since the participants had both welding and computer experience, they were well-qualified to produce a list of national welding-data needs.

The survey also asked the participants to list three industry groups that would describe their interests. The objectives were to characterize the types of industries that were represented at the conference and to select topics for the group discussions in the workshop. The choices (see Appendix B) included the top ten topics identified at the 1986 workshop and an optional write-in topic. Three of the top four choices of the 1986 workshop were listed at the top again (see Appendix C), indicating that these areas of the welding industry have data needs that can be met by databases, and the needs are sufficient to send someone to a conference. Although several new topics received some votes, the top ten topics remained virtually the same.

PRECONFERENCE TUTORIAL SESSION

The preconference Tutorial on Computer Applications was held on October 19, 1988, just before the workshop began. Attendance was excellent—most of the conference participants attended. The tutorial, which was prepared by P. Oberly and M. D'Attilio of the American Welding Institute, consisted of four sections describing the personal computer's role in welding engineering:

- Report writing with a word processor software program
- Designing with a computer-aided design software program
- Cost calculation with a spreadsheet software program
- Welding procedure generation with a database software program

Computers (IBM compatible) were available for participants to use during the presentations and to gain first-hand experience with popular personal computer software. WordStar, AutoCAD, Lotus 1–2–3, and Dbase III+ were used to illustrate the four topics presented. The sessions apparently gave the participants new ideas and techniques for using the personal computer to help them in welding engineering.

CONFERENCE PAPERS – Overview of Computers and Databases

Databases for Technology

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Introduction

Databases are growing in popularity because they have many advantages over other sources of data. They are extremely comprehensive. A read-only compact disk (CD-ROM) contains the equivalent of many pages of text. On-line systems have sizes in the gigabyte (10^9-byte) range.

Databases can be easier to use, faster, and more convenient than other sources of information. With powerful search procedures, they enable one to search many data fields (effectively functioning as the ultimate index). This rapid access to many sources of information substantially increases efficiency.

Databases facilitate manipulation of the data by rearranging the data into subsets or supersets and changing dimensions and units. Programs can be linked so that specific tasks can be performed within the database or a subset of data can be sent to other software for further processing.

The flexibility of a database enables the data to be compared or contrasted in virtually unlimited ways. A very effective way to evaluate comparisons is on the screen, before deciding whether to save the information or to produce a printed copy. Data can be displayed in a wide variety of graphic formats or tables. Desktop publishing programs combine the text, tabular data, and graphic data into a report having the same quality as one that has been typeset.

General Progress in Database Development

A major trend in databases is the growth of those that reside in small personal computers. A 1985 NBS (now NIST) survey revealed only one materials database of this type; a 1988 survey revealed dozens, with many more to be released soon.

Personal databases have some advantages over databases on large, centrally based computer systems: Personal-computer-based systems are available on demand. The user is not subject to the slowing of response that occurs on large systems when another user submits a large job. A PC system is also available during the evening and weekends, when a central system is often committed to batch accounting jobs or scheduled maintenance.

The software for the PC has been developed for a large market of users, justifying a well-designed users' manual, often with a toll-free number to a software engineer. Good support gives users confidence and promotes the use of personal systems over central systems. The personal nature of small computer systems encourages the user to customize it for his individual needs.

Progress has also occurred in the area of interfaces. Color screens enable more striking displays of the data, calling the viewer's attention to selected fields or trends. The designer can include more data on the screen without confusing the viewer. Taking full advantage of the newer color monitors are enhanced-resolution graphics packages. They enable data to be represented on the screen as pictures or detailed schematics, two forms that are particularly appropriate for design work or complex configurations. Improvements in interfaces also include better screen designs, clearer menus, and self-teaching capabilities.

The variety of data now available in databases is increasing. New databases are being developed for material properties that have not been available before in any format. Existing databases are being updated to include new materials and more complex information on existing materials. For example, the NIST Crystallographic Database expanded from 40,000 compounds in 1985 to 137,000 in 1988. This depth and breadth of data are needed if these databases will be evaluated by statistical techniques for process control and design applications.

Progress is also occurring in the development and application of expert systems. This technology promises substantial increases in searching efficiently; it guides the user through a series of customized decision trees rather than through general menus. Expert systems can also help with interpretation of data by developing recommendations from incomplete data, estimating the validity of data, or evaluating conflicting data.

Technical Database Developers

Groups that are developing databases are generally those who have disseminated data in handbook form, those who see this as another way to support a project (for example, a manufactured product), and entrepreneurs responding to this new market. For example, technical societies have traditionally produced handbook data, but they project a loss in revenue if their data are not also available in a database format. Publishing houses perceive it in much the same way, except that the dissemination of information for profit is their main business, rather than an ancillary activity, as it is for technical societies. Databases are another way to distribute the data that government and independent research groups generate. Some government agencies have been assigned the task of giving guidance to database development by working with private organizations to produce standards. Semiprivate agencies and entrepreneurs see the growth in the demand for data as an economic opportunity. The sales and marketing departments in manufacturing firms find that databases can support their products in the field and expand their market.

Trends in Materials Databases

Current trends include the networking of individual databases into large sources of data, development of new and expanded databases, and the development of data standards. Examples of the networks and new databases are

- MPD Network by National Material Property Data Network
- European Materials Information Services Network by the Commission of the European Communities
- MetSel2 and EnPlot database and software by ASM International
- Cor Sur2 database by NACE and NIST
- Software System for Plastic Material Data by International Plastic Selector/IDES
- Low-Cycle Fatigue Material Test Programs by MTS
- Weldselector by the American Welding Institute
- Computerized Alloy Steel Information System by Minitech
- Expert Systems for Hazardous Chemicals by MTI, NDI, and the NACE–NIST Corrosion Data Center

In the area of standards, ASTM Committee E49 is developing standards for material descriptions, reports of test results, data exchange, and data-quality indicators. A task group is devoted to the special needs of the welding industry.

Technical Database Development Needs

A major problem that has developed is compatibility among sources. Complex problems require data from many sources, data which must be combined and processed. Even if the data from each source could be processed separately, the users would not want to learn a large number of commands for each system. It is not certain that standards to produce data-system compatibility will succeed. A related problem is duplication of data in different databases. Will these data be recognized as duplicates or will they receive undue weight during statistical analysis?

Another problem is the substantial investment necessary to construct the database and enter the data, and during the construction phase there is very little income. Before the investment is committed to a database, a clear understanding of the estimated life and income from the data must be developed, so that a current net value can be calculated and compared with the construction cost.

Gaps in the data must be eliminated. Since databases are relatively recent, many are still incomplete. Data entry must not only keep up with the receipt of new data, but must also be able to fill existing gaps in the data. Some databases may have a bias, such as those including only the products of a single producer, and the user must be aware of the bias when interpreting the data.

Quality of the data must be evaluated. Unless some review is made of incoming data, it is possible to put inaccurate data into the system. Even data within the system must be evaluated periodically to ensure that they are not outmoded or obsolete. Simply stating that the data must be of a certain quality may be insufficient, because there are no agreed-upon levels that are used for evaluation.

Lack of awareness will be a continuing problem as long as this field develops rapidly. Few know all the databases that have been developed. Perhaps an on-line catalog is a solution. Conferences, such as this one, help. It is also difficult to keep up-to-date with the many items of hardware. As new and improved database software is developed, better interfaces will become possible. Simpler and more logical interfaces will generate a larger market.

The Future of Technical Databases

These problems and needs are topics for research by database developers. As they develop solutions to these problems, we anticipate substantial growth in the uses and benefits of databases. Compatibility will increase through networking and the development of standards. The uniformity of the data will increase as groups with vested interests or mandated responsibility continue to strive toward this goal. The databases will become more complete as data-entry efforts continue. The quality of the data and the interfaces will increase as the developers respond to user comments and look for additional sales. The awareness of the databases will increase as the developers learn better ways to market the system. Interpretation of the data will improve through the use of expert systems.

Summary

The future for the database looks very bright. The problems that I have mentioned are the normal result of growth in a new technology; they will guide the developers. The search for solutions to these problems should result in a new generation of improved databases.

Review of the 1986 Workshop—Computerization of Welding Information

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Introduction

The United States is recognized as a leader in the development and application of computer systems, from mainframes to microcomputers. Recently, smaller, yet more powerful, computers have become affordable even to small companies. It is quite logical to apply this technology to the welding industry, especially since its recent slow growth[1] has stimulated a search for ways to increase productivity.

A workshop on Computerization of Welding Data, cosponsored by the National Bureau of Standards (now National Institute of Standards and Technology) and the American Welding Institute, was held in 1986 to determine what data the industry needs, if the data exist, and whether the development of national welding databases could increase productivity.

The workshop was organized into two sessions: one to define and rank the data needs of the welding industry and the other to determine desirable characteristics of possible welding databases. Within each of these sessions, invited speakers shared their experiences; then small groups discussed the topic. At the close of each session, all participants discussed the recommendations of the small groups and reached consensus. This report summarizes the detailed workshop report.[2]

Workshop Summary

For convenience, the workshop is summarized under two general concerns, ranking of welding data needs and definition of the needs.

Ranking of Welding Data Needs

The keynote address by F.J. Smith emphasized recent advances and trends in computers and data management systems.

- Most databases have been developed for business or financial applications. Only recently have they been developed for engineering and scientific applications.
- Databases should emulate books to facilitate our use. Retrieval must be sure, convenient, fast, and economical.
- The best systems are on-line; they are limited by media storage capacity. Increases in processor speed and increased memory will enable microcomputers to replace on-line computers in large-scale database applications by the early 1990s.

Four speakers from different disciplines within the welding industry gave their perspectives of database opportunities. H.B. Cary described the rapid trend toward automation in welding and explained how this created demands for information and information processing. G.R. Olejniczak described how the National Training Fund developed a database of personnel qualification records (PQRs) for more efficient matching of qualified welders with jobs. F.C. Breismeister described the extensive data requirements of a large prime contractor or design firm and emphasized that engineering judgment must be used to assess the accuracy of data. J.G. Kaufman described the value of a gateway system to link a variety of different databases and provide supporting information, such as nomenclature or graphics.

The participants developed and ranked a list of topics that described the various interests of the welding industry. The top four topics (thick-section welding, electrodes and welding machines, ferrous-metal welding, and pressure-vessel welding) were chosen as subjects for small group discussions. Participants were asked to identify the welding data needs within their topic area by using some of the ideas suggested by the speakers. When the small groups returned, the lists of data needs reported by each of these groups were added to a master list. The entire workshop then ranked these data needs in descending order of importance for the welding industry. The top four needs were

1. General welding procedures
2. Properties of materials
3. Procedure qualification records (PQRs)
4. Welding variables

Definition of the Needs

J.E. Jones described the differences between traditional data (numerical information, character information, and text) and nontraditional data (graphics, images, recorded speech, annotated speech, motion images, and knowledge information) that can be stored in advanced computer systems. J. Rumble outlined the importance of careful planning, design, selection of hardware and software, and implementation to achieve a successful database. He stressed the importance of database design based on user needs, common sense, modern software, and a realistic schedule.

The participants were divided into four groups again, one for each of the top four data needs. Using the guidance given by the previous speakers, they were to characterize the data needs by developing a list of potential users, content, sources of information, and other key concerns.

Group 1 —General Welding Procedures

Potential Users

The group identified the potential users of the welding-procedures database:

Primary Users	Other Users
Welding engineers	Engineers in manufacturing
Welding foremen or supervisors	Draftsmen
Welders and welding technicians	Design engineers
Quality-assurance engineers	Welding distributors
Quality-control engineers	Customers and buyers
	Manufacturers of filler metal and equipment (such as power sources)

Content

In addressing the amount of data that is required for a reliable data source, the group discussed

- the number of welding procedure specifications (WPSs) that are needed to cover a specific area
- the quantity and degree of coverage that would represent a database sufficient to provide 90% of the required data in the area of sheet-metal work, ASME code welding, pipe welding, and structural welding.

The consensus of the group was

Area	Number of WPSs Required
sheet-metal work	15
ASME-code welding	50
pipe welding	150
structural welding	about 100 to 150

Sources of Information

The primary source of welding procedures information is probably government laboratories, followed by military contractors. Other sources are public and governmental utilities, the Electric Power Research Institute and government contractors, such as contractors for the Bureau of Reclamation and the Army Corps of Engineers. Technical societies and associations could also contribute to the system. Through their research, universities, electrode manufacturers, and technical welding institutes throughout the world also develop welding information. Finally, the welding industry would be another valid source of information, provided that a nontraceability function could be incorporated into the database (see next section). An especially important consideration is the validity of the data from these sources.

Liability Considerations

The subject of data sources included a discussion of strategies for convincing companies to release information for the system. The problem is to obtain WPSs and PQRs from the industry in such a way that the liability of using them does not extend to those who supplied them. Suggested solutions to this problem included disclaimers, limitation-of-liability laws (which could be in the form of laws or guidelines from Congress), anonymity of sources, Department of Commerce guidelines, tax breaks, technical-society administration, studies to defend the competition, and promotion of the system by the government.

Group 2—Material Properties

Potential Users

Potential users consist of

- welding engineers
- design, product, and other engineers
- other technical people

Content

The users of a welding-oriented properties database would be particularly interested in two types of data:

- data that are specific to welding and generally not available from other sources
- data aimed at other applications but useful in welding applications (data needed mainly for completeness of the database)

The following five categories of welding data have significant areas of missing information:

- weldment versus all-weld-metal properties
- fracture and impact toughness of HAZ
- test detail (precise location of HAZ in CVN specimens)
- material history (temper embrittlement)
- welding history and filler-metal traceability

The specific size of the database that is needed to provide an adequate data source was not addressed. Instead, the group felt that the size of the database should be sufficient to provide state-of-the-art data coverage for materials as well as materials-testing data.

Sources of Information

The group listed the following sources of data:

- welding institutes (AWI, EWI, TWI, WIC, . . .)
- Materials Property Data Network
- manufacturers

- literature
- failure-analysis groups
- producers of materials
- universities
- research laboratories
- utilities
- users
- government
- code bodies
- consultants

Group 3—Procedure Qualification Records

Potential Users

The group felt that large fabricators have databases of procedures that are sufficient to cover most of their current needs. However, as the use of materials changes, and as greater code acceptance of the standard PQRs in the database increases, even the large fabricators will find a PQR database useful. Initial users are expected to be

- contractors (small and large)
- fabricators (small)
- welding engineers
- industries with existing databases (to fill gaps in their data)
- consultants
- inspection laboratories and agencies
- universities (limited)

Content

The database content should include the information on the Welding Research Council's (WRC) Welding Procedures Committee forms. Specifically, testing data should be included with the PQRs. An acceptance consensus must be established for PQRs on three issues: standardization of PQR information, codified acceptance of these standard PQRs, and standard forms for PQRs. State and federal regulations (including military standards) should also be incorporated into the PQR database standard.

The group was concerned with "gaps" or "holes" in the data. The database administration should interact with industry and government to obtain data that could be used to fill the gaps. The database should be designed in a modular format so the gaps can be filled easily. Gaps in existing data that must be filled are

- effect of joint misalignment and overlaps
- PQRs for materials thinner than 5 mm (0.2 in)
- PQRs for exotic materials

Although generation of the database will be a massive task that will be more difficult as its size increases, a large database is needed to provide a size that forms a “critical nucleus” for the user. The PQRs entered should cover a very broad scope and include as many codes as possible. If possible, the initial database should include 10,000 to 20,000 PQRs.

Sources of Information

Principal data contributors were identified:

- Welding Procedures Committee of the WRC (including code acceptance)
- industry
- national laboratories (DOD, NASA, DOE, and their contractors)
- bureaus and associations (e.g., National Construction Association, National Certified Pipe Welding Bureau)
- state agencies

Group 4—Welding Variables

Potential Users

The potential users of a welding variables database are diverse:

- welding engineers
- designers
- quality-control and quality-assurance engineers
- researchers
- process engineers
- managers
- design engineers
- regulating bodies

Content

The group decided that the appropriate scope was “all the data needed for a good weld.” Although some disagreement existed with respect to the amount of data coverage represented by that expression, it was felt that providing too much data was better than supplying too little. It was estimated that the minimum size for an effective database was 5,000 data records.

This discussion group approached the issue of gaps in the data in terms of their causes rather than their types. They determined the causes to be

- validation
- lack of access to proprietary data
- incompleteness of records

Sources of Information

Data sources identified for welding variables were also diverse

- cooperative-research societies (especially for PQR data)
- published literature (domestic and foreign)
- manufacturers' literature
- government (domestic and foreign)
- internal documentation from users and suppliers
- patents
- university research

Case Histories

To facilitate the participants' review of these lists of users, content, and sources, four speakers reported their experiences with database development. J.E. Sims related the development and evolution of a 10,000-record WPS database. G.R. Olejniczak described a national database on sheet-metal welders personnel information and qualification histories.

J.E. Jones talked about a welding information network that includes weld- and base-metal composition and properties, welder qualification histories, weld-procedure information, design information (weld symbols and design graphics), and corrosion and wear information. A. Kuhne described an expert system designed to enable welders to diagnose and correct weld defects.

Final Discussion

On the basis of these case histories, the participants refined the characteristics of welding data needs to include safety information and wind-velocity effects. The participants also listed the ways in which the data should be disseminated: tapes or diskettes, computer phone lines, phone lines with trained operators at computer terminals, and the mail.

Summary

The previous workshop on Computerization of Welding Information, sponsored by the National Institute of Standards and Technology (at the time of the workshop, the National Bureau of Standards) and the American Welding Institute, was held August 5–6, 1986. Its goal was to determine whether national welding productivity could be improved through the development of welding databases.

The topics of the workshop were introduced by specialists in those areas. The 42 welding engineers, welding managers, and computer scientists who attended discussed these topics in small groups. These groups identified the most useful topics for welding databases, in descending order of importance, to be

1. General welding procedures
2. Properties of the weld, heat-affected zone, and base metals
3. Procedure qualification records
4. Welding variables

For each of these topics, the participants identified potential users, content, and sources of information. They concluded:

1. A significant portion of the data needs can be met by existing information, but this information should be carefully screened and reviewed before inclusion in databases.
2. Databases should be accessible to the greatest number of potential users.
3. Databases should use the latest computer technology and be upgradable to new technology as it becomes available.

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On-line Access to Worldwide Sources of Materials Performance Data

J. G. Kaufman

The National Materials Property Data Network, Columbus, Ohio

Introduction

A broad, cooperative approach to establish easy access to high-quality materials-property data was the recommendation of the 1982 Fairfield Glad Conference,[1] sponsored by CODATA, the National Institute of Standards and Technology (NIST; formerly the National Bureau of Standards), and the Materials Properties Council (MPC; formerly the Metals Properties Council). Independently, a study of the National Materials Advisory Board arrived at the same conclusion.[2] Subsequently, a number of groups initiated action toward achieving this goal,[3–5] and in 1984, the National Materials Property Data (MPD) Network was formed.[6]

The MPD Network works with technical societies, government laboratories, universities, and more than fifty private industries in the quest for better access to quality data from worldwide sources. This is being accomplished with an on-line network of well-documented databases, each focused on a specific area and managed by experts in that area, and a simple interface that is accessible to the occasional user. The MPD Network does not duplicate other services; it provides users with information on all data sources. The work of the MPD Network includes publicizing and distributing data to material experts, to aid them in design and materials selection.

In this paper are given an overview of the plans and implementation of the MPD Network's pilot and production systems. The plans for databases for welded, adhesive-bonded, riveted, and bolted joints are described.

Implementation of the MPD Network

The implementation program for the MPD Network includes two major elements: (1) the research prototype network that is based on SPIRES and the technology developed by the NBS–DOE–MPDN project, which is known as Materials Information for Science and Technology (MIST) and (2) the production MPD Network based upon MESSENGER on STN International.

The Pilot MPD Network

The development of a prototype network of materials databases began early in 1986, when the MPD Network and Stanford University joined the MIST project initiated by NIST and DOE. The Pilot MPD Network project, built upon the MIST architecture developed primarily by J.L. McCarthy of Lawrence Berkeley Laboratory (LBL),[7] added a new user-interface concept and new databases.

The pilot system utilizes the SPIRES database management system augmented first by McCarthy (version MPDN1) and later by the Stanford University Commercial Information Resources Group under S.B. Parker (version MPDN2). Written in Fortran 4, it runs on an IBM 3091 at Stanford; it can be accessed from anywhere in the world via the GTE Telenet, a telecommunication service connected to local telephone systems.

The MPDN1 version of the MPD Network contained three databases: (1) significant portions of MIL-HDBK-5, an aerospace industry design handbook, (2) a few sections of the Aerospace Structural Metals Handbook (ASMH), evaluated data summaries from the literature, and (3) STEELTUF, a database of approximately 20,000 test results for more than 50 steels. These databases were chosen because they represented different types of data, from single-value design properties to large groups of replicated "raw" data, thus providing a challenge in storage and retrieval.

The MPDN2 version added a fourth database, MARTUF, which was developed jointly by the U.S. Coast Guard, the Ship Structures Committee, and the MPD Network. This database is a compilation of test data on the toughness of steels for marine applications; it includes one of the most completely documented data sources available, especially for weld properties.

