

**RS/hyper: A Hypertext Solution for Reliable
Residual Stress Determination Using X-Ray
Diffraction**

by

Allan Ward III

Thesis submitted to the faculty of the
Virginia Polytechnic Institute and State University
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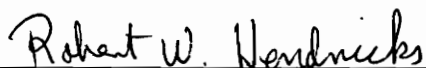
MASTER OF SCIENCE

in

Materials Science and Engineering

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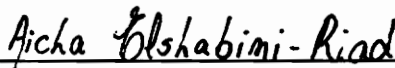
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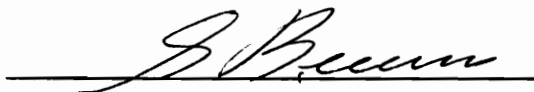
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by

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(ABSTRACT)

Advances in computer automation and control, compact and portable x-ray sources, and reliable and efficient detector systems over the last ten years have allowed X-Ray Determination of Residual Stress (XRDRS) measurements to become a viable method of evaluating the state of stress in metals, alloys, and ceramics. However, problems associated with incorrect XRDRS equipment operation and poor experimental technique are prevalent, necessitating better operator training and education. Therefore, an interactive computer workstation, called RS/hyper, was developed to lead the operator towards correct operating procedures and reliable experimental technique.

RS/hyper teaches the operator proper machine setup, machine maintenance, radiation safety, experimental technique, theoretical understanding, and provides limited data evaluation. Graphical aids are used extensively to avoid confusion and misinterpretation during the learning process. Since RS/hyper is interactive, the operator may select the desired level of understanding on a particular topic. These topics are linked, through a hypertext interface, so that the information is presented coherently and efficiently. Compared to written texts and references, RS/hyper has been shown in preliminary tests to reduce XRDRS training and problem solving time by a factor of 16.

RS/hyper will train novice users of XRDRS equipment so that the data acquired from such machines will be reliable in an industrial environment. Since the software educates the user, the results of the data will be more accurately represented before interpretation. The experienced user should find RS/hyper useful as a reference of XRDRS and related information.

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During the second semester of my first year in graduate school, my grandmother, Ann Ward, paid the entire semester's tuition. Without her support, I probably would not have been able to continue my studies. I therefore owe her a great deal of special thanks.

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Chapter 1

Background

Industrial acceptance of X-Ray Determination of Residual Stress (XRDRS) is largely dependent on *reliable* methods of data gathering and interpretation [1]. Through advances in computer, x-ray source, and detector technologies, state of the art diffraction systems have satisfied the need for reliability from a technical viewpoint [2]. However, human error in experimental design, machine operation, and data interpretation must be significantly reduced to improve the reliability of XRDRS data [3].

1.1 X-Ray Determination of Residual Stress

Over the last ten years, a renewed interest in quality control has led to the revitalization of several fields concerned with non-destructive testing and evaluation [4][5][6][7][8][9] [10]. Especially important to the manufacturing industry is the field of X-Ray Determination of Residual Stress (XRDRS). The importance of XRDRS lies in the fact that residual stress is induced in virtually all manufactured and metallurgically processed parts; in some cases intentionally, in other cases not. In either case, the state of stress must be determined as it may have profound consequences on strength and lifetime of the part or structure in question. XRDRS provides the best non-destructive means by which the state of stress in a material may be determined with accuracy and precision [11].

Modern x-ray analysis equipment allows rapid, automated data acquisition. This is due in large part to the development of high-speed computers with large data storage and analysis capabilities and the development of improved detector systems which allow precise measurement of diffraction peaks in a matter of seconds or minutes [12]. These

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developments, implemented in an economical XRDRS system, have made XRDRS a cost-effective and technically reliable means to determine the state of stress in metals, ceramics, and certain polymer structures [1].

1.2 Acceptance of X-Ray Determination of Residual Stress

The high cost associated with training personnel to operate XRDRS equipment and the level of expertise required to accurately interpret the data have been shown to represent the main obstacle to acceptance of XRDRS in the United States[1]. Training expense is due to the time required to teach detailed XRDRS measurement technique and equipment operation to junior engineers or technicians [13]. High turnover of XRDRS equipment operators further exacerbates training expense [14]. Additional expense is required to either train personnel or hire experts to interpret XRDRS data [15].

1.3 Hypertext Computer Technology

Rapid developments in personal computer hardware and software now make it practical to develop computer-aided instruction systems which involve text and complex graphics in random access, hypertext environments. Such systems show enormous possibilities for education and training. With current hypertext capabilities which allow almost random access to information stored in the system, it is now also realistic to use such systems for reference by specialists working in the field. Although perhaps not a substitute for a well written textbook, this technology offers the possibility for customization of solutions to a particular problem or process that are just not possible with written documents. Finally, such systems, if properly implemented, offer the possibility for rapid and easy updating, and for rapid customization for specialized systems and instruments. They thus need not suffer from obsolescence in the same manner as a textbook or other printed documentation.

CHAPTER 1. BACKGROUND

1.4 Thesis Objective

This thesis describes a system designed to improve the reliability of X-Ray Determination of Residual Stress measurements by teaching XRDRS measurement theory and equipment operation. This system, called RS/hyper, is a computer software program based on hypertext computer technology which is capable of presenting large amounts of text and graphical data with speed and efficiency. Nearly all aspects of XRDRS theory, equipment operation, and data interpretation are incorporated in RS/hyper.

Chapter 2

Review of Previous Work

An earlier work of the Residual Stress Laboratory at Virginia Tech[1], “Intelligent Workstation for Reliable Residual Stress Determination Using X-Ray Diffraction,” by C. F. Dehan, is the only previous work performed, to the author’s knowledge, which addresses the application of computer software technology in the area of XRDRS user education and training.