The Pilot MPD Network is available on-line to its financial sponsors (about thirty-eight accounts are active). Principally, it is a research tool for developing, evaluating, and refining search strategies and the user-interface system. It is also valuable for gaining experience with an interactive metadata system. Users of the pilot system find the interface easy to use and appreciate the many search options and the metadata system. The pilot system will remain on-line at least until the production version is available.

The Production MPD Network on STN International

STN International is the premier on-line scientific and technical information database network. It is operated by the American Chemical Society's Chemical Abstracts Service (CAS) in Columbus, Ohio; FIZ–Karlsruhe, a scientific and educational organization in Karlsruhe, Federal Republic of Germany; and the Japan Information Center of Science and Technology (JICST) in Tokyo, Japan. Through an agreement with the American Chemical Society, the MPD Network services will be offered on STN International, with 1990 the targeted start date.

Production enhancements to the underlying MESSENGER software and the design and loading of a number of files are under way and will continue at an aggressive pace. Although new capabilities are being added, all the features of the pilot-system interface will be retained. Numerical information that will be available includes the mechanical and physical properties and other performance data for all structural materials, related substances, and associated connection and joint materials. The latter encompasses the documentation needed for proper characterization of adhesive-bonded, bolted, riveted, and primarily, welded joints.

Key Features of an Integrated On-line System

Among the many issues to be addressed in implementing an international network of databases are (a) an easy-to-use interface, (b) a variety of search options, (c) presentation formats that provide sufficient documentation, (d) distributed sources, (e) associated analytical and graphics capabilities, and (f) downloading to and integration with PC systems.

User Interface

Users of the MPD Network will include not only professional searchers trained in the use of on-line command-driven systems, but also a new, diverse group of end-users. Searches for numeric or factual data are often so specific that relying upon intermediate searchers, however knowledgeable, may require many iterations and still not be satisfactory. Enabling the search to be performed by the user of the information improves its efficiency.

These end-users will include engineers and scientists from small and large companies and even consultants, who will use the MPD Network occasionally. They do not have time to read ponderous manuals, learn complex command languages, deal with cryptic response messages, and relearn the system operation every time they use it. Thus, a logical, easy-to-use interface is essential for these users.

Responding to these needs, the MPD Network will provide

a. very logical, menu-driven search paths

b. a variety of search paths for the different queries required by different users and different applications

c. a "metadata" system in the form of an interactive thesaurus, which translates user queries to nomenclature and terminology acceptable to the system and quickly clarifies the meaning of names, terms, and abbreviations

d. a directory of data sources, including those outside the MPD Network

Search Options

Depending on the nature of a query, the program will request different kinds of information:

a. a database with specific data, e.g., design values
b. a specific material for which different types of data are sought
c. comparison of one or more properties of different materials, perhaps within a specified range of values

An "expert" mode of searching will be an option for experienced users who do not need the depth of guidance provided by menu-driven screens. This mode will circumvent the many menus and enable the researcher to go directly to the information needed.

Those acquainted with the STN International command language will have the option of searching in the familiar STN mode.

Presentation Formats

The type of user and the type of queries must also be considered in establishing options for presentation formats. Adequate documentation is needed to define properly the source and applicability of data presented on the screen. This may go well beyond the user's request. However, basic facts, such as the type of data (design value or individual test result) and the applicable orientation (longitudinal or short transverse), should never be in doubt.

For the MPD Network, key information will be automatically displayed for each query. Even the brief displays to assist users in narrowing their query will contain certain basic facts, such as the type of data and key variables.

Distributed Sources

A key element of a true network of interactive databases is the ability to provide access to databases in various locations without interfering with the efficiency and ease of the search. Ideally, the network would have nodes in many locations and be able to work with many database management systems and languages. Realistically, those requirements impose a level of complexity for which we are not yet prepared.

The MPD Network designers plan to take full advantage of the three nodes or service centers on STN International and work toward linking European and Japanese databases on materials with those in the United States. Then materials databases loaded by JICST in Tokyo and FIZ-K in Karlsruhe would be available to users of the MPD Network. Such databases will be loaded in STN files accessible via MESSENGER software. Databases not loaded at one of the STN service centers would not be accessible through the MPD Network, although information on their availability would be provided.

Capabilities for Analysis and Graphics

Capabilities for analysis and graphics is a far-reaching subject, too broad for the scope of this paper, but a basic approach can be described. Consistent with the capabilities being developed within STN International, increasing levels of on-line analytical treatment of data will be provided. However, analysis and graphing of data are usually more efficient and economical when done on the users' computer systems rather than on-line.

In certain instances, software products such as STN EXPRESS will be adapted to provide these functions, and downloading capabilities will be provided to enhance the users' ability to interface with their own software.

Performance Data for Welded Joints

The scope of the MPD Network databases includes not only the properties of metals, polymers, ceramics, and composites, but also those of all kinds of joints and connections associated with these materials, including welded joints. We are making every effort to include existing databases, such as that for welds in aluminum alloys from Iowa State University[8] and the Fatigue Database from The Welding Institute.[9] At minimum, we will provide reliable information on how to access them.

We are also working with groups such as the Materials Properties Council (Martin Prager, Executive Director) and the Ship Structures Committee to build new databases that fill voids in data needs. Such a database, MARTUF, is discussed in more detail below.

The MARTUF Database

MARTUF is a database of the toughness of steels for marine-industry applications.[10] It contains about 10,000 individual test results for about 15 steels specifically identified by the U.S. Coast Guard and the Ship Structures Committee as candidates for ship and marine structure applications. Data from many types of toughness tests are included, such as Charpy notched-bar impact, plane-strain fracture toughness, nil-ductility, drop-weight tear, and dynamic tear. MARTUF is being added to the Pilot MPD Network and will be included in the initial production version.

Data fields that are descriptive of the weld process and conditions are summarized in Table 1. The level of detail was prescribed by Dr. Prager as a result of his studies of the data to be included in the database and an assessment of the parameters that are important for determining levels of performance or for making comparisons with other data sets.

The basic type of weld process, the preweld treatment of base materials, and the postweld treatment of joints are, of course, of primary importance. Equally important is careful identification of the location of the test portion of the specimen with regard to the weld metal and adjacent heat-affected zone. The composition of the weld metal will also be included when known.

Those who have searched for data on welded structures know that seldom is all the information given in Table 1 available. In far too many cases, some of this information was never recorded. Nevertheless, the format was designed to store these details when they are available, in the event it is needed by someone.

This format will not unduly submerge researchers in too many details because retrieval can be restricted in two ways:

1. The original presentation of the data is structured to show only the general descriptors of material needed by most users (Table 2); additional information can be requested. For example, "?WELD" leads to a tabulation such as that in Table 3. This is the procedure used in the MARTUF database on the Pilot MPD Network.
2. The format of the data can be set by identifying the desired parameters and their order of presentation. This approach provides the greatest flexibility; it will be used in the production version of the MPD Network.

Table 1. Weld Descriptor Information in MARTUF Database on MPD Network

W-1	WCODE	Weld code	Alphanumeric identifier
W-2	WELD	Weld type	SAW–submerged arc weld, SMA–shielded metal arc, GTA–gas tungsten arc, . . .
W-3	BTHIK	Base metal thickness	(mm or in)
W-4	PHTMP	Preheat temperature	(°C or °F)
W-6	JPREP	Joint preparation	V–vee groove; U–U groove, SB–square butt, . . .
W-7	GAP	Base metal gap	(mm or in)
W-8	INTPT	Interpass temperature	(°C or °F)
W-9	PASES	Number of passes	numbers 1 to 1000
W-10	FILLR	Filler metal specification	alphanumeric
W-11	FILNM	Filler metal trade name	alphanumeric
W-12	FILRC	Filler metal carbon content	(%)
W-13	FILSZ	Filler metal size	(mm or in)
W-14	SHELD	Shielding gas	Ar–argon, He–helium, M–mixed
W-15	WVOLT	Welding voltage	(volts)
W-16	WAMP	Welding current	(amperes)
W-17	POLAR	Welding polarity	text
W-18	WSPED	Welding travel speed	(mm/s or in/min)
W-19	INPUT	Heat input per pass	(kJ/mm or BTU/lb)
W-20	NSIDE	Number of sides welded	1 or 2
W-21	WLOCT	Test location re: weld	all weld metal; along fusion line; distance (mm or in) into heat-affected zone
W-22	SLOCT	Test location re: surface	final surface; back surface at root; midthickness, full thickness, . . .
W-23	PWHTP	Postweld heat-treatment temperature	(°C or °F)
W-24	PWHTM	Postweld heat-treatment time	(hours)
W-25	FLUXT	Flux type	text
W-26	FLUX	Flux trade name	text
W-27	WCOMP	Reference to weld composition	yes or no

Table 2. Detailed Data Display for MARTUF Database

Record 15 of 15	Rows 1–7 of 32	Columns 1–3 of 3	DETAILED DISPL
MATERIAL (UNS):	A588(K12043)		
DATABASE:	MARTUF		
TYPE:	Welded Joint	FORM:	Plate
THICK (mm):	2.0	PRODUCER:	OrStMills
SOURCE:	OGC	REFERENCE:	OGC-1
TEST:	CVN	ORIENTATION:	T-L
SPECIMEN TYPE	FULL	DIDFR:	Yes

Line Num	Posit text	Test T deg C	CVN J
1	1/2T	–100.0	9.0
2	1/2T	–100.0	6.0
3	1/2T	–60.0	6.6
4	1/2T	–60.0	6.7
5	1/2T	–30.0	22.0
6	1/2T	–30.0	21.0
7	1/2T	0	29.0
8	1/2T	0	34.0
9	1/2T	32.0	49.0
10	1/2T	50.0	50.0
11	1/2T	50.0	77.0
12	1/2T	68.0	77.0
13	1/2T	100.0	82.0
14	1/2T	150.0	74.0
15	1/2T	150.0	74.0
16	1/2T	150.0	88.0
17	1/4T	–100.0	4.5
18	1/4T	–60.0	8.2
19	1/4T	–60.0	9.2
20	1/4T	–30.0	35.0
21	1/4T	–30.0	8.0
22	1/4T	0	24.5

Table 3. Weld Description Display MARTUF Database on MPD Network

DATABASE:	MARTUF
MATL:	A302B
FORM:	Welded plate

CODE:	001.PWHT	FILNM:	ABC	WLOCT:	all weld metal
WELD:	SMA	FILRC:	0.1%	SLOCT:	midthickness
BTHIK:	0.75 in	FILSZ:	3/8 in	PWHTP:	1300°F
FPHTMP:	900°F	SHELD:	argon	PWHTM:	2 h
WLDPS:	overhead	WVOLT:	220 V	FLUXT:	dexxxxx
JPREP:	V	WAMP:	20 A	FLUX:	XYZ
GAP:	0.25 in	POLAR:	full	WCOMP:	yes*
INPT:	500°F	WSPED:	3.0 in/min		
PASES:	4	INPUT:	5000 BTU/min		
FILLER:	A303B	NSIDE:	2		

*to view weld composition, enter ?WCOMP

Data for Other Types of Joints

The Materials Properties Council has previously developed, in cooperation with Electric Power Research Institute, a database on the properties of bolted joints in steels for pressure-vessel applications. This database will be added to the production MPD Network. Databases covering riveted joints in aluminum and steel structures and adhesive-bonded joints in a variety of materials are being sought.

Data for Welded Joints

To provide broader guidance to builders of material-property databases, ASTM Committee E-49 (Computerization of Material Property Data) is developing guidelines for the elements of information that will be recorded and stored.[11] One of the activities under way is the development of guidelines for storing data for welded joints; J.E. Jones (American Welding Institute) and T.A. Siewert (National Institute of Standards and Technology) lead this effort. In developing their recommendations, the group will consider input from many sources; readers are encouraged to contact Dr. Jones with their ideas for and comments on this important program.

Summary

A pilot Materials Property Data (MPD) Network system has been developed in a joint program with the National Institute of Standards and Technology (formerly the National Bureau of Standards), the Department of Energy, Lawrence Berkeley Laboratory, and Stanford University. Based on MIFST technology, the system uses SPIRES as the basic database management system. Sponsors can access the pilot system from their own facilities.

Both the pilot system and the production version now in development feature easy-to-use software for the nonprofessional searcher and a metadata system to manage the varied terminology, materials nomenclature, units, and abbreviations typical of this field. The production system will be distributed on STN International in 1990.

Data for welded joints will be an important element of the MPD Network. Databases, such as MARTUF, and other data sources from around the world will be included in the production system. Welding procedures and conditions are being carefully documented in the MPD-Network databases.

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ASM International's Materials Property Data System: Mat.DB®

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Introduction

Mat.DB is ASM International's commercially available materials property data system for DOS-compatible personal computers. It was developed for end-users interested in building their own databases as well as for users who simply want to access precompiled databases. Mat.DB is the latest in a series of products that began with the 1984 publication of MetalSelector, ASM's first PC-based materials property data system. MetalSelector was upgraded in 1986 with MetSel/2, which is now being replaced by Mat.DB. Since 1984, more than 1,000 individuals have purchased the system. The new Mat.DB incorporates many of the comments and suggestions received from this user group over the past five years.

Mat.DB is designed to maintain information on the properties and processing of engineering materials. The system provides a flexible format for structuring diverse data types into a unified system. This format can accommodate information on metals, plastics, composites, and ceramics. Once computerized with Mat.DB, these diverse data compilations are accessed by Mat.DB via a common user interface.

The system has two fundamental components: Mat.DB, the database management system, and databases, collections of materials property data on 5-1/4-inch floppy diskettes. Any database developed for use with Mat.DB serves as a very efficient communications tool for distributing large amounts of computerized materials property data in a format that can be immediately utilized by the recipient.

The Material Record

Three types of information can be maintained: text, numbers, and two-dimensional graphs. Information on materials is gathered in a Mat.DB *record,* which consists of the following fields:

- designation
- common name
- UNS number
- manufacturer
- country
- composition (minimum and maximum ranges for up to 20 elements)
- related specifications (up to 30)
- product forms (up to 30)

- comments (up to 12,000 characters)
- graphs (up to 20)
- properties (As many as 100 properties can be reported for 20 material conditions. Each property value can be qualified and footnoted.)
- indexing terms (Each record can be indexed according to characteristics.)

As you can see, a Mat.DB record can be quite large. If every field were filled with data, the resulting record would exceed 500 kilobytes. A Mat.DB database can accommodate an unlimited number of these records, subject only to the constraints of the computer itself.

Building Databases

Databases are being built by end-users, ASM editors, and commercial materials producers. Users can build their own databases by entering data themselves. The Mat.DB screens prompt the user for input. Consequently, there is no need to know a programming language. Because of the nature of the task, users quickly find, however, that structuring and inputting data can be a tedious and time-consuming process. Fortunately, for many of the standardized materials, ASM-developed databases can be purchased to expand a user's data collection.

ASM editors are systematically computerizing the data in such ASM publications as the *Metals Handbook, Woldman's Engineering Alloys, The Worldwide Guides to Equivalent Metals and Alloys,* and the *Heat Treater's Guide.* The data in these publications are consolidated into Mat.DB databases and then offered for sale to the Mat.DB user group. The ASM data collection is expected to exceed 65,000 records by the end of 1989.

Many materials producers, such as Carpenter Technology Corporation, INCO Alloys International, and the Brush Wellman Company, are using the Mat.DB system to catalog their product offerings. Typically, the company, working with ASM, transfers its product literature into Mat.DB databases. These collections can be quite comprehensive; CarTech's database contains more than 200 materials and occupies close to 4 megabytes of disk space. Company databases are often distributed free to the Mat.DB User Group at the expense of the sponsoring company.

Searching the Database

Data in the system can be searched by indexing terms, alphanumeric field searching, and numeric range searching. The program presents the user with a series of screen prompts that are used to direct the search by using Boolean operators. For example, a typical search command is "Stainless Steel *or* Titanium *and* Bar *and* EL > 15%." This search will locate all bar materials that are available in either stainless steel or titanium and that have an elongation greater than 15%. This search can then be stored for future access. In this way, frequently accessed groups of materials can be segmented from the larger database for quick access and review. Figure 1 shows the Mat.DB screen prompts leading the user through the typical search given above.

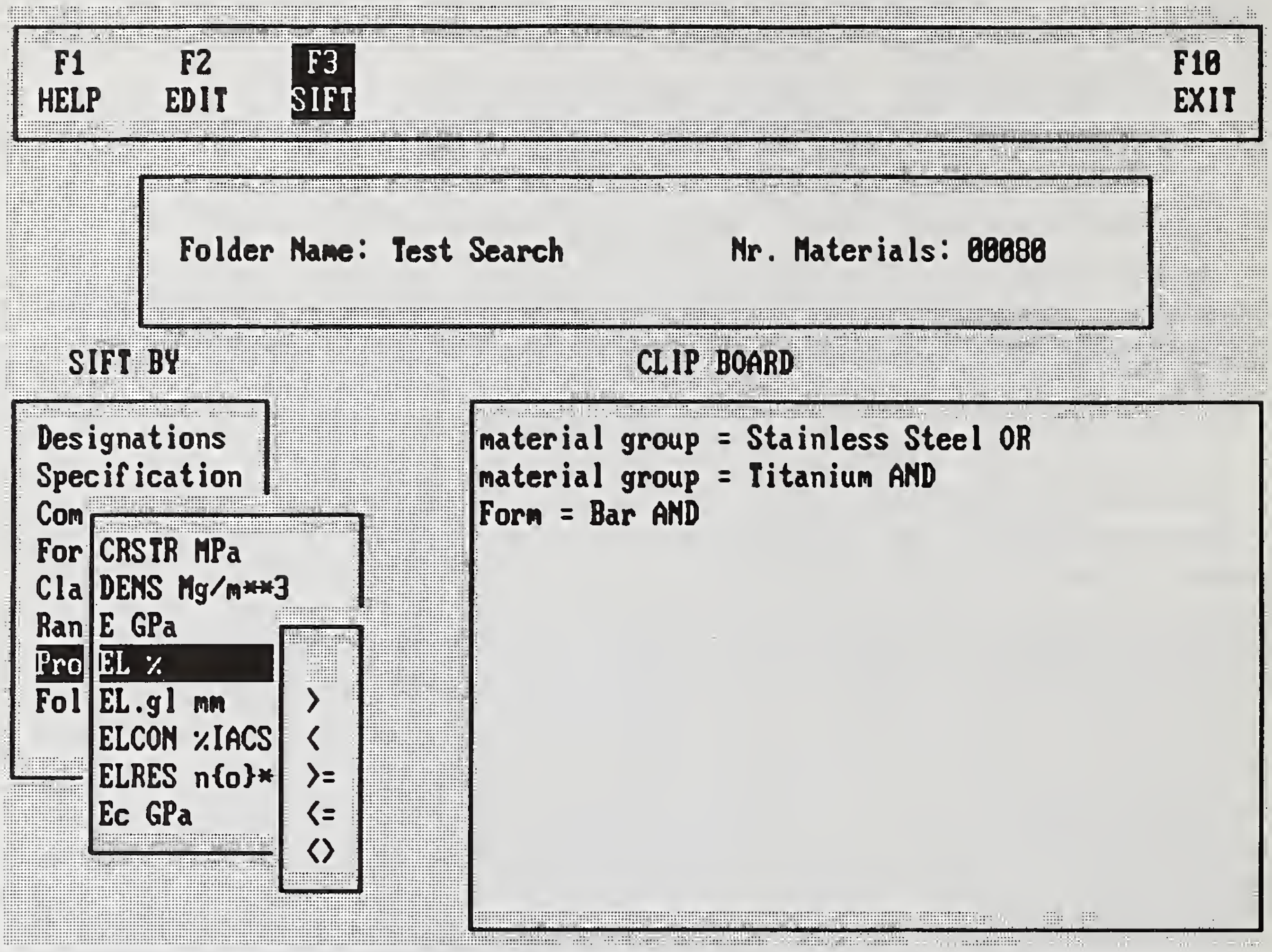

Figure 1. The Mat.DB screen prompts that lead a user through a typical search.

Graphical Information

As mentioned earlier, Mat.DB can also maintain graphical displays of data. The graphs are interactive and can be accessed and modified with Mat.DB's sister program EnPlot, which is an analytical engineering graphics program. Using EnPlot, the user can analyze the data with least-square regression techniques. EnPlot also has the capabilities to add new data points to graphs, delete exiting data points, change the labels and legend, or even create new graphs to add to the database. It also supports a digitizer that enables the user to transfer graphs appearing in books and reports into the Mat.DB database. EnPlot graphs can overlay an unlimited number of data sets. Each data set can contain thousands of data points. Consequently, EnPlot is frequently used to maintain and analyze test data. More importantly, the raw test data is then stored in the Mat.DB database for future access.

Data Security

Mat.DB provides the user with three levels of password support: read only, read–search, and read–modify. Each database can be separately secured, thereby allowing restricted access to sensitive data. Users with read-only passwords can browse on the data in established files; they cannot create files, and they cannot change the data in the database. Read–search users can search the data and create files, but they cannot edit the data. Read–modify users, typically the system operator, can edit and search the database. Figure 2 shows the Mat.DB screen prompts that request a user name and password before allowing access to the CarTech database.

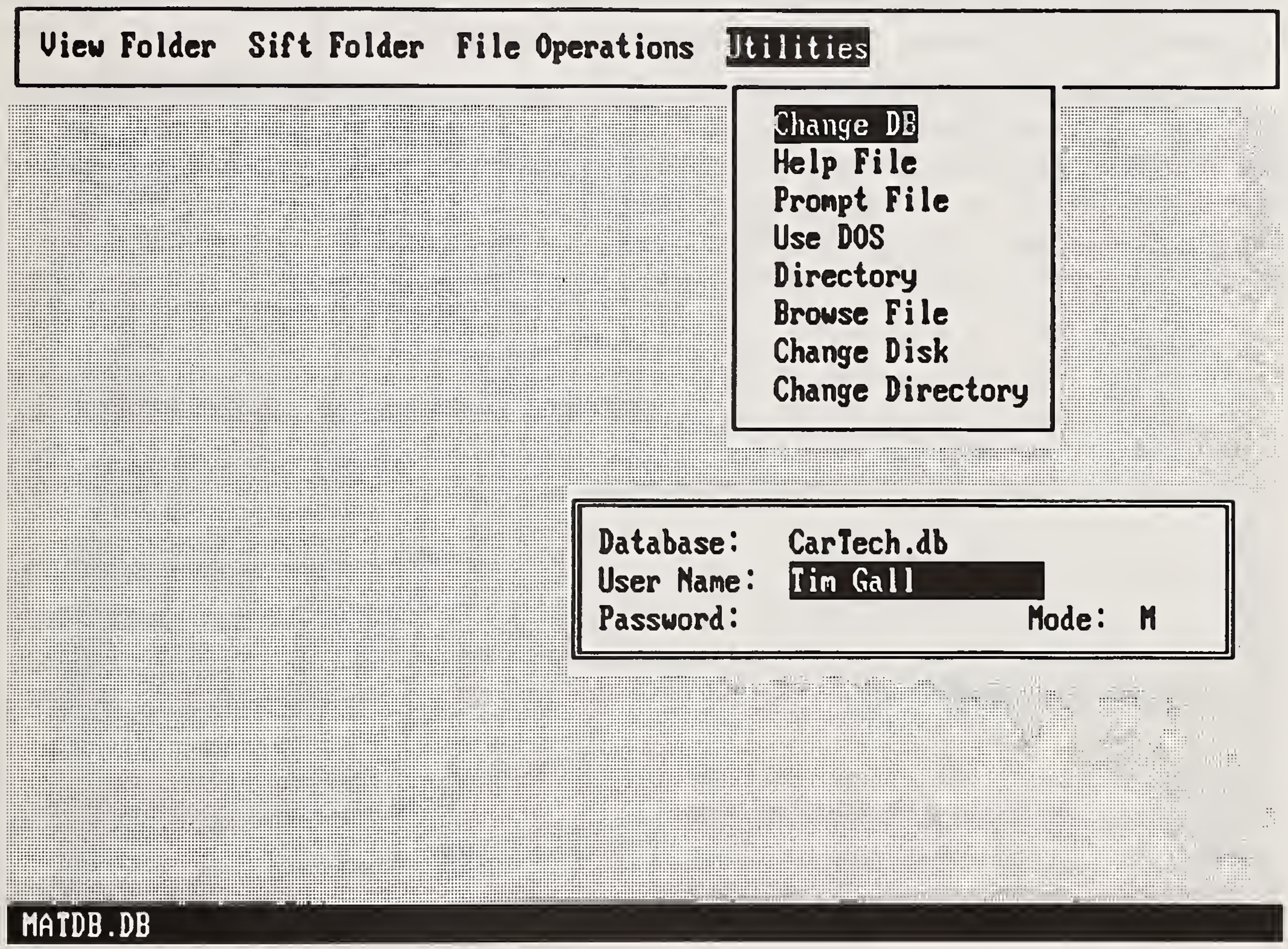

Figure 2. The Mat.DB screen prompts requesting a user name and password before allowing access to a database.

Other Features

Other Mat.DB features include flexible report and print formats, data import and export capabilities via a standardized data-transfer format, and user-modifiable help and prompt files. End-users of the Mat.DB system are supported by a detailed user manual, free and unlimited telephone technical support, and a user newsletter.

During the second half of 1989, Mat.DB will become available for IBM and other personal computers that use the DOS operating system. Current owners of MetSel/2 will be able to upgrade to the new program. An OS/2 version will also become available, and work is under way on a version for the DEC VAX line of computers. The first release of Mat.DB for the VAX will be compatible with the VMS operating system. An ULTRIX version, DEC's version of UNIX, should follow shortly thereafter. A major new program for the collection and review of property data to be entered into the Mat.DB system has been initiated.

Future plans include support for SQL-user interfaces, support for CD-ROM, links with artificial intelligence programming languages, and integration with finite-element programs or other calculation programs that require material property data as input. ASM International views the development of materials property databases as an ongoing project requiring constant attention to keep pace with changing technologies. Work on the development of a computerized materials properties data system will never be completed.

Application of Artificial Intelligence to Welding

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Introduction

Artificial intelligence (AI) is a field of study that is difficult to define owing to the breadth of subject matter that is generally included in the definition. Generally, AI can be defined as the study of logic processes and concepts of understanding which are applied to activities that are usually thought of as distinctly human in nature.

AI does not necessarily require the use of computers; for many years, researchers have done a considerable amount of AI work without using computers. The computer, however, represents a very powerful tool for the application of AI techniques. Consequently, AI techniues, when coupled with the capabilities of modern computer systems, have produced some notable results.

Three areas that use AI techniques are being applied to welding applications with some degree of success:

1. Expert Systems—Expert systems utilize the logic processes of AI and the decision making "rules" of an expert to make logical deductions. When these deductions are applied within the knowledge domain of the expert system, the resulting answers are generally the same as those of the expert whose rules were incorporated into the system. Thus, in some instances, expert systems can be used to replace human experts in decision-making situations.

2. Voice Understanding and Synthesis—Voice recognition is the simplest of the speech-related AI efforts. When coupled with expert systems, it can be used for voice understanding by computer systems. Speech synthesis can take several forms, but the most common and most useful occurs as text-to-speech generation. Thus, a computer system literally reads out loud to the user the information stored in the memory (RAM) or off-line storage (e.g., disk, tape) of a computer.

3. Image Understanding—As computer system speed and capacity have expanded, camera systems have also been developed that can either scan photographic or real images or image two-dimensional arrays to produce digital representations of those images. By application of special numerical analysis techniques, characteristics of those images can be described by numeric and symbolic representations. Work is being done with AI-based symbolic processing that will lead to understanding of the objects in an image.

Artificial Intelligence Computer Languages

Any computer system can be used to describe and manipulate symbols. Symbols are stored in the computer memory as a binary digital representation. A computer language can be used to manipulate and operate on those symbols. However, two schemes, designed to process symbolic information, have been used to generate two specific computer languages. The structural characterizations of those two languages, LISP and PROLOG, make symbol manipulation much easier. Consequently, LISP and PROLOG were the languages of choice for many of the successful AI applications systems that have been developed.

PROLOG is used more extensively in Europe and Japan, whereas LISP is chosen more often in the United States. Each language is built upon a principle of relationships among objects. Neither language is optimized for numerical calculations, except that recursion is favored over looping or algorithmic execution. Thus, calculations, such as the factorial, are made more quickly and easily with LISP or PROLOG than a language like FORTRAN or BASIC.

Expert Systems

An expert system is a scheme developed to emulate the behavior of an expert. The expert is a person or group of persons with identifiable expertise in a specific area of a particular knowledge domain. Expert systems take a variety of forms, and when used appropriately, they can have dramatic results. The most successful expert systems are rule based; they include: MOTION, for analyzing blood diseases; DENDRAL, for analyzing mass spectrographs; DIP-METER ADVISOR for determining of subsurface tilt for oil exploration; and WELDSELEC-TOR for selecting steel welding electrodes.

The knowledge representation in a rule-based system takes the form of "If . . .then . . .," where the input segment or *antecedent* specifies a set of conditions that must be met for the rule to be "triggered." The output segment of a rule or *consequent* is designed to produce new knowledge in a synthesis-type of expert system or to deduce a specific series of facts in an analysis-type of expert system. Rule-based expert systems are highly constrained in the knowledge configuration. This enables great power in both the analysis of problems and the ability to build expert systems. However, the constraint reduces the flexibility in the type of problem than can be solved.

The rule-based paradigm forces a highly constrained format on the structure of the expert system. Consequently, such a system can include several advanced capabilities. Rule-based systems offer utilities that answer questions such as how a fact was deduced or why a fact is needed. This information may be extremely useful to a user who must justify the result to his superiors or comply with a specific code.

A well-designed expert system shell, using rule-based knowledge representation, offers several advantages to the expert system developer: rule-transfer superprocedures, parameter checking, and rule-conflict avoidance. A rule-transfer superprocedure can examine the consequents of a new rule and statistically compare it for form to existing rules. Thus, if the rule form "seems" out of place to the shell software, it will query the developer. The shell also contains an inference engine, which is the logic drive for the expert system. The inference engine "decides" which rules to trigger and which rules to "fire" and in what order.

A conventional software system and an expert system differ primarily in their knowledge-representation methodology (e.g., whether it is rule based) and in the inference engine, which is separated from the domain knowledge. With conventional programs, the logic processes and the domain knowledge are intertwined. The result is a code that is difficult to write and even more difficult to prototype and maintain. Because an expert system uses a knowledge representation scheme and a separate inference engine, it is much easier to develop and maintain. In addition, an expert system can be "knowledge engineered" by building rules that are simple for a human expert to define. Thus, development of an expert system that truly mimics the decision-making behavior of a human expert is much easier.

Representation of Welding Knowledge

For a computerized welding information system to function, methods must be employed that allow the information to be stored and retrieved. Computers should also be able to apply this information to problem solutions. Welding information, as a whole, is the collection of a large body of knowledge about numerous aspects of welding and welding processes. That knowledge exists in a variety of forms because each form was useful for a special application. A computerized information system, therefore, must be able to use knowledge in all these forms. In addition to a rule-based (production system) knowledge representation, other schemes can be applied, some of which are discussed below.

Data Structures

The simplest form of welding information is tabulated data. This information has traditionally been published as relational tables in reference books. However, these tables rarely exist "out of context" and are often useful only when combined with the broader scope of information. For example, a table of recommended preheat temperatures related to carbon-equivalent values is only applicable to a specific set of steels and only for one carbon-equivalent equation. Consequently, the representation of tabulated welding information in a computerized system by using a simple, relational-management system would be inadequate. A more complex system consisting of a series of relational tables organized in a hierarchical structure of information must be used.

Rules for Application of Information

Much of the information about welding consists of data combined with rules that define the application of the data. For example, a welding code may include tabulated data regarding the type of steels that can be grouped together for purposes of applying a single welding procedure, but also in that code are rules that specify the variations allowed in the procedure for those steels. The allowed variation is a series of rules which, when combined, form the codified application of that information. This "production rule" knowledge representation was illustrated in the section describing expert systems.

Graphical and Analogical Knowledge Representation

The design of a welded joint requires not only information regarding procedures, techniques, and materials, but must also include data describing the joint configuration. The joint groove must be machined to useful tolerances, especially for automated welding applications. Small changes in joint design can result in substantial cost differences in producing a weld, which are magnified as the length of the weld seam increases.

Welding design information is generally used in the form of engineering drawings and graphical welding symbols. The representation of this form of knowledge is not well suited to an alphanumeric database or to production-rule type of information storage. Instead, graphical and photographic data are required for computerized welding design information systems. Figure 1 is a typical weld joint and welding symbol graphic representation. The welding information system requirements must include provisions to store, manipulate, retrieve, and display these types of data.

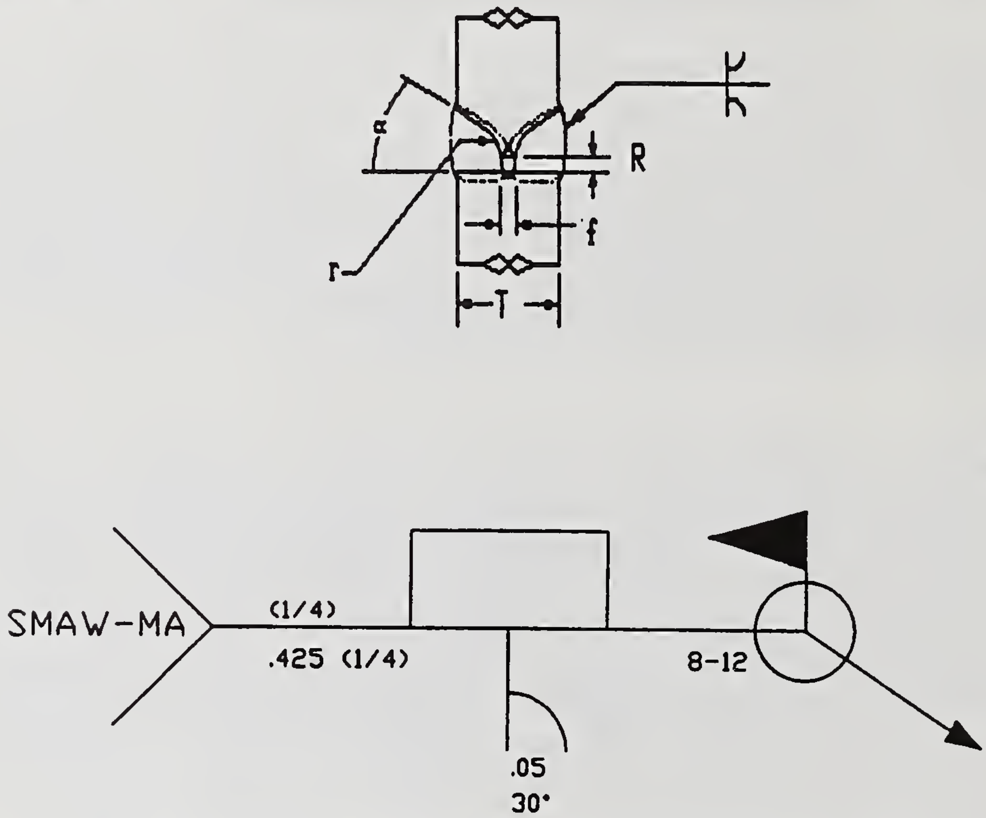

Figure 1. Welding symbol graphic representation for a typical weld.

Frame-Based Information Representation

Objects can be stored in a computerized representation schema by several techniques. The frames technique can be used for object representation as well as for structural organization of other representations. In a frame-based representation schema, objects are stored by maintaining information files about the attributes of the object. The frames technique differs from the database technique in that an inheritance hierarchy is used to describe the objects. Thus, there could be an object known as “welding electrode” that has attributes such as a diameter. Then, there could be an object known as “SMAW electrode” that has attributes such as coating, position, and current type. The object “SMAW electrode” is related to the object “welding electrode” just as a child is related to a parent. Thus, the attributes of “SMAW electrode” include the inherited attribute of diameter.

Expert Systems Technology for a Welding Information System

The American Welding Society now classifies more than 100 welding and joining processes. The number of alloys that can be welded with those processes exceeds 5,000. Each of these alloys, with different compositions and mechanical properties, will exhibit a different behavior when heated to the melting point and allowed to solidify. Consequently, the specific welding parameters used to join a material will be unique to that material or, at the very least, unique to a small, select group of alloys having essentially the same composition and mechanical properties. To specify a welding process and procedure for a fabrication or repair application, a welding engineer must be able to specify the particular welding procedure and parameter values for this application. Depending upon the application, a mistake in the choice of welding procedure can have catastrophic results, leading to loss of life, significant property damage, or loss of service for an extended period of time.

An experienced engineer who works with the same group of materials over a period of time soon becomes familiar with the welding procedures required to produce adequate welds. It is difficult, however, for an engineer to maintain a complete mental record of the welding procedures that are applicable to even one broad category of alloy, such as chromium–molybdenum steels, or to ensure that they comply with applicable codes and other standards designed for those materials. It is virtually impossible for one engineer to recall the information necessary to specify welding procedures for the entire range of metals and all possible applications. A well-versed welding engineer, given a sufficient library of reference information and sufficient time can, by diligent effort, find a welding procedure for almost any application; however, this process can result in a less-than-optimum choice. As the complexity of weld fabricated structures and components continues to increase and as the number of welding processes and engineering alloys continues to grow, the likelihood that optimum choices will be made in the specification of welding procedures continues to decrease. For the welding industry to increase its capabilities, efficient methods need to be found for providing welding information. This approach will result in optimum use of available resources and will not require excessive amounts of personnel resources. Studies by the United States Department of Commerce have indicated that nearly one-half of the gross national product of the United States is dependent upon welding and joining. Even small changes in the ability to optimize the use of welding information could have a dramatic impact on the commercial viability of the United States or any other country. Clearly, then, a computerized welding information system that can be used for efficient search and retrieval of optimum welding procedures and that can also provide other useful information about welding and welding materials is an important step forward and an important undertaking for the welding industry.

The Welding Information Network System

To provide welding information services that are useful for application problem solving, an integrated system is necessary. Its requirements are (1) the capability to work with a wide variety of knowledge representation techniques, so that all required information types can be used; (2) the flexibility and expandability to include future enhancements; and (3) the capability of being updated to take advantage of the latest computer technology.

Based on these criteria, the Welding Information Network (WIN™) System was designed and implemented by the American Welding Institute, working with the National Institute of Standards and Technology (formerly the National Bureau of Standards) and the Colorado School of Mines Center for Welding and Joining Research. The system operates in a desktop computer environment, which makes it accessible to most potential users.

Knowledge-Base Development for WIN

The WIN system is organized as a series of databases coupled with production-rule-oriented knowledge bases and graphic data systems. Figure 2 is a schematic diagram of the WIN system structure showing the relationships among the various represented knowledge sources (AWIKBS) and databases (AWIDB). The WELDSELECTOR expert system exemplifies a hybrid type of expert system, one that was formed by combining a knowledge base and several databases in WIN. The databases that were combined for the WELDSELECTOR expert system include a materials properties database for more than 1,100 ASTM classified weldable steels and an electrode properties database. WELDSELECTOR has more than 1,200 rules in the knowledge base that are used for selecting welding electrodes. In each knowledge base in the WIN system, the technique to represent the knowledge was chosen to optimize the eventual use of the information.

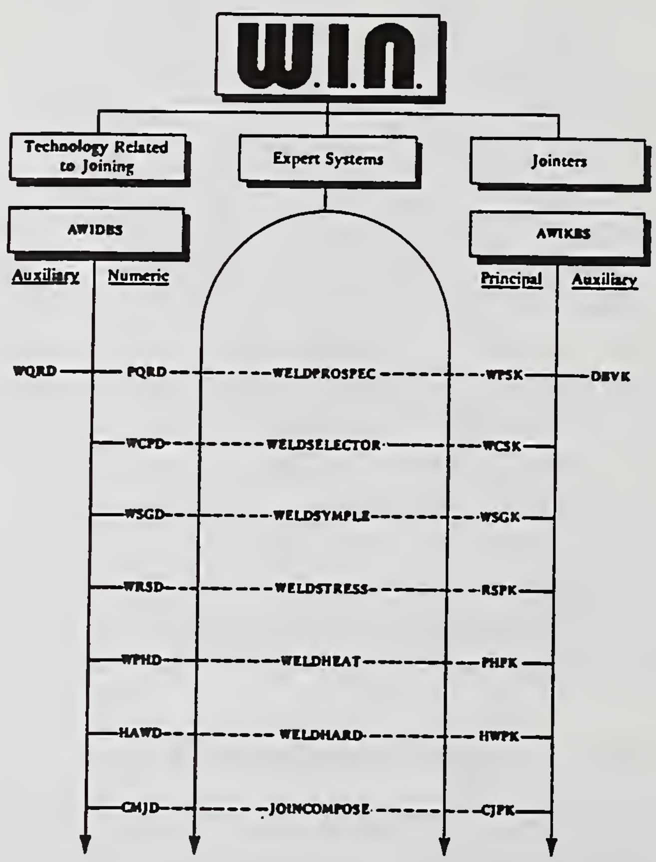

Figure 2. The WIN system structure, showing the relationships among represented knowledge sources and databases.

Expert Systems in the WIN System

All the expert systems in the WIN software network must make extensive use of data; therefore, they are all coupled with large databases to form hybrid expert systems. Three expert systems are being used outside the American Welding Institute:

1. WELDSELECTOR, an expert system for optimum selection of welding electrodes. It includes a database of all the weldable ASTM classified steels and the AWS classified welding electrodes for SMAW, GMAW, and FCAW.
2. WELDSYMPLE, an expert system for the development of welding symbols. Based on the ANSI/AWS A2.4-86 document on welding symbols, it produces a graphic representation of a welding symbol in a CAD computer environment.
3. FERRITEPREDICTOR, an expert system for selection of welding electrodes based on ferrite number, according to either Schaeffler or DeLong analysis. This expert system was developed in close cooperation with the WRC High Alloys Committee, Subcommittee on Stainless Steel Welding.

The current WIN system also contains several prototype expert systems that are being developed for commercial release:

1. WELDSTAINLESS, an expert system for the development of stainless steel welding procedures. It includes the capability of ferrite number prediction by using both the Schaeffler and DeLong approaches. It provides comprehensive decision support for the welding engineering of similar or dissimilar stainless steel welds.
2. WELDHEAT, an expert system for the prediction of optimum preheat and postweld heat treatment of welded steels.
3. WELDPROSPEC, an expert system for the development of welding procedure specifications based on the AWS D1.1 structural welding code and on PQRs from a database system.