Dehan shows in his work that the lack of operator education and training is the major obstacle to reliable measurements using XRDRS. He evaluates the need for a workstation which addresses the “human factor” and concludes that the best solution is the development of a computer based “expert system” based on artificial intelligence (AI) technology. While the hypertext system developed in this thesis is not an expert system, for reasons explained in Chapter 3 of this work, his needs assessment and solution synthesis are still valid for the present consideration.

2.1 A Computer Based System for Reliable Measurements in XRDRS

Reliable XRDRS measurement and interpretation requires that the personnel performing the work have a strong academic background in x-ray science, metallurgy, crystallography, electronics, failure analysis, statistics, mechanics, and general materials science. Since personnel possessing these qualifications are usually hired for work other than performing laboratory measurements, a system to train non-specialist users in XRDRS methodology was necessary.

An “intelligent workstation” concept was proposed by Dehan in which a computer-based

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system, relying primarily on artificial intelligence technology, would train and provide expertise to a non-specialist user of XRDRS. Such a system would contain an extensive data base by which data could be compared, statistically analyzed, and processed automatically. This processed data would then be compared against theory and the experience of a human expert (stored on computer), resulting in a probable explanation of the data. It was argued that this would provide an alternate solution to the problem of user training and competence.

Dehan justified such a system by identifying five concept proposals for improving XRDRS data reliability, evaluating the merits of each, and selecting the optimal solution based on his analysis. Concept I involved training existing personnel. Concept II involved hiring new, qualified personnel. Concept III involved assessing equipment performance and implementing corrective action. Concept IV involved improving the methodology of experimental technique and data interpretation support. Concept V involved development of a computer workstation for a “total quality” materials characterization process.

2.1.1 Concept I: Training Existing Personnel

This concept proposes training of existing employees to perform XRDRS experiments and interpret data. Concept I, as Dehan states, “has only been tried in the past with poor success since the existing personnel are either high school graduates with limited scientific background, or college graduates who are in the position only a short time due to mobility.” He therefore rejects Concept I directly.

2.1.2 Concept II: Hiring New, Qualified Personnel

This concept proposes hiring new employees who have expertise in the field of XRDRS. Concept II, as Dehan states, “is a technically valid solution to the problem, but is not economically wise due to the range of output requirements and the associated cost.” He therefore also rejects Concept II outright.

CHAPTER 2. REVIEW OF PREVIOUS WORK

2.1.3 Concept III: Performance Assessment of Equipment

This concept proposes maintaining records of equipment performance to insure that the equipment is functioning within specified guidelines. Concept III, as Dehan states, “has limited impact on the overall problem, but should be part of a larger total quality approach”. Performance assessment does insure performance consistency, but does not necessarily improve the quality of the data. Dehan accepts Concept III as a partial solution.

2.1.4 Concept IV: Methodology Support

This concept provides a basis of technical support in the proper experimental methodology of XRDRS and data interpretation. Concept IV makes an important stride toward a total solution by improving data quality. As Dehan states, “By providing methodology support, the user thinks about the data collection process before it even starts, thereby identifying potential problems in the experimental technique. An identifiable drawback is to overwhelm the user with information, especially when involved in relatively simple measurements. The problem with data and information manipulation therefore makes this concept part of a larger solution.” Dehan accepts Concept IV as a partial solution.

2.1.5 Concept V: Computer Workstation

Concept V integrates the features of Concepts III and IV with the data and information manipulation power of a database management system into a computerized workstation. Such a system incorporates a knowledge base, methodology support, data analysis, validation and interpretation tasks, instrument performance assessment, and other features. Dehan accepts Concept V as the most thorough approach and develops it as his principle solution.

CHAPTER 2. REVIEW OF PREVIOUS WORK

2.2 Development of the Computer Workstation

RS/hyper is one of four Residual Stress programs developed in the Residual Stress Laboratory of the Materials Science and Engineering Department at Virginia Polytechnic Institute and State University. Other programs in the RS/-series are RS/analyze [19], RS/base [17], RS/cite [18], and RS/expert [16]. Together, these programs will combine to form a residual stress workstation which will be able to teach operators the concepts of XRDRS science and equipment operation (RS/hyper), store and retrieve XRDRS data and provide a knowledge base for such data (RS/analyze and RS/base), interpret XRDRS data using AI/ES technology (RS/expert), and provide an index to the XRDRS literature (RS/cite). While RS/hyper currently runs independently, it has been designed to integrate into the workstation concept, involving RS/analyze, RS/base and RS/expert.

Chapter 3

Development of the Hypertext System

The expert system proposed by Dehan has proved to be a practical solution to the problem of operator training and data evaluation. Work has begun on the expert system, as detailed in “An Expert System for the Validation and Interpretation of X-Ray Residual Stress Data,” by M. Tricard. [19]. However, even with a complete expert system which evaluates and interprets XRDRS data, the likelihood of operator error associated with incorrect experimental procedure and machine operation still remains.

Thus, the present and future need for a system which trains operators of XRDRS equipment still exists. Furthermore, the present and near-future need for a system which will allow the operator to evaluate data for the purpose of determining the validity of that data still exists. RS/hyper was designed as the system to train operators in all aspects of XRDRS equipment operation¹ and data evaluation. Since Proto Manufacturing² provided the funding for this research, RS/hyper was adapted to the Denver/Proto XRD-1000 X-Ray Analysis System for the purposes of this thesis.

This chapter describes the development of RS/hyper by stating Proto Manufacturing’s system requirements, the functional system design, and the detailed system design.

3.0.1 Description of the Proto Project Requirements

Proto Manufacturing required hypertext training and education hypertext software for their Model XRD-1000 Residual Stress Analysis System and their Model 8188 Electropol-

¹While RS/hyper can provide operation instructions for any XRDRS machine, the version used by the operator must be machine-specific.

²Proto Manufacturing, 2175 Solar Crescent, Oldcastle, Ontario, Canada, N0R 1L0.

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isher. Additionally, a written installation and introductory operation manual to accompany the hypertext system was required. This written installation and introduction manual is included in Appendix C.