Automation Applications

As welding automation becomes more sophisticated, the requirements for information in automated systems will grow significantly. This need can be met only by a computerized welding information system, which will require different kinds of computerized information (e.g., welding procedures, process control data, digital signal template data for sensor control, and welding design data for joint tracking control).

Neural Network Simulation

Recent work by the Colorado School of Mines on the WIN system has included investigation of methods to store, retrieve, and manipulate various types of sensor data for welding uses. Rapid processing of visual image data can be a monumental task with traditional computational methods. By using a parallel processing environment with a neural network simulation (NNS), the task can be reduced considerably. Because a NNS system does not require a point-by-point or pixel-by-pixel comparison, the time required for identifying images is drastically reduced, and appropriate decision making is possible without an exact match. Thus, by using a rule matrix and an image matrix, and then teaching the system in a parallel processor environment, the system can learn to identify images and begin to "understand" those images by binding conceptual ideas to the elements of the image.

Artificial neural systems are well suited to robot vision tasks, especially in welding. Neural networks have several advantages over traditional programs: they deal with noise well; they can handle more input with fractional time increases; and they can be taught new configurations without reprogramming. In a typical welding situation, spatter and other inconsistencies, such as poor lighting conditions, combine to give a relatively high noise level. This requires either a great deal of filtering in a standard vision program or an algorithm that deals with noise. Since scale up is often necessary to encompass the data necessary to make appropriate welding decisions, a method that increases computation time fractionally rather than linearly is preferable. Figure 3 shows a typical interpreted graphic display of a weld joint using the neural network as it tracks a weld joint.

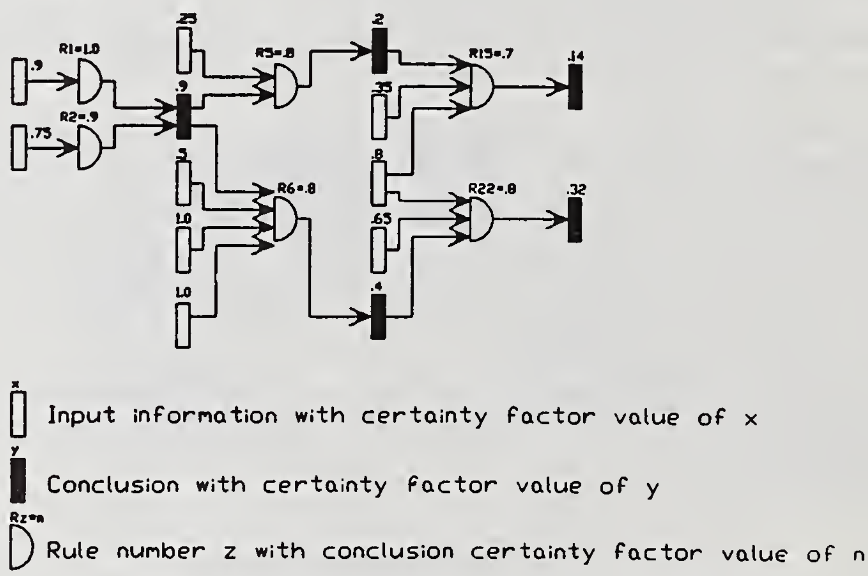

Figure 3. Neural network tracking of a weld joint.

Tests of the ability of NNS systems to recognize noisy images have been conducted. Images were created that contained randomly distributed black spots (spatter). The degree of noise was determined as a percentage of pixels contained in the weld joint image itself, not in the total image. This measure of noise has the advantage of being independent of magnification or other camera characteristics, but it can report noise levels greater than 100%.

The results of the test indicate that images of welded joints can be processed at a rate exceeding 600 images per minute. At that rate, 100% accuracy was achieved at noise levels of up to 130%. Since this NNS system was being operated at approximately 30% of capacity, it appears likely that it is capable of completely accurate image processing in excess of 2,000 images per minute at more than a 100% noise level. This is more than adequate to perform real-time seam tracing for any arc welding procedure.

CONFERENCE PAPERS – Welding Applications Software

Computerized Software for Welding Engineers

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Introduction

Computer systems are commonly available to engineers in a wide range of technologies, but especially in

- design and drafting
- analysis and modelling
- capacity planning
- manufacturing management

However, until recently, there has been very little specialist software available to help the welding engineer carry out his many tasks. For example, the welding engineer is increasingly asked to provide information and advice at the various stages of manufacture. The type of information required ranges from the initial design of the component and the selection of a suitable welding process to the best method of manufacture to achieve maximum productivity with an adequate level of welding quality. If weld defects occur in the course of manufacture, the welding engineer is required not only to identify the cause, but also to recommend a solution.

In support of its design advisory service to Member Companies, The Welding Institute has a number of specialist databases and software (e.g., finite-element analysis of weldments), which are held on a mainframe computer for in-house use by staff. However, one database, Weldasearch, which contains abstracts of technical papers relating to welding engineering, is stored on the Dialog Information Services Computer (Lockheed Missile and Space Company). The company maintains a 22-hour, on-line information-retrieval service that is available worldwide.[1]

Over the last four years, The Welding Institute has produced a range of low-cost packages for use on the desktop microcomputer. The packages range from databases (e.g., for storing welding procedures) to specialized software (e.g., for calculating preheat requirements when welding carbon–manganese steels). The subject areas covered are

PREHEAT	Calculations and analysis of standards and the recommendation of preheat or minimum heat input necessary to avoid hydrogen cracking
WELDVOL	The volume of weld metal in any joint type as well as the amount of consumables required
WELDCOST	Calculations for estimating the cost of welded fabrications
MAGDATA	Advice on GMA welding parameters for steels
WELDSPEC	Database for the storage and fast retrieval of welding procedures
WELDSPEC Utilities	Set of utilities for use with WELDSPEC
WELDERQUAL	Database for the storage of welder qualification records providing a constant update of when welders must be requalified
FATIGUECALC	Fatigue design calculations according to the requirements of BS 5400, part 10
Al-WELD	Expert system for generation of GMA welding procedures for aluminum
UNITCALC	Memory-resident unit converter

Several hundred packages have already been sold to welding engineers in the United States and other parts of the world.

In addition to the use of computers for storing information or carrying out calculations, current research is aimed at developing "intelligent," or expert systems. A simple definition of an expert system is one that encapsulates the specialized knowledge of a human expert in a form that can be accessed by other users. Although it is in an early stage of development, the prototype systems have demonstrated their capability to provide expert advice (e.g., on the preferred choice of welding process or equipment).

Software Packages

There is a dearth of specialized commercial software for the welding engineer, but computers have been used in related tasks. Examples are

- finite-element analysis[2–4]
- calculation of cooling rates and prediction of preheating[5–7]
- selection of welding processes[8]
- fitness-for-purpose analysis of weld defects[9]
- database for storing welding procedures[10]

The Welding Institute software supports the information-technology-related tasks of the welding engineer.[11] Since the software packages are intended for the personal use of engineers, they are relatively inexpensive, within the range $300–$800. They can be run on the IBM-PC range of desktop microcomputers and certain IBM "compatible" machines. Typical system requirements (shown in Figure 1) are

Machine

- IBM PC, XT, AT, or OS/2
- 256k RAM (minimum)
- 1 floppy disk drive
- 1 fixed disk (for WELDSPEC only)
- color/graphics monitor and adaptor (CGA, EGA, or VGA)
- Epson-compatible printer (optional)
- Microsoft mouse (WELDSPEC and WELDSPEC Utilities only)

Software

- MS-DOS or PC-DOS version 2.0 or later
- IBM BASICA interpreter (PREHEAT, WELDVOL, WELDCOST, and MAG-DATA)

Figure 1. Typical system requirements.

PREHEAT

Cracking in welded structures can occur through the buildup of hydrogen and stresses in the heat-affected zone of the weld. In practice, the risk of cracking can be minimized by controlling the amount of hydrogen generated, the microstructure, or both. As the problem of hydrogen cracking and techniques to avoid cracking are well-known, various standards have been produced from which "safe" welding procedures can be predicted. The data in the standards are presented in tabular and diagrammatic form; they can be used to provide a measure of confidence that a given welding procedure will be safe for welding a specific type of steel.

In operation, for a given welding procedure and material composition, the data are used to recommend a minimum preheat level above which the cooling rate of the component will be sufficiently low to soften the microstructure and also to facilitate the diffusion of hydrogen away from the joint area (see Figure 2a). Another approach is to use the data to provide recommendations on the welding procedure, in particular, the minimum heat that can be supplied by the arc while ensuring a safe weld. In this case, by specifying the chemical composition, preheat level, and hydrogen level generated, the minimum arc-energy input necessary to control the heating rate will be defined.

The PREHEAT program enables the welding engineer to conduct all the necessary calculations (arc energy, carbon equivalent) to determine the appropriate preheat or arc energy levels for the avoidance of hydrogen cracking. Thus, an important feature of the program is the "approved" data published by The Welding Institute[12] or British Standards Institute.[13] Interrogation of the program is via single or multipage entry mode, and four parameters can be calculated:

- minimum workpiece preheat level
- minimum arc energy of the welding procedure
- maximum hydrogen level of the weld metal
- maximum carbon equivalent of the parent metal

Special features of the program that were designed to make its operation attractive to welding engineers include

- welding procedure alternatives (e.g., electrode run-out tables) for SMA welding or current and travel speed options for other arc processes provide procedure guidelines for calculated arc energy
- numerical and graphical presentation of the results with a printout of input values and results of calculations

A typical display of welding procedures for carbon–manganese steels in which the minimum preheat level is specified for a particular combination of combined thickness and arc energy values is shown in Figure 2b.

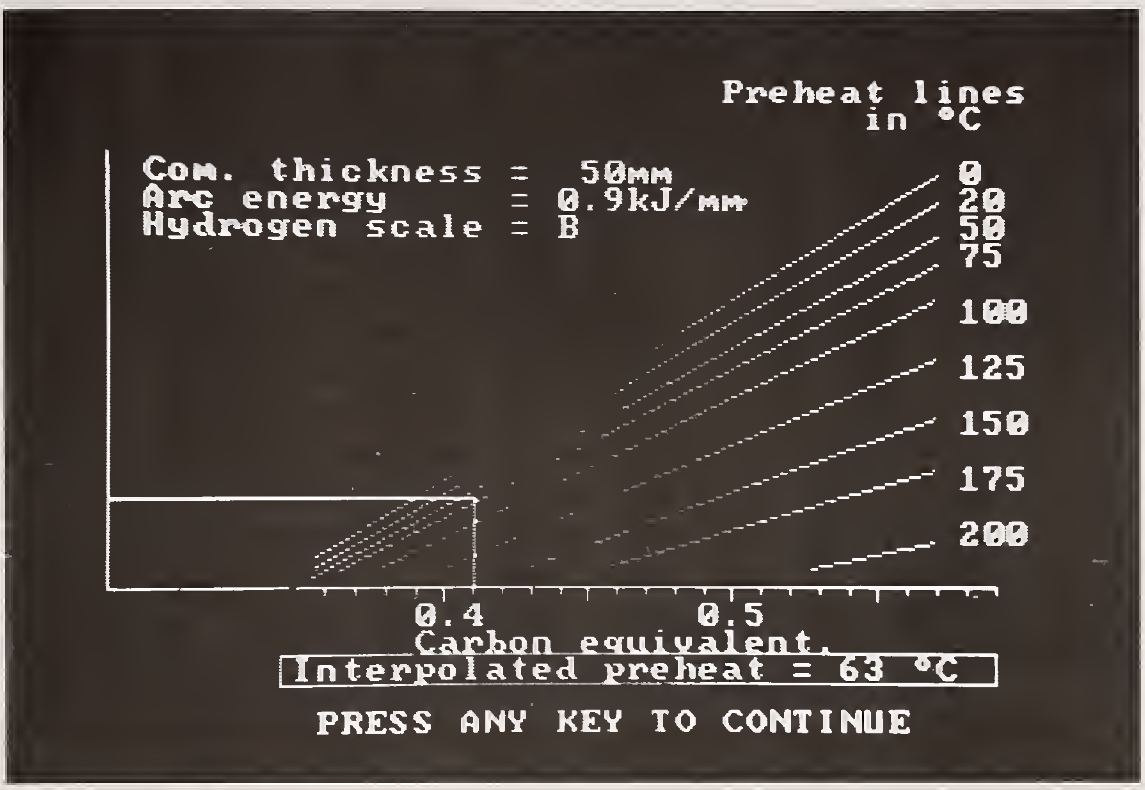
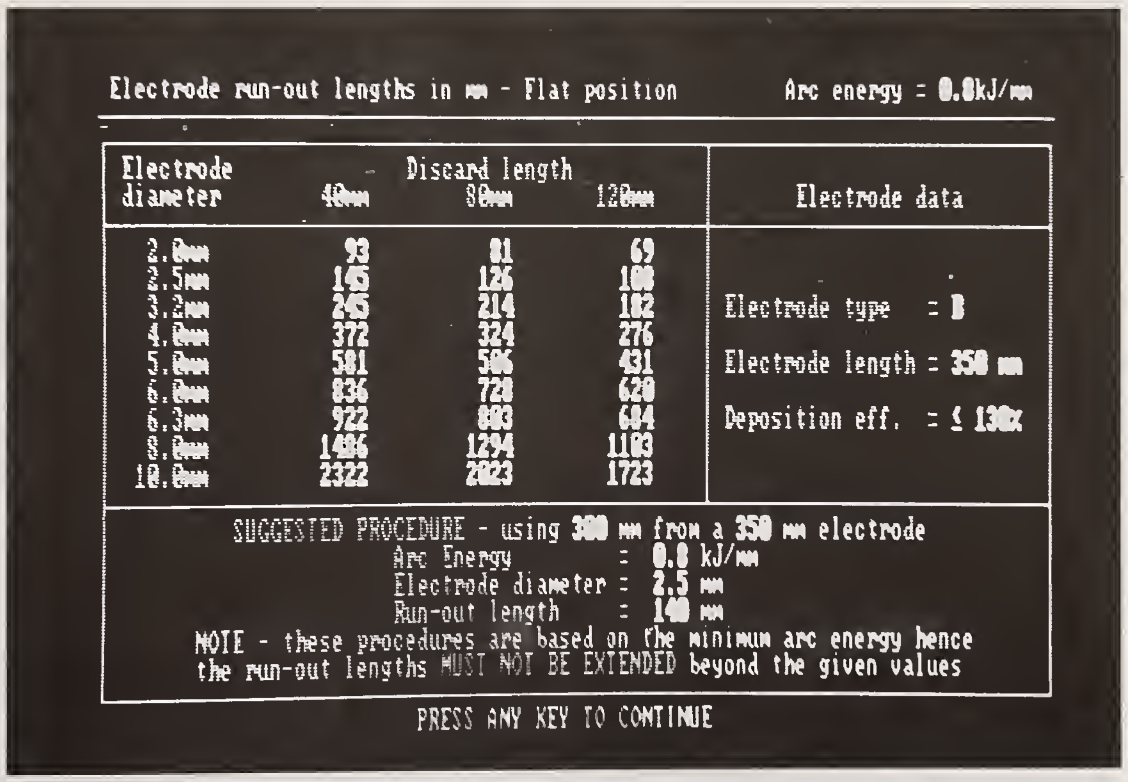


Figure 2a. Recommendations of preheat temperature from PREHEAT.



Electrode run-out lengths in mm - Flat position   Arc energy = 0.8kJ/mm

Electrode diameter	Discard length 40mm	80mm	120mm	Electrode data
2.0mm	93	81	69	
2.5mm	145	126	108	
3.2mm	245	214	182	Electrode type = B
4.0mm	372	324	276	
5.0mm	581	506	431	Electrode length = 350 mm
6.0mm	836	728	620	
6.3mm	922	803	684	Deposition eff. = ≤ 130%
8.0mm	1486	1294	1103	
10.0mm	2322	2023	1723	

SUGGESTED PROCEDURE - using 300 mm from a 350 mm electrode
Arc Energy = 0.8 kJ/mm
Electrode diameter = 2.5 mm
Run-out length = 140 mm
NOTE - these procedures are based on the minimum arc energy hence the run-out lengths MUST NOT BE EXTENDED beyond the given values

PRESS ANY KEY TO CONTINUE

Figure 2b. Welding procedure options from PREHEAT.

WELDVOL and WELDCOST

WELDVOL is designed to help the welding engineer carry out the routine and often time-consuming task of calculating the quantities of consumables (i.e., the number of electrodes) required for specified arc-welded fabrications. With the keyboard, the user enters the dimensions of the weld joint, and from these dimensions, the cross-sectional area is calculated. A typical screen display (Figure 3a) shows how easily the dimensions can be entered.

By specifying the details of the welding process, material type, and total weld length, the consumable requirements can be calculated. The program is flexible: it can handle all the major welding processes, the common materials, many types of joints, and different electrode sizes. A screen display showing the results of a typical calculation is shown in Figure 3b.

To calculate the welding cost per metre of weld, the results from a WELDVOL consultation are used as input data for the WELDCOST program. The weld cross-sectional area and details of the welding procedure and labor organization are entered into this program. An attractive feature is that the user can vary the individual cost centers (e.g., for consumables and labor) to determine their influence on the total welding cost. An example of the costings and cost comparisons is shown in Figure 4.

MAGDATA

MAGDATA enables the welding engineer to produce GMA welding procedures for carbon and carbon–manganese steel fabrication. The user enters the cross-sectional area, wire diameter, metal-transfer mode, deposition efficiency, and welding duty cycle. The stored data are then used to calculate

- permissible ranges of welding current and travel speeds
- maximum and minimum number of runs to fill the joint

Once the appropriate number of runs has been established, the program can automatically generate suitable welding parameters and times:

- welding current, arc voltage, travel speed, wire-feed speed, and arc energy
- arc time, indirect time, and total time per metre

A typical screen display illustrating the results of a MAGDATA consultation is shown in Figure 5.

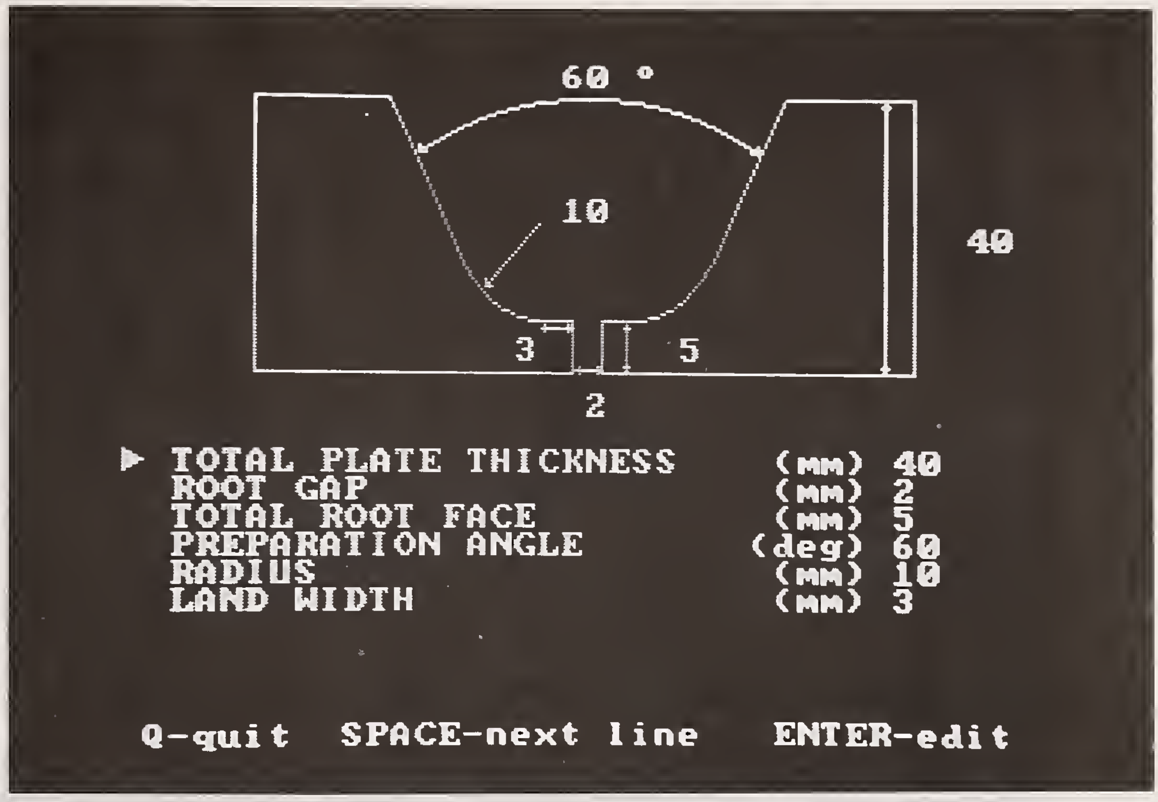


Figure 3a. Entering weld dimensions for WELDVOL.

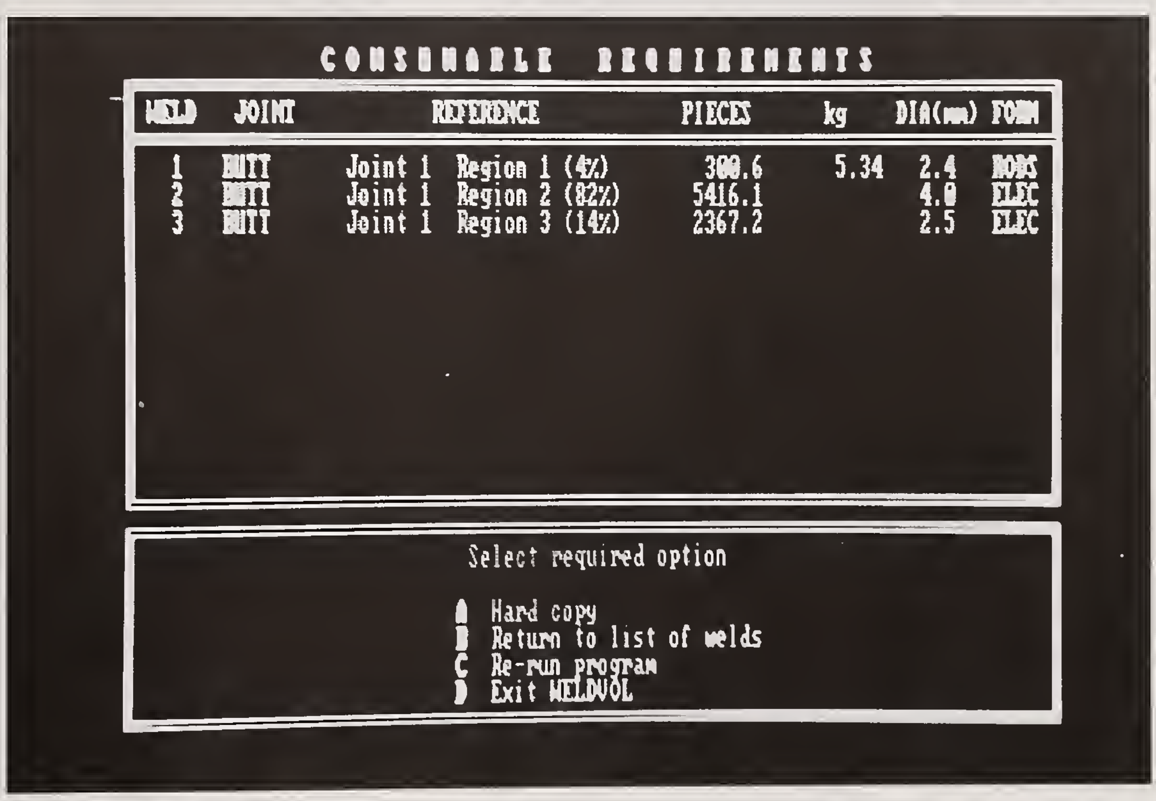


Figure 3b. A results screen from WELDVOL.

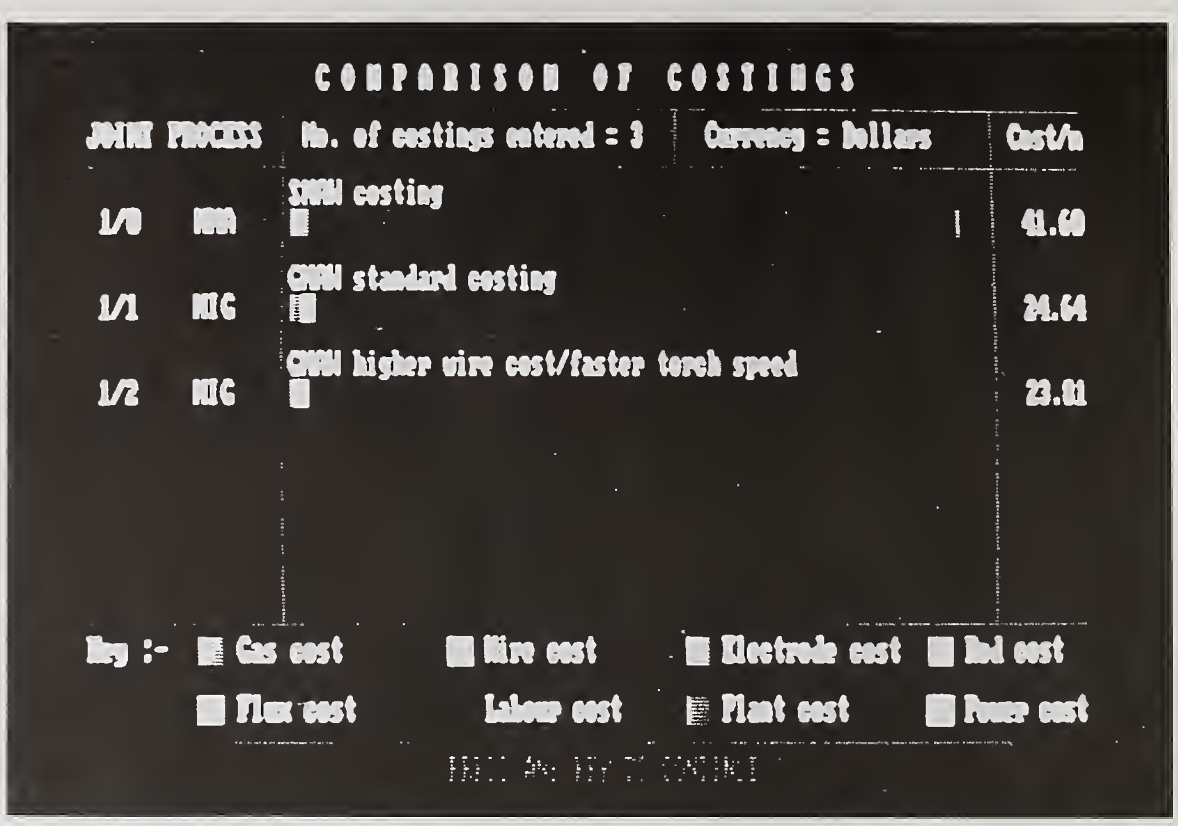


Figure 4. A costing comparison chart from WELDCOST.

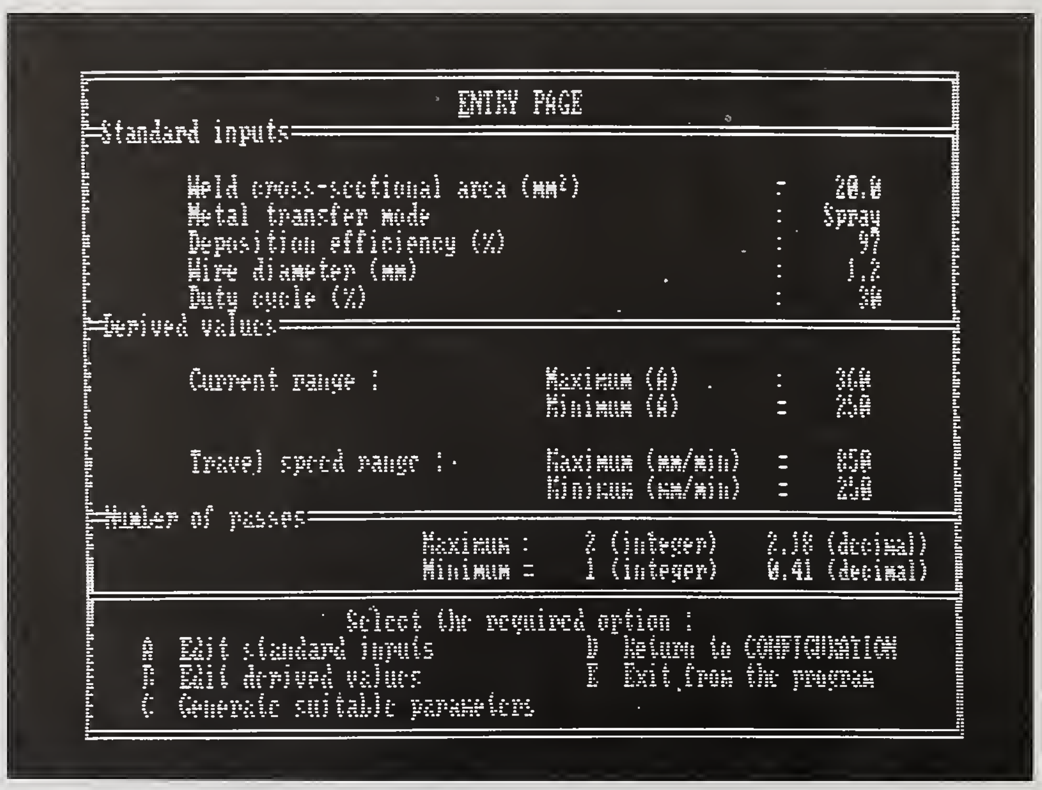


Figure 5. A screen of intermediate results from MAGDATA.

WELDSPEC

WELDSPEC is a database for the storage and retrieval of welding procedures. The information is that required for approval of a welding procedure on the standard welding-procedure sheet; i.e., component details, welding parameters, consumables, and results of inspection and mechanical testing, can be stored in the database.

In designing the database specifically for welding procedures, the following operating features were considered to be highly desirable:

- The system must be extremely easy to use since it will be accessed by nonspecialists in computers.
- Information should be displayed in a manner similar to that on the procedure sheet.
- The system should contain a graphics capability for drawing components and joint details.
- The program for accessing information should be menu-driven with full prompting at all levels.

An important feature of WELDSPEC is its user friendliness. Each item of procedural information is typed into the box reserved for that information on one of the seven screens that represent a full welding procedure (see Figure 6a). Diagrams can be entered by means of a mouse and a drawing package; a typical schematic drawing is shown in Figure 6b.

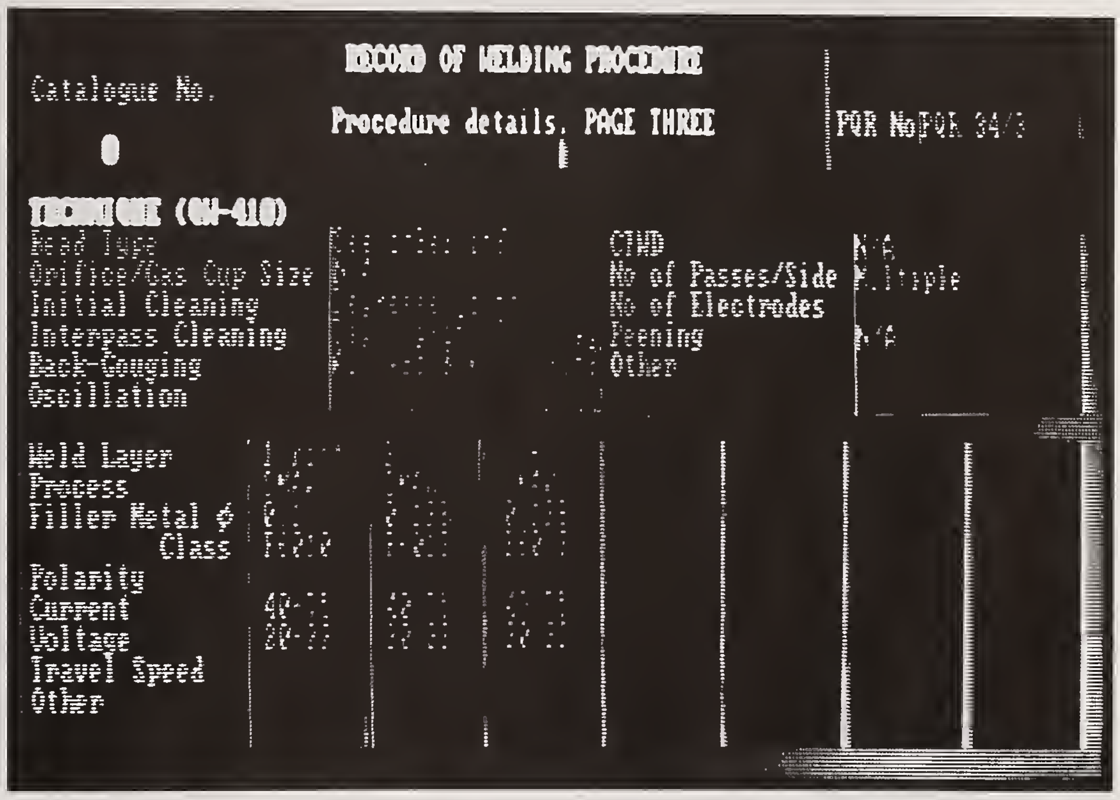


Figure 6a. One of seven text screens that represent a WELDSPEC welding procedure record.

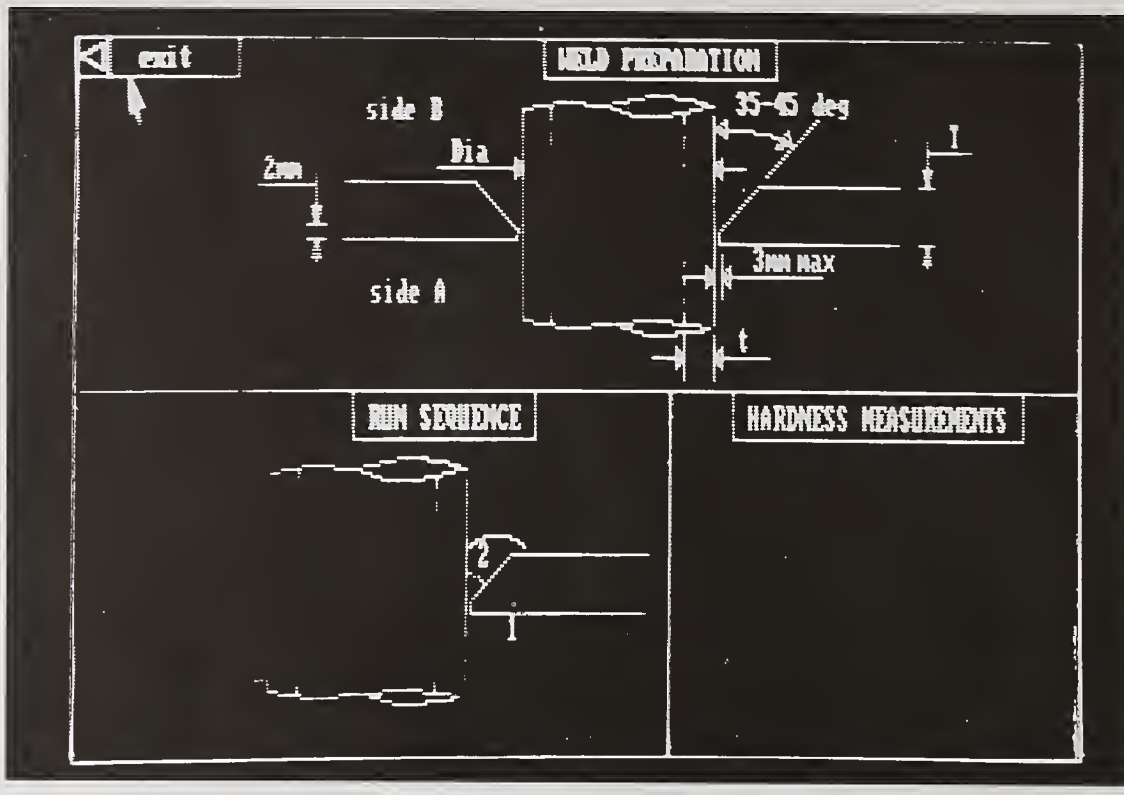


Figure 6b. A diagram showing a tube-to-tube plate weld from WELDSPEC.

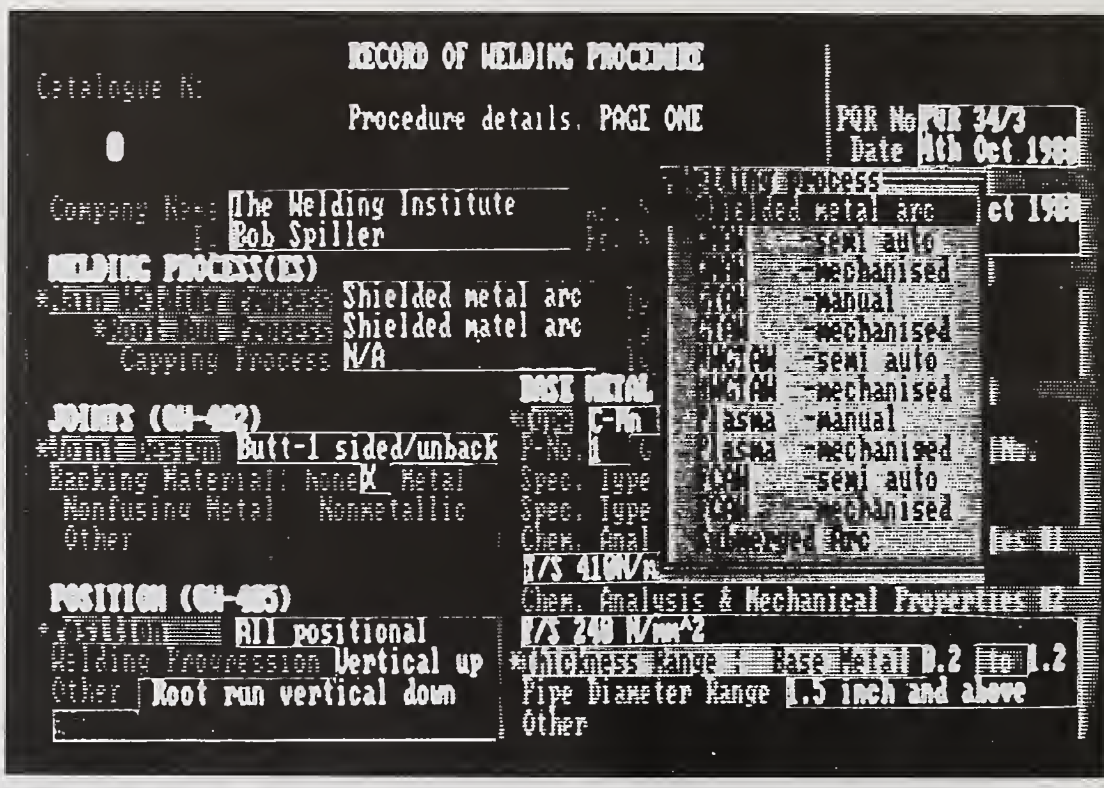


Figure 6c. Entering data by the use of menus in WELDSPEC.

To extract one or more welding procedures, the user may specify any of several main search parameters for which instantaneous searches can be made:

- welding process (main *and* root run)
- joint type
- welding position
- parent material type
- parent material thickness range

These searches are made, by using a mouse, from menus that are overlaid on the screen, as shown in Figure 6c.

The user may also search through the database for the occurrence of sequences of characters, enabling searches to be made on other information, such as material properties, consumable trade names, and company welding procedure.

Once located, welding procedures can be printed out in a standard format, or the unique catalogue number of the procedure can be used to find the original procedure document.

WELDSPEC Utilities

This package, complementary to WELDSPEC, was designed to enable the user to manage the welding procedure database created by WELDSPEC in the most efficient manner. It contains routines to facilitate the following tasks:

- additional printout routines
  - to print a welding worksheet
  - to print a sorted, summary register of welding procedures
  - to print a batch of PQRs
- data management routines
  - to import or export procedure data to other WELDSPEC systems
  - to back up and restore data from floppy disks automatically
- graphics conversion route
  - to convert diagram from CGA format to EGA or VGA format

WELDERQUAL

WELDERQUAL is a database package designed to store welder qualification information. Having entered details of all the qualification data, the welding engineer can keep track of the work force on computer, helping to ensure that (1) qualifications that are due for renewal can be found quickly and easily prevented from lapsing unnecessarily, (2) suitably qualified welders are assigned to perform certain types of welds, and (3) unnecessary qualification tests need no longer be carried out, since a rapid search of the database will inform the user immediately if any welders already hold a qualification for a particular kind of weld. A typical screen display showing the format of a welder qualification record is shown in Figure 7.