The areas which the hypertext system are to address are:

- Radiation Safety
- Machine Maintenance
- Sample Preparation
- Hardware Manipulation
- XRDRS Theory
- Experiment Design and Implementation

The areas not specified by Proto, but later developed as part of the complete system are as follows.

- Help Screens
- Program Operation Instructions
- Low Level Data Interpretation
- Tabulated Information (e.g., recommended Bragg angles, radiation type, etc.)
- DOS Interface

These topics were specified to be explained in text and graphics so that the operator could read instructions or explanation, then view a pictorial representation of that instruction or explanation. The pictorial representation was specified to be both drawings and scanned images incorporated into the text screens.

CHAPTER 3. DEVELOPMENT OF THE HYPERTEXT SYSTEM

3.1 Functional Design Specification

The functional design specification (FDS) for the hypertext system is formed as a solution to two interrelated problems; physical operation of XRDRS equipment and theoretical understanding of XRDRS science. This section describes and justifies the topics which must be addressed by our proposed system.

3.1.1 Physical Operation of XRDRS Equipment

First, the physical operation of XRDRS equipment must be carried out properly to insure the quality and validity of the data. This requires that the operator of XRDRS equipment be trained in all aspects of hardware assembly, system maintenance, and hardware configuration.

Hardware Assembly

Hardware assembly includes instructions describing installation of the x-ray tube, installation and positioning of the detector system, installation of the x-ray filter, manipulation of the sample position, and operation of the computer control system. To insure proper hardware assembly, it is required that detailed instructions be provided with equipment diagrams which focus solely on the instruction at hand. In this way, the operator has no doubt as to the part in question, or the objective of the instruction.

System Maintenance

System maintenance includes procedures for cleaning the equipment, preventative maintenance, consumable parts, and warranty considerations. To obtain reliable data, the equipment must be in proper working order. Either due to neglect or ignorance, proper maintenance is often not performed, resulting in possible electrical and radiation hazards to the operator and possible data errors due to an unclean and ill kept machine.

CHAPTER 3. DEVELOPMENT OF THE HYPERTEXT SYSTEM

Hardware Configuration

Hardware configuration includes physically setting the 2θ position of the detector, calibration of the detector system, and configuring the hardware for the correct data acquisition technique (i.e., single exposure or multiple exposure technique). Without understanding the physical system, important procedures may be overlooked in order to save time because they seem unimportant to the untrained operator. This will result in systematic errors in the data, which may be incorrectly interpreted as real stress effects in the sample.

3.1.2 Theoretical Understanding of XRDRS Science

Second, the theoretical understanding of XRDRS science must be implemented by the operator of the system when designing experiments or determining the validity of the data collected. Without this knowledge, the operator has no way of determining whether or not the stress intended to be measured is the stress actually measured or if other factors have tainted the data, giving the appearance of stress effects, when in fact, there aren't any. Furthermore, the operator must have theoretical knowledge of XRDRS to correctly report the state of stress, validity of data (estimate of error), and limitations considered in the experimental design. Theoretical understanding must include scientific aspects of hardware selection, measurement techniques, sample preparation, non-stress effects on the data, and limitations of XRDRS for reliable data acquisition and interpretation.

Hardware Selection

Hardware selection depends on the choice of radiation wavelength, Bragg angle, and filter. Obviously, without an understanding of x-ray diffraction theory, the operator will not be able to determine these parameters. If the operator is simply given information without the scientific understanding of why particular choices were made, the operator has no way to compensate for the inevitable difficulties found when measuring most materials. An example of this is changing the Bragg angle to improve the signal to noise ratio of the

CHAPTER 3. DEVELOPMENT OF THE HYPERTEXT SYSTEM

diffraction peak or to reduce the effects of preferred orientation. Without understanding the theory behind Bragg's relation, the operator could not relate the signal to noise ratio or preferred orientation to the detector positioning, and therefore, not make the correct modifications to the experimental procedure.

Measurement Techniques

Measurement techniques include the single exposure technique, the double exposure technique, the multiple exposure technique, stress mapping, and determination of stress gradients normal to the surface. Without understanding the advantages and limitation of each technique, the operator is unlikely to select the correct procedure for samples which are in a state of triaxial stress. Ignorance of the proper use of each technique will likely result in statistically valid data, assuming the technique was performed correctly, but incorrect interpretation, since the triaxial stress state was not properly measured.

An example of this is the case in which the Single Exposure Technique is performed on a sample containing preferred orientation (texture). Since preferred orientation shows oscillation in the d versus $\sin^2\Psi$ graph, it is necessary to perform the Multiple Exposure Technique to correctly characterize the oscillation. If the Single Exposure Technique is performed, in which only two points on the d versus $\sin^2\Psi$ are measured, the data may very well be statistically valid, but incorrect since there is no way to determine the oscillatory behavior by measuring two data points. Thus, the choice of correct technique becomes essential to XRDRS measurements, requiring that the operator understand the theory associated with the experimental technique.

Sample Preparation

Sample preparation includes methods to determine whether sample preparation is necessary, suggestions to remove surface coatings (e.g., corrosion, galvanization, paint, and anodization), and procedures to properly prepare the sample surface. Since any form of abrasive sample preparation will change the near-surface stress state in a sample, the first

CHAPTER 3. DEVELOPMENT OF THE HYPERTEXT SYSTEM

task is to decide whether or not to perform any sample preparation. As a rule of thumb, the operator is advised to perform a measurement to determine the signal to noise ratio of the diffracted beam. Experience has shown that a signal to noise ratio greater than 2:1 does not require sample preparation. If the signal to noise ratio is less than 2:1, a sequence of surface layer removal procedures is given with literature references. Also included in sample preparation are procedures for assembling and using the Proto Model 8188 Electropolisher.