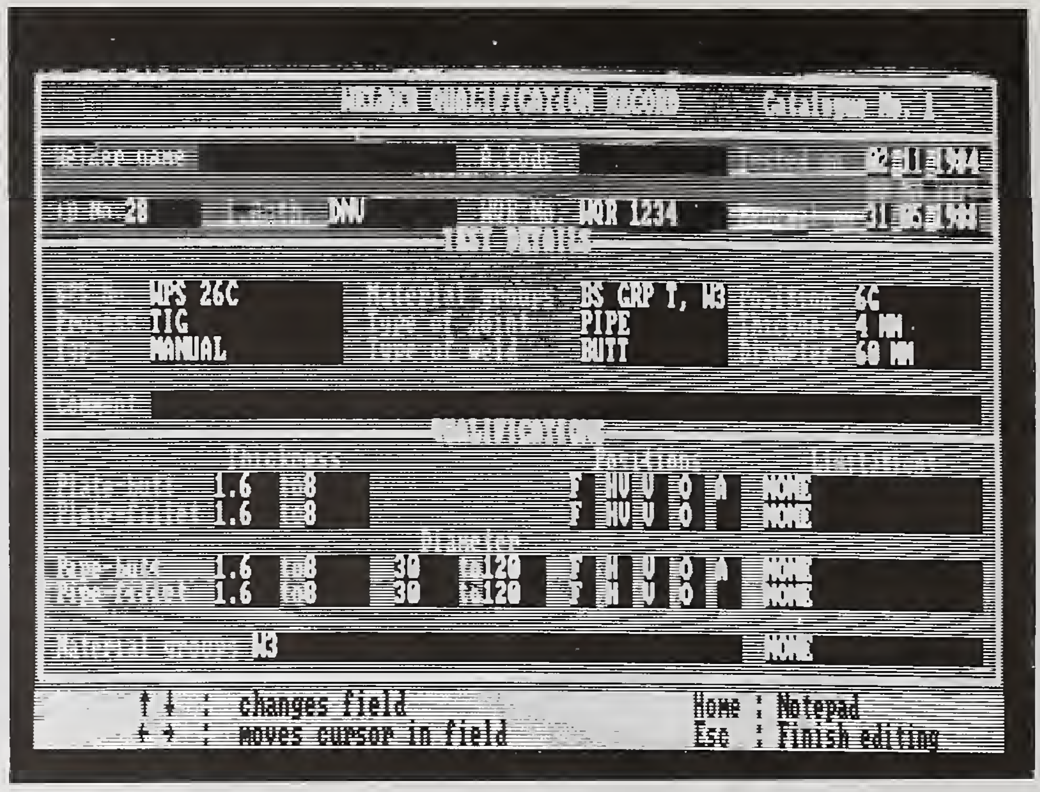


Figure 7. The format of a WELDERQUAL welder qualification record.

FATIGUECALC

The FATIGUECALC program enables designers to perform fatigue design calculations. Both constant and variable amplitude loading are handled by the program, and if desired, the following corrections can be applied to the S–N curve used in the calculation:

- plate thickness
- unprotected joints in a seawater environment
- allowance for toe grinding

FATIGUECALC is a spreadsheet-style program with extensive help capabilities for those not familiar with computers. It enables experienced designers to perform complex calculations quickly and accurately. Graphics are used to plot stress range and fatigue life together with the appropriate S–N curve.

Details of the calculations can be printed out in two forms: a one-line summary of the numbers and other parameters used or a full-page description suitable for inclusion in a report. Typical results of a FATIGUECALC calculation are shown in Figure 8.

Stress spectra, input parameters, and calculation results can be communicated to and from other programs via standard ASCII files.

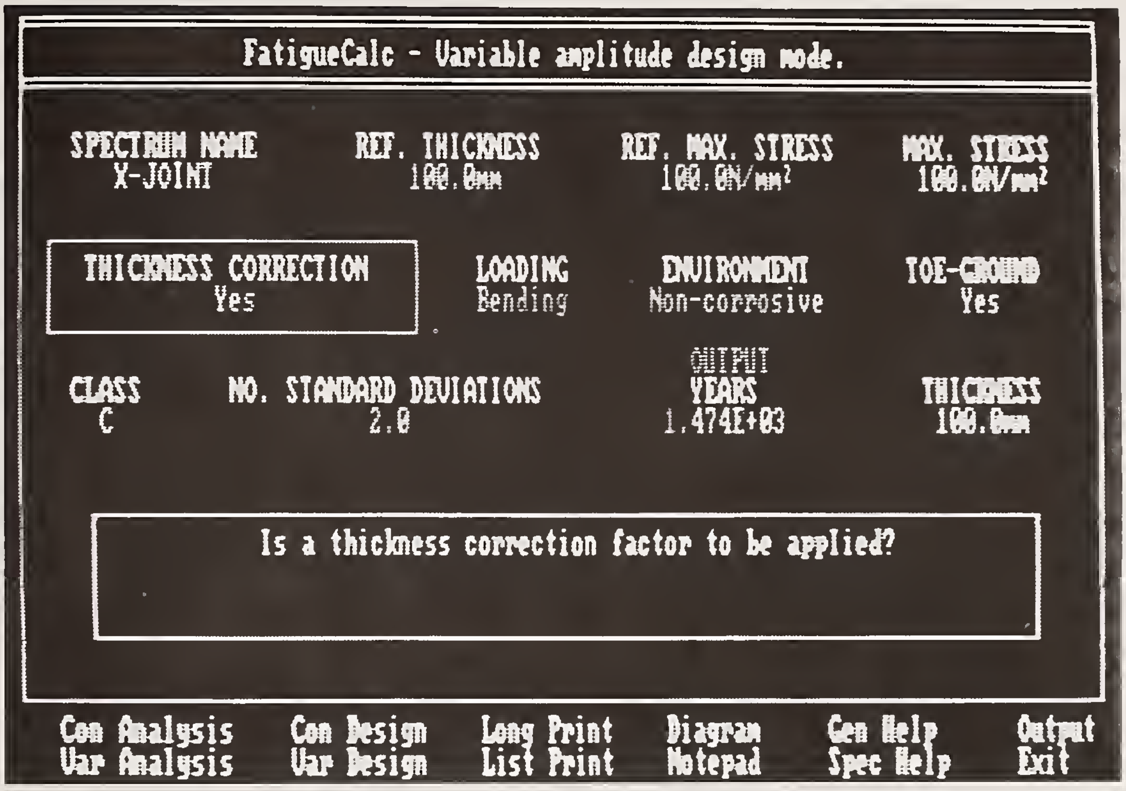


Figure 8. The results of a calculation in FATIGUECALC, showing the spreadsheet driving style.

UNITCALC

UNITCALC is a memory-resident program that enables rapid and convenient conversions of commonly used engineering units (e.g., units for flow rates, stress, heat input). A memory-resident unit converter has the following advantages:

- Conversions can be performed during the operation of other programs, such as PREHEAT, WELDCOST, and WELDSPEC.
- The results of the conversions can be imported directly into the program currently being used.

For example, the program can convert English units to metric and vice-versa.

Expert Systems

Welding engineers with a specialist knowledge are normally consulted at the various phases of manufacture, for example, about the best method of manufacturing a product or solutions to production problems. Expert systems can mimic a human expert; they contain sufficient knowledge and reasoning mechanisms to offer "intelligent" advice. A typical system contains three basic elements:

- a knowledge base
- an inference engine
- a user interface

The distinction between the knowledge base and static database of a conventional program, such as WELDSPEC, is that the knowledge is stored largely as statements about uncertain facts and rules, and as more information becomes available, the knowledge base grows. Since WELDSPEC simply involves the data storage, it has been written in "C," which is a conventionally structured programming language. Many areas of engineering, such as the solution of problems, are subjective or poorly defined and, therefore, not well suited to conventional methods of programming. However, these subject areas can be modelled by using an expert-system approach.

An expert system usually gives advice as its output, not definitive data, that is, it tends to recommend a certain course of action rather than to specify parameters. This resembles the way a human expert would state his conclusions; for example, "In the circumstances you have described, my recommendation for reducing undercut would be to reduce the torch travel speed."

An expert system should have extensive explanatory facilities. In the same way that a human expert explains his line of reasoning, the computer should be able to answer the following user questions:

> What does that question mean?
>
> Why have you asked that question?
>
> How have you arrived at that conclusion?

Expert Systems in Welding

A number of expert systems in the field of welding technology have been reported:

TIG:[14]	a system designed by Framentec for the diagnosis of faults in GTAW equipment
Weldselector:[15]	a system for the selection of wire and electrodes from consideration of the parent material and welding positions
Weldex:[16]	a system for the automatic inspection and interpretation of pipeline radiographs
Robot diagnosis:[17]	a system to diagnose malfunctions in ASEA robots by Ford (U.S.)

At The Welding Institute, a system has been produced for generating welding procedures. A rule-based shell was used that is capable of handling probabilities. It also provides a means of accessing externally written programs, such as tables of data or graphics routines for diagrams.

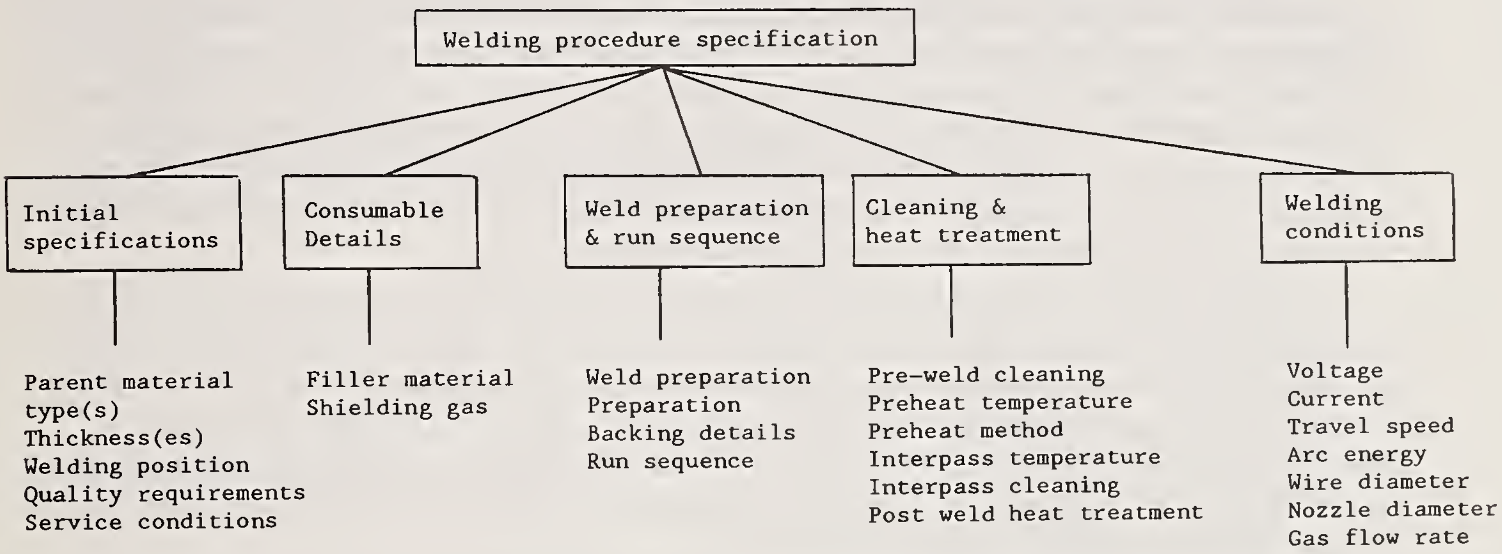


Figure 9. The structure of a welding procedure specification.

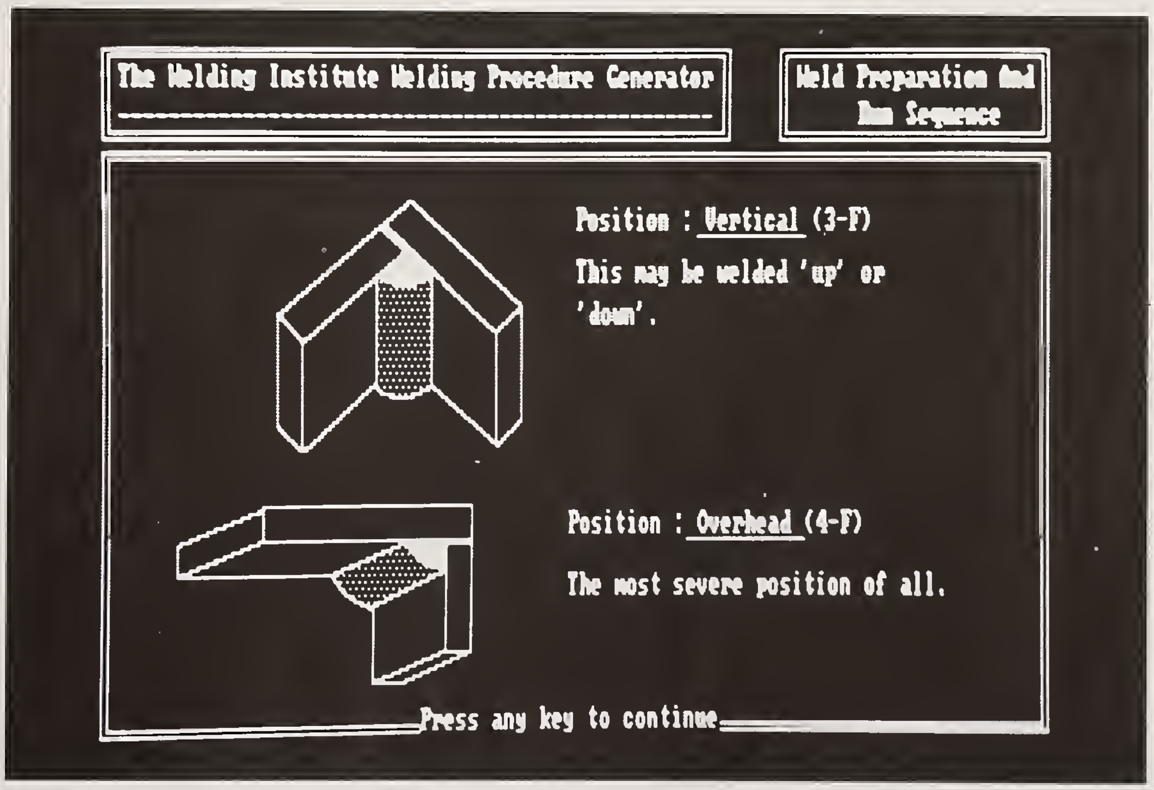


Figure 10. Graphics "help" from the welding procedure generator.

The expert system is capable of generating aluminum GMA welding procedures. The task of generating a welding procedure may be divided into five sections, each of which may be subdivided into the individual items that constitute a welding procedure specification (Figure 9). The user of the system may either progress completely through a consultation or simply use a single section of the program if, for example, information is required only on which consumable to use for a particular combination of parent metals and service conditions. The system may, therefore, be thought of as being knowledgeable in the domain of GMA welding of aluminum rather than simply as a welding procedure generator.

As the program progresses through a consultation, evaluating each item of a welding procedure in turn, it requests information from both the user and external data files. The results of major decisions are displayed on the screen at the end of each section of the consultation, giving the user the opportunity to disagree with, and if necessary, override the program's recommendations. The user is also presented, where necessary, with screens giving a graphical representation of certain pieces of advice, such as the details of recommended edge preparations or different welding positions (Figure 10).

At any point in a consultation, although usually after all five sections have been evaluated, the user may request a hard copy of the advice given.

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Computer Applications in Welding

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Introduction

This paper describes some of the areas in which the Central Electricity Generating Board (CEGB) has been using computers to handle welding information.

Welding Procedure Storage and Retrieval

MELSPEC is a welding procedure specification (WPS) and procedure qualification record (PQR) database program that has a number of characteristics in common with other systems and also some features that are special to the CEGB. The system is a compiled DBASE III program operating on three system databases, two of which store welding procedures and one that holds the PQR information. The program also supports a variable number of personal databases, which are the destination for edited WPSs.

The particular database structure of MELSPEC illustrates one of the issues that must be addressed when setting up a company system, namely the need for the program to reflect the company's in-house logic for handling WPS and PQR information. In this context, commercial software is limited in value unless it is tailored to meet these specific requirements.

Thus, the CEGB maintains, in effect, two corporate WPS databases, the larger containing essential welding variables for a very wide range of materials and weld types, and the smaller, the fully worked-up procedures. The PQR database contains the standard weld approval information needed by the welding engineer to check and avoid disqualification of a WPS that is in the process of being edited for a particular application. This ability to edit corporate WPSs to meet local, plant-specific needs and to maintain an archive of these procedures for future reference is an important requirement of the system that is met by the multiple personal database facility.

Although the type of information given on a WPS is common to most users, the style or layout of a WPS is often very specific to a given company. Welding engineers are very reluctant to make changes to suit the computer; rather, they expect the machine to mimic the familiar house style. With a programmable language such as DBASE, this requirement is not too difficult to meet. MELSPEC presents its WPS information in a screen layout that emulates the CEGB style but stores the data as a conventional database.

Welding procedures are printed out as required onto a pro forma with blank spaces to be filled in. Pro formas are used because the printing quality of standard, inexpensive, dot-matrix printers, although improving, is still much poorer than that of typewriters or typesetting machines.

Because most WPSs are drawn up to meet standard situations, weld preparation and heat-treatment diagrams are predrawn. However, the program has a graphics interface, which enables user-defined drawings to be incorporated. We hope to exploit this aspect in the future in the area of specialist plant-repair procedures.

Weld Modelling

METWELD is a weld modelling program for thick-section manual metal arc (MMA) welds. The program was originally written in Hewlett Packard Basic and then nearly completely rewritten in Pascal. It provides the welding engineer with a rapid evaluation of the microstructure and cost implications of a range of MMA welding options.

Features of the program include variable weld preparation geometry and a built-in materials database. The program output is in the form of a graphics display of the modeled weld cross section that shows the position of the weld-bead layers together with their associated heat-affected-zone (HAZ) isotherms at the sidewall. The isotherms computed are the Ac1, Ac3, fusion line, and a critical-grain-size isotherm. Separate capping electrodes may be specified so as to control the HAZ at the outer surface of the weld. The program also gives a summary of costs associated with making the weld.

Several databases are used by the model. For the base materials, these include data on grain-growth characteristics and transformation temperatures, which have been determined by using weld simulation techniques.

Extensive bead-on-plate trials have been carried out in the laboratory to generate bead-shape data for a number of commercial electrodes. Bead height, penetration, and width were measured as a function of welding position and weld preparation angle and related to welding conditions.

Expert Systems

While their potential in the long term is considerable, expert systems have yet to make any serious impact in the welding area.

The CEGB, in common with others, has been going through the “learning curve” in the expert systems field. It is currently working with the University of Southampton to develop a welding process selector for the welding of thin-section austenitic tubes.

From this exercise, the CEGB has learned the importance of the user interface and that the system should be essentially advisory. Users felt restricted by the way the first version’s program was structured to lead inexorably towards a single conclusion. The revised program presents the user a list of options with ratings alongside that change during the session, depending on how the questions are answered. The questions remain on the screen throughout the consultation, and a HELP facility is provided to explain any questions that are not clear to the user. Changing the program to be advisory rather than assertive has produced significant improvement in user acceptance.

An earlier expert system model was built to generate welding procedures from the comprehensive knowledge base available on the welding of high-temperature materials and the AI language SAVOIR. This turned out to be a valuable development exercise, but its usefulness was limited by the fact that such procedures were already available! The lesson here was that the requirement must be clearly identified at the outset and then applied to the appropriate solution. In this case, welding engineers needed a welding procedures database rather than an expert system.

The CEGB is currently interested in the development of real-time control systems for welding processes. The role of the expert in this context is to be in charge of a conventional control system that would intelligently interpret the performance of a process and adjust or control the process parameters accordingly. This in-process control function is normally carried out by a human operator, who assimilates information on the progress of the weld by using his sight, hearing, and knowledge derived from training and experience. The expert system should simulate this operator's judgment.

Process Control

Computers are used to control the welding process by processing sensory data from a weld and detecting and controlling the onset of penetration. This requires real-time processing of data in a closed-loop configuration where the computer is in charge of, say, the welding power supply. Systems have been built that view either the weld back face or front face. In the former case, penetration can be sensed directly, whereas in the later, it must be inferred.

A recent novel development has been to observe and analyze the spectrum of weld-pool vibrations that either have been deliberately induced or occur naturally when the current is pulsed. This information is used to predict the onset of penetration and to control arc power in response to changes in the pattern of heat flow away from the weld. These changes in heat-flow patterns may arise, for example from changes in section thickness. The system has been named MELODY–MEL oscillation dynamics for control of penetration in welding.

Registration of Welding Personnel

Rapid developments have been taking place in the United Kingdom regarding the establishment of database registers for welding personnel. Three registers are being established under the auspices of the Professional Board of The Welding Institute to cover welding engineers, welders, and supervisors. The Welding Engineer Register was successfully launched in January 1987. The Welder Register will be introduced in November 1988. The Supervisor Register will follow as the role of this newer category of personnel becomes more clearly defined.

These changes are timely; the pressures on industry to provide adequate quality assurance systems to control the manufacturing process are increasing. The CEGB sees considerable scope for these registers and anticipates that they will provide a ready framework for assessing the competence of welding personnel by second- and third-party organizations undertaking approval of manufacturers and contractors to British Standard 5750.

The Welder Register will particularly benefit the power industry; their welder population is mostly migratory and there are difficulties in verifying the approval status of potential welders.

CONFERENCE PAPERS – Welding Case Studies

Update on Procedure Qualification Records and Welding Procedure Specifications

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Among the top welding data needs that were identified in the Computerization of Welding Information Workshop were procedure qualification records (PQRs) and welding procedure specifications (WPSs). These needs were recognized long before the workshop gave them priority, but I will briefly report only the recent events and my outlook on the future.

The Welding Research Council (WRC) has been deeply involved in a very extensive program to provide hundreds of PQRs to support the development of standard WPSs. Since the focus is on computers, I will neglect the aspects of welding, but I want to report the status of the procedures.

The first ten WPSs have been balloted through the WRC Welding Procedures Committee and two technical levels of the American Welding Society (WPS). The various committees have also reviewed the data format and have agreed with the current version. I do not have an example because it is still in the balloting process and has not been released for public comment yet. The final ballot is expected to be completed by the end of the year.

The voluntary consensus process that we follow is very important to the welding community that we serve. It has been described as both a curse and a cure. The curse is that it takes a long time to resolve all points of view. The cure is that the final result is virtually a liability-free product. I expect to have this first group of WPSs published before the next AWS Welding Show.