Improper sample preparation may alter the state of stress in the sample, leading to unreliable results, even if the measurement technique and data interpretation are later performed correctly. Thus, it is important that XRDRS users become knowledgeable about sample preparation.

Non-Stress Effects on the Data

Non-stress effects on the data are categorized as either materials effects or x-ray optics effects. Materials effects on the data include the effects of preferred orientation and large grain size. X-ray optics effects include poor signal to noise ratio, the role of the $K\alpha_2$ doublet, peak shape fitting, and focusing errors. These non-stress effects lead to most of the incorrect interpretation of XRDRS data. To insure reliable interpretation of the data, it is essential that the operator understand the causes and indications of these non-stress effects so that they may be identified and reduced, if possible. This requires an understanding of x-ray diffraction science, diffractometer x-ray optics, and materials science. Although the equipment operator may not interpret the data, knowledge of these effects is still important to proper experimental design, since these effects can be reduced or eliminated using proper experimental technique.

As an example, consider the case of d versus $\sin^2\Psi$ data in which large grain size has considerable effect on the data. If the operator was aware of the problem of large grain size, the experimental design would include using a larger aperture or moving the x-ray beam location to reduce this problem. Otherwise, statistically valid data would not be obtainable, causing XRDRS to appear unreliable.

CHAPTER 3. DEVELOPMENT OF THE HYPERTEXT SYSTEM

Understanding XRDRS Limitations

Depth of x-ray beam penetration, oscillatory data, and multiphase material considerations limit XRDRS in some cases. It is important for the operator to understand the limitations of XRDRS, to insure that it is not applied improperly. For example, the depth of penetration limits XRDRS to measuring the near-surface state of stress in a material. Without knowledge of the depth of penetration limitation, the operator may incorrectly represent the state of stress as that which is in the bulk of the sample. With knowledge of depth of penetration limitations, the operator would know to use an alternate technique, perhaps neutron diffraction or hole drilling, to measure stress well below the sample surface.

3.2 Detailed Design Specification

The detailed design specification (DDS) was implemented on Proto Manufacturing's Model XRD-1000 residual stress diffractometer. It was determined that facets of the workstation concept developed by Dehan were valid, but modification of the original solution was needed to incorporate modern hypertext software technology.

3.2.1 Selection of Hypertext Software

Three hypertext systems were studied and tested to determine which had the greatest potential for successful implementation of the objectives; Toolbook, by Assymetrix, Knowledge Pro, by Knowledge Garden, and Guide 3.0, by Owl International. The criteria for selection were the graphics capability of the software, the access speed to information screens, the availability of program controls to manipulate the display, and the ease of programming the system. Knowledge Pro was rejected due to the complex nature of the user interface and programming control. Toolbook was rejected due to limitations in the graphics capability, the slow access speed to information screens, and the lack of programming features required to develop the relatively complex data access code. Guide 3.0 was selected because it met all the requirements necessary for implementation of the hypertext system.

CHAPTER 3. DEVELOPMENT OF THE HYPERTEXT SYSTEM

3.2.2 Selection of System Hardware and Support Software

As proposed by Dehan, the hypertext system was implemented on a personal computer (PC). The main advantages of a PC based system are low cost, portability, and compatibility with the other components of the “intelligent workstation.”

After learning how to use Guide 3.0, the hardware requirements of the system became clear. These requirements are based on the need for high resolution graphics and near-instant access to information screens. Thus, a system was selected comprising:

- a 80386 or 80486 class personal computer,
- 4MB or more RAM memory,
- 40MB or more HD memory,
- VGA or better resolution display, and
- a serial mouse.

The software requirements of the system are as follows:

- MS-DOS 5.0 by Microsoft,
- Windows 3.1 by Microsoft, and
- Guide 3.0 by Owl International.

3.2.3 Modification of Graphical Information Specifications

Proto originally specified that scanned photographic images be incorporated into the hypertext software. The reasons for not incorporating the scanned images are as follows:

- The information to be conveyed by scanned images was more effectively related in drawn graphics than in the scanned images, since drawings could exclude unnecessary parts of the image.

CHAPTER 3. DEVELOPMENT OF THE HYPERTEXT SYSTEM

- The quality of the scanned images did not meet expectations and would degrade the appearance of the information display.
- Upgrading scanned images would require several hours of programming time per image, which would be cumbersome to Proto personnel.

Proto agreed with the recommendation that all graphical images be computer drawn rather than scanned; thus, RS/hyper contains only drawn images.

Chapter 4

Description of RS/hyper

RS/hyper is considered the non-written portion of this thesis, and should be viewed “first-hand” so the reader may appreciate the hypertext organization and program features which cannot be adequately described in the written portion of this thesis. A copy of RS/hyper may be viewed in the Residual Stress Laboratory at Virginia Polytechnic Institute and State University by arrangement with Professor Robert W. Hendricks.

4.1 Information Efficiency

RS/hyper’s information-efficient presentation structure has been designed to be simple to use, regardless of the user’s computer experience (or lack thereof). Information efficiency is attained by presenting only that information which the user wants and hiding the rest. This is accomplished in two ways; hiding tabular information and suggesting the user’s next course of action.

First, detailed tabular information is hidden until the user requests that it be shown. This prevents the user from becoming inundated with screens of information when trying to find a relatively simple answer. For example, the user is first presented with a high level information screen showing various classes of materials. Then, by clicking the mouse cursor on the material class, specific information about recommended radiation, 2-theta and hkl plane parameters is given.

Second, the program guides the user by assuming which information the user wants by considering past actions within the program. For example, if the user viewed a series of screens having to do with grain size effects on a d versus $\sin^2\Psi$ plot, the program would

CHAPTER 4. DESCRIPTION OF RS/HYPER

likely assume that the user is attempting to evaluate data and would suggest a series of screens related to non-stress effects on the d versus $\sin^2\Psi$ characteristic, such as composition gradient or preferred orientation effects. However, the user can ignore the suggested sequence of screens and proceed in any manner desired.

4.2 RS/hyper ORGANIZATION

The hypertext system is organized into three sections and four levels of information. This is a natural result of the logical presentation of information from the most general to the most specific.

4.2.1 Program Tutorial

The first section contains the tutorial describing the operation of the program. Here, users are introduced to the manner in which hypertext screens are accessed, how underlined words indicate the existence of a definition, and how italicized words indicate a branch point where related information pertaining to the topic at hand can be reached. Additionally, the tutorial explains the color coding of the text, red for safety and blue for key ideas, and the use of the icon menu and hyper-index. The purpose of the tutorial is not only to teach the user about the operation of the program, but also to reduce any “computer shyness” which may exist in operators with little or no computer experience.

4.2.2 Safety Screens

The second section contains safety information. This information describes the National Bureau of Standards (NBS) guidelines [20] [21] [22] for the operation of x-ray producing equipment. The user must pass through this section and acknowledge that the information was read and understood before proceeding to section three.

CHAPTER 4. DESCRIPTION OF RS/HYPER

4.2.3 Information Screens

The third section contains the bulk of the information contained in the program, which is presented in a collection of information screens. These information screens are organized in the hypertext environment to instruct novice users of XRDRS methods and to serve as a reference for experienced users.

4.2.4 Levels of Information

The first level contains the title screen, the tutorial, the safety section, the icon menu, and the exit screen. The second level contains the help screens, the hyper-index, and the menu screens under the maintenance, theory, sample preparation, hardware, and experiment icons. The third level contains general information regarding the aforementioned menu screens. The fourth level contains graphics, tabulated information, and detailed information.

4.3 Program Features

4.3.1 Icon Menu

The icon menu, shown in Figure 4.1, is a feature of the program which categorizes the logical order of information presentation into seven topics. These topics are accessed by clicking the mouse cursor on the icon which describes the topic selected.

Icons were chosen at the top information level to decrease the time spent at this level. Written text requires the user to read and then perform the mental process of interpreting the words into an idea. The icons simply require that the user associate a symbol with an idea. Icons also are intended to add to the attractiveness of the software, as they have been drawn with interesting designs and colors.

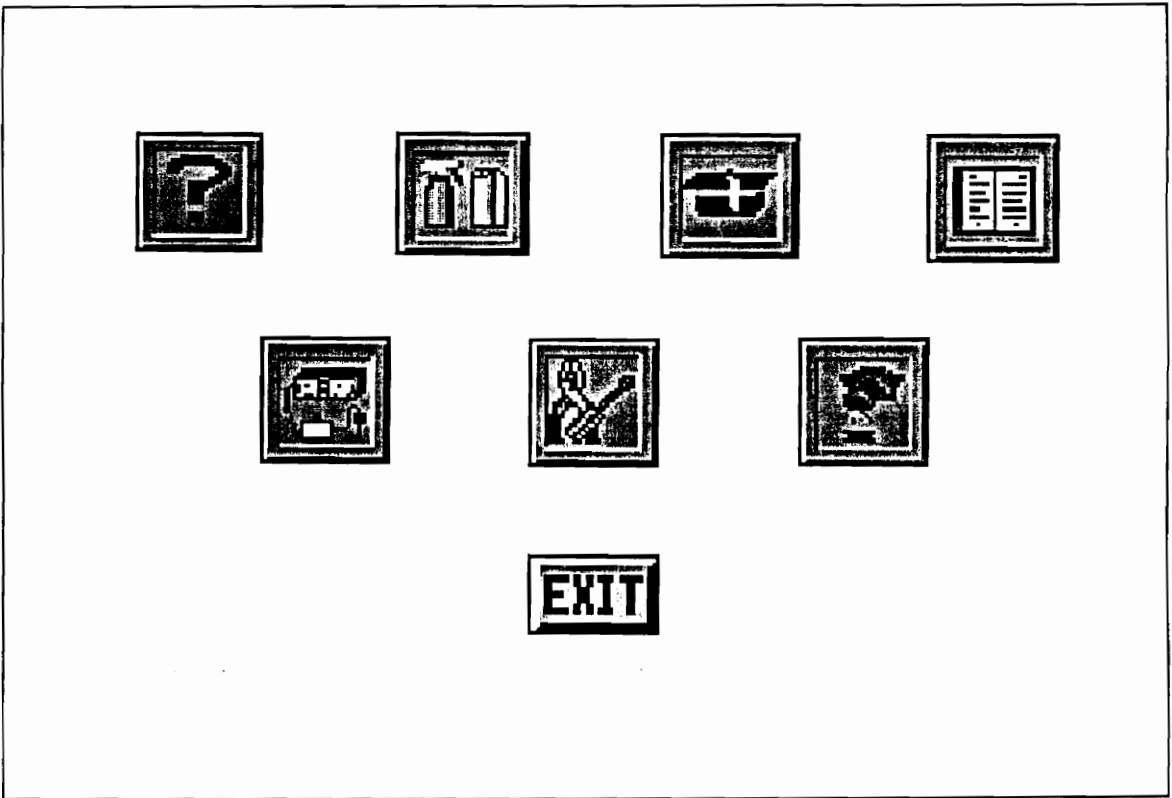


Figure 4.1: Icon Menu

CHAPTER 4. DESCRIPTION OF RS/HYPER

The HELP Icon

Proceeding left to right and top to bottom on the icon menu screen, the first icon is the HELP icon, which is in the shape of a question mark. In the icon menu and at lower levels, the HELP icon accesses a screen which provides the user with information pertaining to the operation of the hypertext program. From this help screen, the user can branch to the tutorial section if more detailed help is required. When finished with the tutorial and the help screen, the user is sent back to the screen from which the help screen was accessed.

The MAINTENANCE Icon

The MAINTENANCE icon, which is in the shape of a sprayer and paper towels, accesses a menu which presents information pertaining to the machine upkeep, consumable parts, and warranty information.