What do I think will occur in the future? Many more standard WPSs are required to satisfy the needs of the industry. As soon as the first WPSs are published, there will be a clamor for the committees to produce more. It will require a substantial increase in effort to produce the additional procedures, and additional funding will be required to support the effort. Both WRC and AWS will be working on this issue. By the time the third conference is held, I hope to report that significant progress has been made.

Computers in Welding—from Breadboards to Desktops

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Introduction

Maintaining welding procedure and operator qualification records, listing welders who have worked on specific jobs, and calculating design and shop-layout information are ways in which pressure-vessel and heavy-plate fabricators have used computers for nearly four decades. In more recent years, typical applications include computer stress analysis, computer-aided drafting, and programming numerical controlled machines with PCs. There are many in-house programs to do welding-related tasks, but these generally are well-kept secrets. Some new programs have been written specifically for the welding industry; some are available now; others will be available soon.

History of Computers

Imagine a room with metal shelf racks arranged wall-to-wall in rows with little space between them, the shelves solid with vacuum tubes, and bird nests of wiring plugged into pull-out drawers. These drawers were aptly called *breadboards,* and the metal racks, the *mainframe.* In a room adjacent to the mainframe, a control panel covered most of the wall, polka-dotted with panel lights busily winking on and off in green and red. This describes the IBM 650, a computer that was up and running in 1951. This computer used the familiar do-not-fold-or-spindle punch cards that required keypunch and card-reader hardware. The 650 had a 2,000-word capacity, used a language called *SOAT*, and had math functions comparable to a modern $5 hand-held calculator. The hand-held alphanumeric computers with an attached tape printer and 2 kilobytes of memory of ten years ago had a capability similar to that of the 650.

In 1951, a large pressure vessel and heat exchanger manufacturer, with plants in Canada, New York, Pennsylvania, and Texas, kept records on roughly 800 welders involved in code fabrication. In addition to the welding procedure and operator qualification records required by the ASME Boiler and Pressure Vessel Code; the Navy, Air Force, and the Army each required operator tests, not necessarily accepting those of ASME. Likewise, many of the major oil and chemical companies required operator qualification tests witnessed by their own inspectors. The qualifications expired and required retesting at different intervals. To maintain these records and retest dates manually, two full-time clerks and a typist were needed.

When we stored the records on keypunch cards, we were able to provide each plant with a list of their approved qualified welders and expiration dates, plus printouts of the dates and hours these welders had worked on any job. This virtually eliminated the problems of welders working on jobs for which they did not have qualification approval. One part-time keypunch operator maintained the system.

Almost forty years later, many companies maintain similar records , but they are generated with word processors using in-house-developed programs or spreadsheet-type programs.

Twenty years ago, time sharing came into use. Keyboard work stations, called "dumb" terminals, with black-and-white video displays were attached to the company's mainframe or to a larger computer somewhere else, even in another city. FORTRAN was the favored language. As a user, one encountered frustrating delays when the terminal simply went dead because the mainframe was ignoring the task. Although tedious to format, its capabilities for mathematical computations, interactions, and printing pages of tabular data were much more valuable than the one-number output of the then-$100 hand-held calculators.

We used the time-share system to write some powerful programs, some of which are in use today by the companies for which they were developed. One of these programs asked a few simple questions about the dimensions of a spherical tank. From this, the computer would produce a detailed plate layout, required ingot size, the stock-plate dimensions, the blank-cut dimensions, the finished-plate contoured dimensions, and *x–y* coordinates for flat layout of cut-to-size plates before forming. The computer also calculated the price per pound and printed bills of material for the entire tank. This took twenty minutes.

At the same time, twenty years ago, engineers frustrated with the slowness of the time shares started building their own computers. Some built them in their garage at their own expense; others built them at the office at company expense. We used one that had a nest of PC boards, desktop size. It handled the complicated engineering programs we had written as well as the big mainframe computer. These computers were improved, made smaller, and became the personal computer.

The success of some of these engineers, as well as the established companies, in marketing their creations led to a proliferation of personal computers. The user was confronted with noncompatible operating systems (such as CPM and DOS), with the possibility of the computer manufacturer going out of business, and with worries about software availability.

To compound these problems, professional programmers, who had never done anything but accounting, started to write software, and thus the "post-office-box" age of computing began. A small fortune would buy a floppy disk, a shelf full of books, and a second shelf full of third-party books to make sense out of the first set. With all this, you could now stuff a number in a mailbox, multiply it by a number from another mailbox, and stuff the result in a third mailbox. You could also print the results in huge tables and even exchange column locations. Some of these programs require patience and time to learn to use, and any numerical errors can lead to costly errors in the output data. Programs written by programmers may not fit engineering needs, and often the engineers have neither sufficient programming skills nor the time to write useful programs for themselves. ASM is attempting to solve this dilemma with some tutoring disks on programming that are available now.

Meanwhile, the machine-tool industry developed a host of numerical-controlled shears, press brakes, die-punch machines, profile cutters, milling machines, and more, that are in use today. The programming method for these varies from shop-floor punch-in to computer-controlled input from a time-shared computer in another city. An automatic culvert-making machine produces any diameter or length of corrugated culvert; the entire plant is controlled with a 64-kilobyte home computer with data loaded from a tape cassette. In Trieste, Italy, there is a computer drafting room with 20 D-sized plotters that completely design a ship, down to individual bracket drawings. Japan has out-of-chamber electron-beam welding of two-inch-thick stainless steel pipe, with the parameters controlled by microprocessor. The latter two were observed in the mid-1970s.

Also available in the early 1970s were several mechanized welding travel carriages with wire-feed units and rack-positioned torches. Within a short time, powered weaving and torch-height positioning were added. Next came some very sophisticated systems with all of the above plus one to three torches and push-button control of travel and wire-feed speeds, first with analog and then digital readout. The wire-feed manufacturers picked up on this and started adding wire-speed readout to the wire feeders, even though most welders had no idea how to use it. Operator ignorance led to the abandonment of the exotic travel systems or, at least, their advertisement. This is sad, because the production can be increased as much as 1000% by the use of multiple torches—one operator running ten GMAW or SAW heads at once.

Trade journals, sincerely wanting to be at the cutting edge of technology, are filled with articles about robotics, flexible manufacturing systems, video comparators, and machine-vision quality control. ASME, with CIME magazine, presents high-level articles on the many developments in this field. The users of this technology seem to be aircraft manufacturers, the automotive industry, and other high-volume industries.

Many shop production managers in smaller industries, unable to justify a million-dollar integrated work station in typical one-of-a-kind situations, could only hope to improve their production with some simple torch-holding or moving devices. Many of these devices could produce at a unit rate close to those of a robot and at a far lower unit cost because of reduced labor.

For the engineering group, an almost overwhelming collection of software was available, mostly post-office-box style, but there were some programs related to simple design. The first huge finite-element programs could be rented, then purchased, and now bought at reasonable prices. The finite-element programs are still expensive to implement because of the long learning time and the time required to enter the node coordinates. Computer-aided-design (CAD) programs for drafting were at first prohibitive, but now they are common. The trend toward these systems is so strong, that high schools should be teaching computer drafting. The trade magazines give much space to three-dimensional drafting, stress analyses by color shadings, and more, but users seem to be the automotive and aircraft industries plus the academic community.

The development of the supercomputer, such as the Cray, and the developmental work in parallel processing systems should be mentioned, because, they may affect the competitiveness of U.S. industry. Look for time-shared use of these supercomputers to be available.

Current Systems, Software, and Trends

The combined efforts of the Japanese electronic industry to develop a standardized operating system for all their computers could cause U.S. systems to become obsolete, unless similar U.S. efforts are initiated to develop a better system. For the moment, the emphasis seems to be on 386 chips. The development of PCs that can use three operating systems (DOS, OS/2, and Xenix) is encouraging. There are also third-party boards that enable both DOS and Macintosh to be used in a DOS-type computer.

There is a trend toward better software manuals, tutoring discs, or even better, software requiring neither manuals nor tutoring. Shop programs should allow the user to select their program with one key and enter their data directly or by a selection of multiple choices. The output should appear on a monitor and a hard copy.

Programs useful to the welding industry would

- estimate welding time and filler-metal requirements
- calculate a bill of materials for a welding job or quote
- control qualification tests, both procedure and operator
- match existing qualification procedures against ASME Section IX or AWS D1.1 requirements
- control production schedules, equipment loading, and manpower
- write ASME or AWS procedures

A program for estimating arc time and filler requirements for any arc process in any joint design, WELDBEST, is now commercially available. It will also write AWS procedures. A program, Primavera, will handle virtually all the requirements for scheduling, but it requires tutoring and an intensive learning period. Programs for matching existing procedures to ASME and AWS requirements are being developed. Computer design programs can prepare bills of material for quotation or production.

Parameters for Wire-Feed Processes

For shops that have mechanized welding equipment or arc-welding robots, some of the setup weld testing can be eliminated by calculating the starting conditions for any welding process that uses a wire feeder. In fact, a PC containing this system can be used to control real-time welding, provided accurate measurements are made of wire speed, deposited metal weight and volume, and travel speed. Real-time control is also affected by the type of power supply, control of wire contact-tip-to-work distance, effectiveness of proximity controls, and parameter-control circuitry.

The basic conditions for a wire-feed welding process are

1. A given volume of wire feeding into an arc at a constant speed will deposit essentially the same volume of weld metal in a given time.

2. The volume of the weld deposit changes directly with wire-feed-speed and inversely with travel-speed changes.

3. The volume of weld metal going through the arc is equal to the cross-sectional area of the wire times the length of wire passed through in a given time:

$$v = 3.1416d^2l/4 \qquad (1)$$

where v = volume, d = diameter, and l = length of wire going through the arc

It is easier to work with cross-sectional area than with volume:

$$a = wck/t \qquad (2)$$

where a = cross-sectional area of deposited bead

c = cross-sectional area of wire

k = a constant: 1.0 for bare wire; 1.0 for FCAW or SAW with iron-powder additions

t = travel speed of torch

w = wire-feed speed

To find the weld-travel speed required to produce a bead of a desired cross-sectional area at a known wire-feed speed, the relationship is

$$t = wck/a \qquad (3)$$

For proper wire-feed speed to give a bead of desired area where travel speed is known (as in a two-torch setup on a single-travel carriage), the equation is

$$w = ta/(ck) \qquad (4)$$

Most available welding-deposition-rate data relate pounds deposited per hour to amperes. The relationship between wire-feed speed and amperes for a particular process is not readily available, except for aluminum. A family of curves will result, for example, for the GMAW process, and the deposit rate varies with shielding gas and contact-tip-to-work distance. Deposition rates of the SAW process are also sensitive to contact-tip-to-work distance.

When the equations are applied to actual welding situations, they are very accurate when constant-current power supplies and constant-speed feeders are used and only "ball park" accurate with constant-voltage power supplies, depending on slope characteristics. The amount of metal deposited seems to be consistently greater than the amount calculated; no one has an explanation.

Welding operators use these equations, and they are useful in training operators of machine-welding setups, especially those with multiple torches.

Summary

The welding industry has used computers for welding-related tasks for nearly four decades, but the programs have been proprietary. Commercial PC programs are helpful, but they may require a significant learning period to apply them to welding fabrication.

Welding parameters for mechanized welding setups can be calculated, provided the wire-feed speeds versus deposition rates are known.

Specific welding programs are now commercially available for PCs.

WELD IMPROVEMENT PROGRAM: WELD AND WELDER TRACKING SYSTEM

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Introduction

A significant portion of the O&M and capital projects of the Potomac Electric Power Company (PEPCO) involve welding. Welding is performed on a large number of critical components in PEPCO's generation system. Failure of those components almost certainly results in loss of generation revenue, and in some cases, could result in injury to PEPCO personnel. Many failures can be directly related to the quality of welding during repairs and installation of these components. Consequently, welding quality is of prime importance to the Generation Group. In a constant effort to improve weld quality, PEPCO has established a Weld Improvement Program. One of the main components of the program is a Welder Tracking System, a reliable record of welders' performance and qualifications.

The American Welding Institute (AWI) was chosen by Edison Electric Institute (EEI) to study the feasibility of using a computerized database system for tracking welder qualification history and to suggest a "generic" system to be used by all EEI members.

AWI created a prototype system based on data from the normal operation of a power plant. PEPCO was chosen to supply the data. The success of the prototype established the feasibility of the database system.

Objectives

The program to implement a computerized system for welder tracking incorporates the overall objective of the EEI–AWI feasibility study: to develop management tools to improve the quality of welding in the construction, repair, and maintenance of electric generating system components. Two specific objectives were also established: (1) to improve the welding quality of PEPCO contractors so that PEPCO derives the maximum quality consistent with schedule and budget constraints and (2) to increase the productivity and effectiveness of project management and inspection personnel.

The EEI/AWI study concluded that the implementation of a computerized welder tracking system could greatly improve the quality of welding when applied appropriately using good management principles. The two specific objectives of PEPCO were attainable through the achievement of more specific goals.

Goals

The success of the computerized welding tracking system depended on designing a system that was simple, flexible, economical, integrable, historical, capable of providing information about contractors, and capable of process control.

1. The system must be simple for the user to apply to the problems encountered in welding project management, from data entry through the use of color-coded, interactive data entry and update screens. A menu-driven program that both data-entry and project-management personnel could use easily was also required.
2. The system must be easily altered, especially the area that generates reports. Although considerable effort is expended in developing a system that meets all the needs of the Generating Construction, Production, and Quality and Reliability Departments, it is impossible to foresee all potential applications.
3. The system must be relatively inexpensive to produce (not requiring restructuring of the existing management systems)
4. The system should be easy to integrate into the existing project management system. The existing data forms used by PEPCO (e.g., weld maps, traveler sheets, radiographic reader sheets) should provide all the required data and in a format compatible with the data input system.
5. The system must be capable of maintaining records of both welds and welders. The specific details of weld manufacturing are useful in many applications. For example, if a weld failed, the historical details of this type of weld could be examined. By identifying welds with a similar history, remedial action for this type of weld could be determined. On welders, the system must provide welder history and qualification information.
6. The system should be capable of providing information about contractors, including the quality of the welders used by a contractor and the overall weld quality achieved by a specific contractor.
7. The system should be able to provide an assessment of visual and radiographic inspections as work progresses.

Implementation

The *Weldertrack* software system was tested as a pilot project during two scheduled PEPCO outages at fossil-fuel generating stations. The first was at the Chalk Point station in the fall of 1986, and the second, at the Potomac River Station in the spring of 1987. Each case was an opportunity for a fairly extensive test of the system and for making modifications specific to PEPCO's requirements. The applications tested were boiler-tube butt welds subjected to PEPCO's process-control-sample radiographic examination and to visual inspection.

Installation

The *Weldertrack* software system was installed on an IBM-XT personal computer. Information loading was accomplished in essentially two phases: prior to the onset of production welding and during tube butt-welding operations. Specific information—the project name, start date, anticipated completion date, contractor's name, and applicable inspection criteria for radiography—was loaded first. As the contractor supplied the required project documents, other relevant information—personal and performance-qualification test data of welders and the approved welding procedure specifications of the contractor—were loaded into the system.

Once production welding had begun, weld data were loaded daily. This information consisted of a list of weld joints completed, identification of the welder(s) responsible for the joint, results of visual inspections, and results of radiographic examinations of both original and repaired welds. All information loaded into the *Weldertrack* system came directly from existing inspection data sheets, welder performance qualification test records, and welding procedure specifications, thus meeting the goal of easy integration with existing programs.

Following the input of all available data, reports were generated for project tracking and management.

Input Screens

The inherent flexibility of the *Weldertrack* system enabled a variety of data input screens to be developed. To simplify data entry, the input screens were designed to match existing paper records used by PEPCO. Since the system is menu driven, many input screens are generated in a step-by-step sequence, depending on the data file being developed or updated. For practicality, only five of these screens are included in this discussion.

The main menu screen enables the operator to access files to enter or update file data, view existing file data, generate reports, delete records, or copy file data to back-up disks (see Figure 1). Selection 1 of the main menu would call up the data entry screens, one of which is shown in Figure 2. Further selection would depend upon the information to be entered. For instance, welder performance qualification information would be input by using the screen shown in Figure 3; tube butt-weld data, by using the screen shown in Figure 4; and test and inspection data for completed welds, by using the screen shown in Figure 5.

Main Menu

Please choose a subject:

1 — Data Entry/Update
2 — View Data
3 — Query/Report
4 — Record Deletion (Password Access)
5 — Backup
0 — Exit to DOS Command Level

Enter your selection (1 2 3 4 5 0)

Figure 1. Main Menu screen.

EEIDB – DB Access (Maintenance)

Please select a process:

1 — ENTER New Welders
2 — ENTER Projects/Qualified Welds for a Welder
3 — UPDATE Qualified Welds for a Welder
4 — UPDATE Welder's Personal Information
5 — ENTER Weld Data for Projects
6 — UPDATE Project Information
7 — UPDATE Weld Data for a Project
8 — ENTER WPS Information
9 — UPDATE WPS Information
0 — GO BACK TO MAIN MENU

Enter your selection (1 2 3 4 5 6 7 8 9 0)

Figure 2. A data entry screen.

QUALIFICATION INFORMATION: FOR SSN;

PROJECT ID:
PROCEDURE #:

QUAL ID:
QUALIFYING DATE (CONT.): Q/R APPROVAL DATE:
Symbol:
Process 1: Process 2:
THICKNESS PROCESS 1: TO
THICKNESS PROCESS 2: TO
Position: Direction:
———Screen 1 of 2; press F8 for next screen———

Figure 3. Screen for entering welder performance qualification data.

EEI WELDERTRACK SYSTEM (F3 TO EXIT)

WELD INFORMATION:

Station: System ID:
Elevation:
Tube:
Assembly:
Repair #:
Year:
Procedure Specification:
Procedure #2:
Root Welder 1: Root Welder 2:
Root Welder 1: Root Welder 2:
(PRESS F8 FOR NEXT SCREEN)

Figure 4. Screen for entering tube butt-weld data.

TEST INFORMATION:

Visual Test Result:	(PASS, FAIL)
Identifier:	(PASS = 1, FAIL = 0)
Test Date:	
Comments:	
Radiographic Test Result:	(PASS, FAIL, NORT)
Identifying:	(PASS = 1, FAIL = 0, NORT = 0)
Test Date:	
Failure Reasons: 1:	
2:	
3:	
Comments:	
Hydro:	(FAIL or blank)

———F7 TO SEE LAST SCREEN, ENTER TO UPDATE———

Figure 5. Screen for entering test and inspection data for completed welds.

Reporting

Several standard reports were built into the system. They were designed to match reports already produced by site project management and quality control personnel. Other reports were designed on the basis of system capabilities; previously, they would have been impractical to produce. Only three of the more widely used and distributed documents are discussed here. These reports were generated daily during the course of the project.

The report shown in Figure 6 focuses on weld quality, providing information on welds previously rejected and subjected to repair. A similar report was generated for all production welds deposited. The report identifies the weld, repair cycle, and date repaired; welders responsible for root and fill passes; and finally, inspection results. These data become a part of the weld history maintained in the reliability database.

REPAIR DATA FOR PROJECT E8303

SYS	ELEV	TUBE	REP#	VIS DATE	RT	RT DATE	R1	R2	F1	F2
WF	80	371	1	10/30/86	NORT		5608	4764	5608	4764
WF	80	375	1	11/10/86	NORT		3013	3013	3013	3013
WF	80	397	1	11/21/86	NORT		8605			
WF	82	371	1	10/30/86	NORT		5608	4764	5608	4764
WN	38	238	1	11/24/86	FAIL	11/26/86			1372	
WN	51	177	1	11/03/86	NORT		8638	3574	8638	3574
WN	52	177	1	11/03/86	NORT		8638	3574	8638	3574
WN	55	128	1	11/29/86	NORT		5819	3595	5819	3595
WN	55	134	1	11/24/86	PASS	11/28/86			9947	
WN	55	135	1	11/30/86	NORT		5608	4764	5608	4764
WN	55	139	1	11/24/86	FAIL	11/26/86			9947	
WN	55	176	1	11/21/86	PASS	11/25/86	7571	5822	7571	5822
WN	55	227	1	11/15/86	NORT		3013	8020	3013	8020
WN	55	227	2	11/19/86	NORT		7571	5822	7571	5822
2N	55	229	1	11/15/86	FAIL	11/18/86			3013	3013
WN	55	229	2	11/19/86	FAIL	11/22/86			7571	
WN	55	229	3	11/25/86	PASS	11/28/86	9947	5817	9947	5817
WN	55	230	1	11/15/86	FAIL	11/18/86			3013	8020
WN	55	230	2	11/19/86	PASS	11/22/86			7571	
WN	55	231	1	11/15/86	FAIL	11/18/86			8020	8020
WN	55	231	2	11/19/86	FAIL	11/22/86			7571	
WN	55	231	3	11/25/86	PASS	11/28/86	9947	5817	9947	5817

Figure 6. Report on weld quality.

Individual welder performance is tracked throughout the course of the project with the report shown in Figure 7. This information enables project management to identify welders responsible for depositing rejectable welds and to initiate appropriate corrective action.

Overall project weld quality is tracked by means of the report shown in Figure 8. As with the individual welder report, the effectiveness of contractor corrective action becomes readily apparent, particularly when the information is plotted.

REJECT RATES TO DATE FOR ALL WELDERS ON 11/26/86

EMPID	VIS DATE	JOB#	WELDS MADE	WELDS RADIOGRAPHED	WELDS REJECTED	REJ. RATE
5617	11/20/86	E8456	8	7	3	42.86
	11/18/86	E8456	5	0	0	.00
	11/17/86	E8456	2	2	2	100.00
	11/15/86	E8456	20	2	0	.00
	11/14/86	E8456	35	3	1	33.33
	11/13/86	E8456	17	6	0	.00
	11/12/86	E8456	7	4	1	25.00
	11/11/86	E8456	3	3	1	33.33
	11/10/86	E8456	14	2	0	.00
	11/08/86	E8456	12	2	0	.00
	11/07/86	E8456	15	5	0	.00
	11/06/86	E8456	7	5	0	.00
	11/05/86	E8456	11	0	0	.00
	11/04/86	E8456	18	7	1	14.29
	11/03/86	E8456	21	5	3	60.00
	11/01/86	E8456	21	5	0	.00
	11/31/86	E8456	5	2	0	.00
*TOTAL EMPID 5617			225	60	12	20.00

Figure 7. Report on a welder's performance

GENERATION GROUP

QUALITY & RELIABILITY DEPT

DAILY WELD REPORT

01/23/87

DISTRIBUTION

Q/R MQCI
Q/R MQCE
Q/R GEN ASSIST.

FOR PRODUCTION RESP.
MGR. PROD. MAINT.
FOR ENG. CONST. RESP.
MGR. CONST.

CHALK POINT UNIT 2 WATERWALL REPLACEMENT

J.A. JONES / UNIVERSAL TESTING

VIS DATE	JOB#	WELDS MADE	WELDS RADIOGRAPHED	WELDS REJECTED	REJ .RATE
11/18/86	E8303	37	13	1	7.69
11/17/86	E8303	54	18	1	5.56
11/15/87	E8303	137	23	5	21.74
11/14/86	E8303	40	21	0	0.00
11/13/86	E8303	46	25	8	32.00
11/12/86	E8303	94	36	2	5.56
11/11/86	E8303	62	22	3	13.64
11/10/86	E8303	78	34	8	23.53
11/08/86	E8303	69	24	1	4.17
11/07/86	E8303	66	35	7	20.00
11/06/86	E8303	72	31	2	6.45
11/05/86	E8303	57	34	3	8.82
11/04/86	E8303	28	23	5	21.74
11/03/86	E8303	49	20	9	45.00
11/01/86	E8303	62	23	1	5.00
10/31/86	E8303	62	21	3	14.29
10/29/86	E8303	47	23	7	30.43
10/28/86	E8303	67	22	8	36.36
10/27/86	E8303	52	23	10	43.48
10/25/86	E8303	30	6	3	50.00
10/24/86	E8303	50	38	8	21.05
TOTAL		1354	549	101	18.40

Figure 8. Report on overall project weld quality.

Another advantage of *Weldertrack* was discovered during the pilot project implementation: the interactive query system provided project management personnel with the capability of generating new reports, as needed, for requirements that had not been anticipated before the project was begun. The new reports might be in response to

- Weld rejections that exhibit a certain characteristic (e.g., porosity)
- Welds at a particular elevation or section of the boiler
- Welds done on a certain day
- Welds by a particular welder

Evaluation

Examples of Improved Reject Rate

Chalk Point Unit 2 Outage

The tests of the welder tracking system during the Chalk Point Unit 2 outage were extremely successful. The reject rate for this project was 18%, which is the lowest rate ever achieved on the 7/8-inch tubes during a major outage. The success cannot be entirely attributed to the computer program, but the program did play a very important part in evaluating welder performance. The end result is that it gave the contractor and PEPCO the ability to know, with complete certainty, which welders were making quality welds and which were not.

Of course, like any prototype system, this one was not without problems. The most significant problem was computer response time, which prevented the user from utilizing data in a timely manner. Since the Unit 2 outage, this problem has been resolved: response times have been reduced from 50 seconds to less than 10 seconds. Other revisions have also been completed and tested.

Potomac River Unit 3 Reheater and Chalk Point Unit 3 LT Superheater

The system was tested at two additional outages: the Potomac River Unit 3 reheater replacement and the Chalk Point Unit 3 low-temperature superheater surface reduction. These two tests were also very successful, and the revisions made the system quite usable for PEPCO.

Project Management Time Saving

During the two additional tests (above), the turnaround time for weld data was estimated to be as short as one and a half hours a day. Take, for example, the 1,952 welds of the superheater project:

130 welds/day; 20 radiographs/day

10:00 a.m.	receive weld data and review for correctness
10:20 a.m.	load weld data
11:00 a.m.	load RT data
11:20 a.m.	run applicable reports
11:30 a.m.	distribute copies of reports

At the Chalk Point Unit 4 low-temperature superheater surface reduction, similar reports were developed manually. It took approximately 3 to 4 hours on each of two shifts to process the weld data into a format that could by analyzed by both PEPCO and the contractor.

Conclusions

The *Weldertrack* system was developed and implemented by AWI with the assistance of PEPCO personnel. In-house pilot projects used the computerized welder tracking system for two outages. The usability and capability of the PEPCO system was very successful. The project management capabilities of the system were considerably more extensive than existing manual methods, and it saved substantial management time. Some of the other benefits with regard to system uses that were demonstrated during the pilot project testing are:

Short-term Uses

1. Process control
    a. overall project performance on a daily basis
    b. welder performance on a daily basis
    c. project status
2. Maintenance of welder qualification records
3. Weld selection for radiography
4. Concise data printouts regarding repairs
5. Weld history

Long-term Uses

1. Reliability database for welded joints
2. Assessment of contractor performance
3. Assessment of individual welder performance
4. Tracking of welder qualification records
5. Budget forecasting
6. Tracking of tube failures (not only those due to weld failures)
7. Library for weld procedures

Expert Systems for Diagnosing Problems in Welding Power Sources

T. Flynn

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Introduction

The introduction of high-frequency solid-state power sources has created a need for new service and manufacturing strategies in the welding industry. Although these power sources offer many advantages as welding tools, a different approach is required to service the equipment. Computer software in the form of expert systems offers such an approach. Miller Electric Manufacturing Company is currently involved in developing systems for diagnosing problems in inverter welding power sources. These expert systems are used in the manufacture and service of inverters at Miller; they are also available to customers for field service.

New Technology in Welding Power Sources

Over the past several years, the design of welding power sources has changed dramatically. Traditional power sources were designed from a mechanical standpoint and used relatively simple electrical components. New designs, such as resonant inverters, are based almost totally on microelectronics.

These power sources provide better control of arc starting and weld parameters, and their electrical efficiency is higher. By converting the line voltage from 60 Hz to a much higher frequency, they eliminate the need for large main transformers. Thus, the new power sources are smaller and lighter.

Although there are many advantages to be gained by using these welding power sources, servicing them is often a problem for the following reasons:

1. Many service people are unfamiliar with the principles on which these power sources operate. They find it difficult to determine an effective troubleshooting procedure.
2. The electrical components and proper testing procedures may be unfamiliar.
3. It is difficult to disassemble these power sources and locate a specific part for testing or replacement.
4. Large capacitors will hold high voltages for a short period of time after the unit is shut down, which can be dangerous for service personnel.
5. Additional time is required to train personnel in the repair of this equipment.

DIAGNOSTIC EXPERT SYSTEMS

The MILLER EXPERT PROGRAM™ was developed to increase serviceability of the new welding power supplies by providing step-by-step troubleshooting procedures to diagnose problems. The program is an expert system computer software package that runs on IBM or IBM compatible personal computers.

An expert program consists of two parts: the domain and the inference engine. The domain is the knowledge necessary to make a decision about a specific problem. In this case, the domain includes the test conditions and the corresponding solutions for a particular failure in the power source. The inference engine is the decision-making process provided by the expert system shell. The program is based on the Texas Instrument Personal Consultant™ plus an expert system shell.

The domain information is obtained from the design engineer, electronic technicians, and service personnel. This information is formatted into a flow chart from which IF/THEN statements are written.

These IF/THEN statements are used to write the "rules" that are entered into an expert system software shell. Each IF statement represents a series of troubleshooting test points, and each THEN statement represents a solution. For example, assume a welding power source provides only a limited output. The troubleshooting procedure suggests checking the condition of a contactor. For this situation, the following "rule" would appear:

IF: OUTPUT = LIMITED AND CONTACTOR = BAD

THEN: REPLACE CONTACTOR

where OUTPUT and CONTACTOR represent value holders called "parameters." Each parameter represents a DVM reading, visual inspection, or oscilloscope trace. Warning information is included if the test is dangerous. Precautionary information is added if damage to the unit could occur as a result of improper testing. In the example given, the user would be prompted to enter the condition of the contactor. If the contactor is BAD, this rule would become true or "fire," and a message to replace the contactor would be displayed on the screen. If the contactor is GOOD, the system would move on to another test.

At this point, graphics are added to the system. Graphics are used to highlight important points in the program. Many of the graphics pinpoint areas that are difficult to see. The correct pins to be tested on a control relay would be one example. Graphics may also be used to show correct test results, such as the proper waveforms for oscilloscope tracings or the proper placement of jumper links. For the contactor example, a graphic showing the contactor and the correct position of meter leads could be added. Help text, available on a function key, clarifies the question and gives more detailed information about the test procedure. For the contactor example, a help statement could pinpoint the location of the contactor inside the power source and indicate the meter settings required for the procedure.

After an expert system prototype is developed, in-house testing is started. Initial testing is accomplished by creating problems in the power supply. For example, a good fuse may be replaced with an open fuse, or leads may be disconnected from a printed circuit board. A technician who is unfamiliar with the power source is given the task of finding the problem using the expert system. After any problems discovered in the procedure are corrected, the system is installed in the Service Department, whose personnel use the program to answer customer questions. They suggest changes in the program and are responsible for its final approval. The program is also used in manufacturing areas to determine the cause of problems on the assembly line.

Applications to Traditional Technology

Although the initial reason for developing expert systems at Miller Electric to aid in the manufacture and service of inverter power sources, a market also exists for such systems for traditional industrial welding equipment. Many large end-users and distributors are interested in these systems for the following reasons:

1. Turnover in the service department makes it difficult to keep "experts" on the various equipment used in the plant.
2. The service staff may be responsible for maintenance throughout the plant and, therefore, may deal with welding power sources infrequently. Both new and veteran employees have a low familiarity with the equipment.
3. A long down time for a welding power source represents a loss in production as well as service time.

Requests from such end-users has led to the development of expert systems for Miller's industrial line.

Conclusions

Internal use and market research has shown that expert systems can be useful troubleshooting tools because

1. They are easy to use. Only seven keys (the four arrow keys, F1 and F2 function keys, and the RETURN/ENTER key) are required to run the system, therefore little or no computer training is necessary.
2. They provide a starting point for troubleshooting. The technicians are required to identify only the output problem. The system uses this information to determine a troubleshooting procedure.
3. They provide testing information. The expert system will explain unusual or unfamiliar test procedures to the user.
4. They highlight potential dangers in a troubleshooting procedure. This alerts the service technician so that he or she can take proper precautions.
5. They indicate the location of components. The expert system cuts down on time spent in searching for components by pinpointing their location.

6. They are useful in training new personnel, who need time to learn the product line. Through the use of an expert program, he or she can be more productive during the learning process.

All these factors contribute to a reduction in down time for the welding power source.

Miller Electric plans to continue developing expert system software, with emphasis on maintenance and diagnostic products for industrial and inverter welding sources. Currently, the Deltaweld^{TM} 451 and 651 are supported by MILLER EXPERT PROGRAMS^{TM}. A software package to support the ARC PAK^{TM} 350 is being developed.

WORKSHOP SUMMARY

Introduction

Since the 1986 workshop had been reviewed at the conference, the participants had a good perspective of its role in producing a list of database needs that could guide software developers. The twenty four participants accepted the development of database needs as a primary role for this workshop as well. The workshop consisted of three phases 1) the development of industry categories which represented the attendees interests and which would form the topic for detailed discussions 2) the identification of database needs by each of these groups, and 3) the combination of the needs identified by each group into a list ranked by all the participants. Each of these phases will be discussed separately.

Development of Industry Categories

The workshop participants had completed a survey form which included a question on their interests. The results of their responses to this question (number 9) are included in Appendix C. We offered them a chance to vote for their top three choices. They could select from the top ten industry categories identified at the previous workshop or write in a new category. We combined their votes by scoring three for their first choices, two for their second, and one for their third. Using this technique, we could rank their choices into the order shown in Appendix C. We found three of the top four categories were the same as those identified at the last workshop and which formed the topics for smaller discussion groups at that workshop. The attendees thought we should investigate other ways to find topics for the small discussion groups since this might produce new ideas for discussion.

One attendee suggested that we could divide the groups on the basis of whether they were involved in manufacturing or in repairing of structures. On further discussion, these two topics were further defined to indicate repetitive operations (such as an assembly line in a manufacturing plant) or single operations (such as construction of a large vessel, repair functions, or installation of some unit). Most attendees thought these were suitable topics for smaller discussion groups. Several thought another category "other interests" should be added to represent those who did not fit into either of these categories. In a vote taken to gauge the interest in these three topics, eleven attendees voted for manufacturing, eight for repair and installation, and five voted for the other interests category. This seemed to be an equitable way to divide into groups for more specific discussions. Each group was charged with the task of listing topics for database development and ranking them in the order of their importance.

Listing of Database Topics

Before breaking into the three groups, a short time was spent in developing several topics so all three groups would have some examples and some practice. The combined attendees identified the following topics:

- Universal product code (bar code) - As consumable manufacturers begin to include these codes on their products, the consumers can use the same codes to track their inventory and control the use of various lots and heats of material for specific customers and projects.
- Material safety data sheets (green sheets) - Safety information can be incorporated in a database for easy retrieval.
- Computerized filler metal specifications (eg AWS A5.1).
- Computerized code information (eg ASME Section IX) - Several attendees indicated this had been done for some parts of the code.
- Weld planning - From the material requirements for a job, a program could choose the welders with the appropriate qualifications, the proper procedure, and approximate inspection techniques.
- Data base on possible joint designs.
- Standardized format for PQRs and WPSs.
- WPS selection - A program to help choose appropriate WPSs for a particular application. If none were available, one might be constructed from applicable PQRs.
- Filler metal comparison chart - a database showing the various consumables and their sources.

Since these examples showed that the attendees had a clear concept of how to develop a list of topics, the attendees were divided into groups, one for each of the three categories; manufacturing, repair and installation, and other interests. The following sections list the topics they identified.

1. Manufacturing

- Database system of welding codes including:
  - ASME
  - AWS
  - MILSPEC
  - API
- Ease of integrating welding databases with each other
  - For example, to insure code conformance of PQRs during data entry

- Welding parameter generation by expert systems
- Filler metal selection and consumables database (e.g. computerization of the AWS Filler Metal Comparison Chart)
- Software implementation concerns
  - How to implement software without interrupting manufacturing process flow
  - Software portability across different hardware platforms
  - Networking support
  - Connecting with mainframe computers
- Expert systems for:
  - Filler metal selection
  - Process selection
  - Welding parameters determination
- Databases of:
  - PQRs
  - WPSs
  - WPQs
  - Base material properties
  - Brazing and soldering data

2. Repair and Installation

- WPSs, PQRs, and WQRs
  - Databases to manipulate and sort them
  - Expert systems to generate WPSs from PQRs
- Welding-related material properties
  - Creep
  - Sigma phase formation in stainless steels
- Installation data - requirements and guidelines
  - Post weld heat treatment
  - Nondestructive testing
  - Inspection
- Code interpretation
  - An expert system to guide one through code requirements and interpretation

- Design and handbook databases
  - Design tables
  - P number and F number
  - Filler metal specifications
  - Manufacturers data
- Calculation programs
  - Carbon equivalents (CE)
  - Ferrite number (FN)
  - Cost
  - Young's modulus (E)
  - Barlow's formula
  - Temper
  - Consumable requirements
- Job management
  - Labor-related forms
  - Personnel profiles
- Failure investigation and analysis expert system
- Health and safety expert system

3. Other Interests

- Computerized code and standards data (AWS D1.1, ASME IX, etc) searchable by key word or field.
- Computerized filler metal specification, searchable by key word or field.
- Work planning expert system
- Electronic consultant
- Design evaluation - an expert system to evaluate feasibility of production
- Computerized Unified Numbering System (UNS) , searchable by any field
- Expert system to predict and reduce distortion and shrinkage,

Development of a Unified List

The workshop attendees reconvened as one group and heard reports from the three groups. The top four choices for each group were combined on one list. The total number of topics came to only ten because of duplication. The items on the list were defined in greater detail so all would be aware of what was desired in the various topics. The attendees voted for the choices on this list so a list could be produced that represented the broadest possible spectrum of the welding industry. In descending order of importance, their choices were:

1. Computerized Code and Standard Information (AWS D1.1, ASME IX, etc.)

- Searchable for the specific requirements
- Able to cross list, classify, and compare the different codes
- Could tie code interpretations to specific paragraphs
- Able to develop and organize this information for qualification, then design requirements.

2. Customized software for WPSs, PQRs, and WQRs

- With a standardized format and nomenclature
- Able to handle multiple codes
- With expert system so WPSs that are generated do not exceed code limits

3. Database on weldment material properties

- Reference data on base metal, weld metal, and the HAZ
- With an expert system to model how the variables (welding parameters) affect the material properties

4. Work planning expert system - integrate PQRs, code requirements, and expert systems

5. Expert system to suggest welding parameters, and based on problems, suggest changes

6. Expert system for filler metal selection

- Mechanical property database
- Chemical composition database

7. Installation data, to assure fitness for service

- Post weld heat treatments
- Preheat temperatures
- NDT procedures
- Inspection criteria

8. Electronic consultant, an expert system with wide-ranging data

9. Design and handbook data

- Pipe pressure limits
- Electrode reconditioning

10. Expert system to evaluate the producibility of a design

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Appendix B: Survey Form

Survey Questionnaire on
Welding Industry Database Needs

1. Name____

2. Company____

3. Address____

4. Telephone Number___________________________________

5. Did you attend the previous workshop on 5-7 August 1986?

   Yes_____ No_____

6. Will you be attending the tutorial session on 19 October 1988?

   Yes_____ No_____

7. Do you have or have access to a microcomputer in your work?

   Yes_____ No_____

8. What is your experience with computers?

   ____

9. Which of the following interest groups do you belong in?
   (Choose up to three with #1 as first priority).

_____ Thick Section Welding (greater than 1/4 inch)

_____ Thin Section Welding (less than 1/4 inch)

_____ Electrodes and Welding Machines

_____ Ferrous Metal Welding

_____ Pressure Vessel Welding

_____ Non-pressure Component Welding

_____ Reactive Metal Welding

_____ High Energy Processes

_____ Non-ferrous Metal Welding

_____ Other ____________________________

Appendix C - Responses to the Survey

From the 61 conference participants, we received 37 responses to our requests for information. The responses are tabulated below, with notes to explain how some respondents interpreted certain questions differently.

Question 5 Did you attend the previous workshop?

yes - 5 no - 32

Question 6 Will you be attending the tutorial?

yes - 32 no - 5

Question 7 Do you have access to a computer in your work?

yes - 36 no - 1

(When asked about the type of computer, the responses typically included both a size and a manufacturer's name. Some had multiple computers.)

by size: mainframe - 3
minicomputer - 4
workstation - 1
80386-based - 4
80286-based - 5
8086/8088 or other personal computer - 28

by manufacturer:

IBM - 25
Apple - 5
Zenith - 4

DEC - 4

Compaq - 3

Wyse - 2

HP - 2

Question 8 What is your experience with computers? (Some interpreted this to request years of experience while others interpreted this to request the type or level of experience.)

Years of experience: Beginner to 38 years; the median experience was near 12 years

Type of experience: Word Processing - 6

Programming - 5

Spreadsheets - 4

Question 9 Which of the following interest groups do you belong in?

	First Choice	Second Choice	Third Choice
Thick section welding	9	7	6
Ferrous metal welding	8	10	4
Pressure vessel welding	8	4	1
Thin section welding	2	4	1
Non-ferrous metal welding	1	3	5
Electrodes and welding machines	2	2	3
Nonpressure component welding	1	3	
Reactive metal welding	2		
High energy process	3		
Hardsurfacing and maintenance	1		
Resistance welding	1		
Pressure piping	1		
Robots and seam tracking	1		
Materials	1		

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T.A. Siewert, J.E. Jones, and H.G. Ziegenfuss, Editors

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American Welding Institute, Knoxville, Tennessee
American Welding Society, Miami, Florida

10. SUPPLEMENTARY NOTES

☐ DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This publication comprises the proceedings of an October 1988 conference on computerization of welding data. A written summary of each speaker's presentation is included in its appropriate conference session:

- o Overview of computers and databases,
- o Welding applications software, and
- o Welding case studies.

This publication also includes the proceedings of a workshop which listed future computerization needs in the welding industry and an informal survey of the registrants' usage of computers on the job, both of which occurred at the conference.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)
computerization; database; mechanical properties; procedure qualification records (PQRs); welding information; welding procedures

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