The THEORY Icon

The THEORY icon, which appears as a mortarboard and tassel, accesses a menu which presents topics of information pertaining to XRDRS theory, single and multiple exposure techniques, preferred orientation and grain size effects on the data, and corrections made to the data by the system software.

The SAMPLE PREPARATION Icon

The SAMPLE PREPARATION icon, which appears as the Proto Model 8188 electropolishing unit, accesses a menu which covers sample preparation, electropolishing, and surface coating removal.

The HARDWARE Icon

The HARDWARE icon, which appears as a screwdriver and pliers, accesses a menu which covers information pertaining to the manipulation of machine hardware such as x-ray

CHAPTER 4. DESCRIPTION OF RS/HYPER

tube and filter installation, detector positioning, and computer software operation.

The EXPERIMENT Icon

The experiment icon, which appears as a diffraction head, accesses information pertaining to experimental design and implementation such as the calibration procedure, powering the x-ray tube up and down, and how to measure stress gradients. It is closely linked with the hardware and theory icons, as both these topics directly relate to experimental set-up and performance.

4.3.2 The Hyper-Index

The HYPER-INDEX icon, which appears as the index in a written textbook, accesses an alphabetical listing of all topics covered in the manual, much like the index in a conventional text. The advantage of the hyper-index is that it may be accessed on virtually any screen, then return the user to that screen when the information has been located. In this way, the program sets an invisible bookmark when the user branches to the hyper-index, then returns to that bookmark as necessary.

4.3.3 DOS Interface

Apart from the program itself, RS/hyper provides an immediate link to the Proto XRD-1000 machine control software, which operates under DOS. This allows RS/hyper to act as an online help and reference source. RS/hyper can also easily link to any other DOS application which the user may find useful, eliminating the need for manufacturers and users to rewrite computer software into the Windows environment. RS/base and RS/cite (both DOS based) can be accessed by RS/hyper and will eventually be linked to form part of the "intelligent workstation."

CHAPTER 4. DESCRIPTION OF RS/HYPER

4.3.4 Windows Interface

RS/hyper runs under the Windows 3.1 software environment and can therefore easily link to other Windows-based programs by program launching or dynamic data exchange (DDE). Other components of the residual stress workstation (RS/analyze and RS/expert) are also Windows-based, facilitating the eventual linking of these programs to form part of the “intelligent workstation.”

Chapter 5

Program Evaluation and Testing

As is always the case in the development of quality software, the designer must seek user input and feedback the system. To this end, an informal study was performed using four engineers with previous XRDRS experience to determine whether or not RS/hyper satisfied the FDS. The objective of this limited study is to evaluate the effectiveness of RS/hyper's program tutorial and to compare the time required to find selected XRDRS information between RS/hyper and written texts. A more extensive study evaluating the effectiveness and efficiency of RS/hyper in an industrial environment is recommended, but such a study is beyond the scope of this thesis.

5.1 Test Design

Task 1 was to learn how to use the program by reading the self-tutorial. Tasks 2 through 5 were intended to evaluate the ability of the subjects to find selected information in RS/hyper and the effectiveness of the program's self-tutorial. Tasks 6 and 7 were to find selected information in hypertext and find that same information in written texts and references.

Tasks 2 through 5 are detailed below:

2. Find instructions for replacing the PSSD¹ cylinder.
3. Find the correct electrolyte for electropolishing aluminum.
4. Find the recommended hkl diffraction plane for 304 stainless steel.

¹Position Sensitive Scintillation Detector

CHAPTER 5. PROGRAM EVALUATION AND TESTING

5. Find the correct filter to use for FeK_α radiation.

Tasks 6 and 7 are detailed below:

6. The subjects were given a plot of d versus $\sin^2\Psi$ data showing the effects of preferred orientation. They were required to find the information necessary to identify the characteristic and then find recommendations about reducing the preferred orientation effect.
7. The subjects were required to find information necessary to setup an experiment to determine the state of stress in an aluminum plate using the Single Exposure Technique. The information required included sample preparation, Bragg angle and hkl plane selection, radiation wavelength, theory about the Single Exposure Technique, and how to perform the Single Exposure Technique.

The study was conducted using each subject independently. Test results are detailed in Appendix A.

5.2 Summary of Results

All subjects found the tutorial clear and did not have significant difficulty operating the program. In tasks 2 through 5, most subjects found the information without looking in a wrong location. Only one subject had difficulty finding Task 1 information; the same subject had difficulty finding Task 3 information. In tasks 6 and 7, the information was found in hypertext in an average of 30 seconds and 165 seconds, respectively. The information was found in written texts in an average of 451 and 2740 seconds. Note that the time was limited in task 7 to 50 minutes (3000 seconds) and that three subjects did not find the information in the written texts before the time limit. On average, information was found in RS/hyper a factor of 16 faster than in written texts and references.

Chapter 6

Conclusion

RS/hyper – Summary

A hypertext-based software package, called RS/hyper, was developed to provide a solution to the problems associated with training individuals in the use of X-Ray Determination of Residual Stress (XRDRS) equipment. This software package is intended to train users, regardless of educational ability and prior experience, in five general areas. First, the program provides a step by step tutorial about how to use the program itself. This is intended to remove possible computer “shyness” which may occur in individuals who are unfamiliar with the personal computer. Second, the program presents safety information according to the National Bureau of Standards X-ray safety guidelines. Third, the program contains instructions regarding proper equipment maintenance. Fourth, the program shows the user how to configure the hardware for experiments and guides the user through the experimental procedure. With the help of detailed drawings, the user is told and shown each step of the experimental procedure. Fifth, the user is educated in the science of XRDRS. Without scientific knowledge, the user will not always obtain reliable results since there are often non-stress related effects which may corrupt data. With proper training and education, the user may think about data collection before it begins and thus be able to assess the validity of his or her data, in most cases.

The main feature of hypertext is the nonlinear manner in which information is presented which increases information efficiency. This information efficiency allows the user to access only the data required, thus preventing the user from becoming overwhelmed or bored. Since the software is interactive, a “push button” program, in which the user does not think, has

CHAPTER 6. CONCLUSION

been avoided. This has been implemented so that the software will remain interesting, long after the user has become familiar with the equipment.

Arguably, the main obstacle preventing XRDRS acceptance in U.S. industry is the difficulty in training users to produce reliable results. While this program is not intended to act as an expert system, it does provide a basic education in experimental setup and data interpretation which should result in a vast improvement in data reliability. It is believed the improvement will be sufficient to make XRDRS an accepted means of industrial quality control and materials characterization in the United States.

Recommendations for Future Work

It is anticipated that improvements in computer memory and speed will allow the eventual incorporation of scanned images into the hypertext manual, if it is determined that these images are necessary. While scanned images are not required to meet the objectives of this thesis, sufficient quality images which are easy to manipulate by Proto programmers would add to the attractiveness of the hypertext system.

Guide 3.0 has the capability of dynamic data exchange (DDE), which may allow the hypertext system to be integrated into Proto's system software and data collection interface. With the improved multitasking capability of Windows 3.1, this may prove to be a useful upgrade to the current hypertext system. The DDE link also will allow RS/hyper to act as the user interface for the complete XRDRS Workstation involving RS/analyze, RS/base, RS/cite, and RS/expert.

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VITA

The author was born October 26, 1968 in Durham, NC. He graduated in May, 1986 from James B. Robinson, Jr. Secondary School in Fairfax, VA with the Advanced Studies Diploma and the Governor's Seal of Excellence. He then attended Virginia Polytechnic Institute and State University where, in May 1990, he received a Bachelor of Science Degree in Electrical Engineering. In August, 1990, the author was admitted to the Graduate School at Virginia Polytechnic Institute and State University to pursue a Master of Science Degree in Materials Science and Engineering.

Appendix A

RS/hyper: Program Evaluation Data

Table A.1: RS/hyper Evaluation Results

Task	Subject 1	Subject 2	Subject 3	Subject 4
2	22	24	15	42
3	12	15	12	17
4	9	11	14	21
5	4	6	6	8
6	16/342	22/418	35/612	48/432
7	151/1955	212/*	108/*	189/*

Time is in seconds. Task 6 lists time using RS/hyper and time using written texts and references respectively. In the Task 7 data, * indicates time was greater than 3000 seconds.

Appendix B

RS/hyper: Technical Notes for Programmers

Read the Guide and LOGiiX manuals. It is worth while to perform the tutorial and create a few documents yourself as practice. After thoroughly understanding how to operate Guide and LOGiiX, programming RS/hyper should be easy.

- Before altering screens or creating new ones, be sure to study the layout of similar screens. Many subtle details exist which are necessary to maintain consistency within the program. Pay attention to color coding, font selection, icon location on the screen, structure of explanations, and so forth.
- fflag is a flag used to specify the frame screen to be shown.
- iflag is a flag used to store the frame number when the user is going to the hyper-index.
- ifile is a flag used to store the document name when the user is going to the hyper-index.
- ireturn is used to set the return sequence when using the hyper-index. For example, the user leaves screen 4 in theory.gui and uses the hyper-index to view frame 45 of setup.gui. ireturn is set to 1 when the indexed information is found so that the return icon knows to return the user to the hyper-index. Upon returning to the hyper-index, ireturn is set to 0 so that the user is returned to the original screen. As long as ireturn is zero, the return icon will send the user to the return point in the document, not the hyper-index.
- When copying icons, it is easiest to use the edit feature in the scroll bar. However, the definition of that icon must be recreated using “make definition.” Otherwise, it

APPENDIX B. RS/HYPER: TECHNICAL NOTES FOR PROGRAMMERS

will have the same definition as the icon which was copied.

- CTRL+Y allows access to the edit bar.
- CTRL+Z freezes icons so that their function is not performed.
- CTRL+S shows symbols. When typing around or within objects (notes, expansions, commands, etc.) it is useful to display the symbols so that text is in the appropriate location.
- The command line to start the program from the DOS prompt is “win guide title.gui”.

Appendix C

RS/hyper: Installation and Operation Manual

RS/hyper: Installation and Operation Manual

Proto Manufacturing, Ltd.
2175 Solar Crescent Drive
Oldcastle, Ontario, Canada N0R 1L0

Version 1.0
August 15, 1992

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Proto Manufacturing, Ltd. reserves the right to revise this manual and the accompanying software, RS/hyper, and to make changes from time to time in the content hereof without any obligation of Proto Manufacturing, Ltd. to notify any person or organization of such revision and changes.

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Origin of RS/hyper

RS/hyper¹ is one of four Residual Stress programs developed by the Residual Stress Laboratory of the Materials Science and Engineering Department at Virginia Polytechnic Institute and State University. Other programs in the RS/series are RS/base², RS/analyze³, and RS/cite. Together, these three programs will combine to form a residual stress workstation which will be able to teach operators the concepts of XRDRS science and equipment operation (RS/hyper), store and retrieve XRDRS data and provide a knowledge base for such data (RS/base), and interpret XRDRS data using AI/ES technology (RS/analyze). Currently, RS/hyper and RS/base are complete; RS/analyze is still under development.

While RS/hyper runs independently, it has been designed to integrate into the workstation concept, involving RS/base, RS/analyze, and RS/cite. RS/base runs independently and RS/analyze requires RS/base.

Textbook Used with RS/hyper

Included with RS/hyper is Residual Stress by Noyan and Cohen. RS/hyper references Residual Stress by giving page numbers where more information about a topic may be found. This was done to avoid long discussions about relatively esoteric topics or discussions which we felt are better explained in a textbook format, such as experimental techniques with unusual samples or the mathematical development of equations.

While Proto believes that RS/hyper and Residual Stress serve their purpose in training non-expert users, X-Ray Determination of Residual Stress (XRDRS) is far too complex a field to be thoroughly covered in a computer program or textbook⁴. We therefore strongly recommend library research and consultation with Proto's team of XRDRS experts for unusual materials or complex measurement data⁵.

¹RS/hyper was written by Allan Ward under the supervision of Robert W. Hendricks.

²RS/base was written by Scott Courtney under the supervision of Robert W. Hendricks.

³RS/analyze was written by Marc Tricard under the supervision of Robert W. Hendricks.

⁴Hundreds of research papers are published every year as referenced in RS/cite.

⁵Proto Technical Assistance: (519) 737-6330

Chapter 1

About This Manual

This introduction manual is intended to familiarize the user with the computerized operation manual, called RS/hyper, used with the Proto Model XRD-1000 Residual Stress Analyzer¹. After reading this document, the user should be able to install the software, understand the concept of hypertext, and operate RS/hyper.

This document is organized as follows:

- Chapter 2 shows the user how to install the hypertext software and load the title screen.
- Chapter 3 describes the concept of hypertext software and the reason it was used in the Proto system.
- Chapter 4 describes the organization of information in hypertext and the navigation tools used to guide the user through the program.

This manual does not contain any information regarding the operation of the XRD-1000 Residual Stress Analyzer. All information pertaining to the XRD-1000 is located in the program RS/hyper.

¹Proto Manufacturing, Ltd., 2175 Solar Crescent Drive, Oldcastle, Ontario, Canada N0R 1L0

Chapter 2

How to Install RS/hyper

This chapter shows the user how to install RS/hyper and prepare the program for use. After reading this chapter, the user should be able to install the hyper-text software and load the operation manual's title screen.

RS/hyper requires the following computer configuration:

- IBM¹ compatible '386 or '486 class² computer
- VGA or higher resolution monitor
- 4 MB or more RAM memory
- 40 MB or more free hard disk memory
- MS-DOS 5.0 or higher previously installed³
- Windows 3.1 or higher previously installed⁴

The following procedure installs RS/hyper on your computer's hard-disk.

Installation Procedure for RS/hyper

1. It is recommended that you back up DISK1 and DISK2 by using the **DISKCOPY** command, as explained in your MS-DOS documentation.
2. Place DISK 1 in a floppy drive. For example, the A drive.

¹IBM is a registered trademark of International Business Machines Corporation

²386 and 486 are trademarks of Intel Corporation

³MS-DOS is a registered trademark of Microsoft Corporation

⁴Windows is a trademark of Microsoft Corporation

3. Change the current drive to the drive where you inserted DISK 1, and type **INSTALL**. For example, if the current drive is C (as indicated by the C prompt, C: or C:) and you placed DISK 1 in drive A, type **A:** to change to drive A, then **INSTALL**.
4. The message "RS/hyper is being installed, please wait" should appear on the screen. The installation should take less than 1 minute.
5. When installation is complete, the computer should automatically load and run RS/hyper, indicating that the program was successfully installed. **If the program does not install properly, call Proto Technical Assistance at (313) 965-2900.**
6. To run the program in the future, type **PROTO** at the C prompt.

The message "Out of environment space" may appear during installation. If you see this message, try adding the DOS **SHELL** command to your system's CONFIG.SYS file:

SHELL=COMMAND.COM /E:360.

If the **SHELL** command already exists, add 200 to the number following /E:. After modifying the CONFIG.SYS file, reboot the computer and restart the installation procedure. For more information about the **SHELL** command, see your MS-DOS documentation.

Chapter 3

What Is Hypertext and Why Is It Used?

3.1 Definition of Hypertext

“Hypertext” refers to computer software which is designed to efficiently present large amounts of detailed information about complex instructions or ideas using text and graphics. RS/hyper was written using GUIDE 3.0¹.

3.2 The Proto XRD-1000 Operation Manual and Tutorial

X-Ray Determination of Residual Stress (XRDRS) is the best non-destructive method available to determine the near-surface state of stress in metals, alloys and ceramic materials. However, only with proper instruction concerning equipment use and XRDRS theory is the operator likely to obtain accurate results. Thus, an operation manual with a tutorial about XRDRS theory (RS/hyper) was designed for the XRD-1000.

A written text containing equipment instructions and XRDRS theory, with diagrams and data tables, is estimated to be over 400 pages long. Since much of the experimental design is related to both hardware and theory, a written text would require that the user flip back and forth through the pages to find the information desired. This is time consuming and frustrating. More importantly, the user may miss important information, especially safety information, by reading large amounts of text in a piecemeal fashion. Furthermore, essential information may be missed because the user may have no idea that the

¹Guide is a trademark of Owl International, Inc.

information exists and does not know to look for it.

Hypertext software has the capability to store and retrieve large amounts of text and graphical information. Topics which are related can be accessed in any order automatically by the program, eliminating the need for “flipping through pages” of information as in a written text. The risk of missing important information is greatly reduced since the software automatically informs the user of related topics and safety information.

Hypertext has additional advantages which cannot be found in any other information presentation format. Most importantly, the software anticipates the information that the user wants by evaluating previous actions within the program. This way, the user can find answers without becoming overwhelmed or confused with related, but unimportant information. Although the software anticipates what the user wants, it is the user who is in control of the program, so suggested courses of action can be ignored. Another unique feature of a hypertext program is the ability to skip familiar information and only see what is unknown. This eliminates the problem in a written text of having to re-read pages of familiar information to find answers which may have been forgotten. Finally, the hypertext software follows a format which first tells the user what to do, then shows the user how to do it. This reduces the chance of misinterpreting instructions, thus reducing the chance of incorrectly operating the equipment or creating a safety hazard.

RS/hyper has been designed to be simple to use, regardless of the user's computer experience (or lack thereof). Help screens are easily accessible, as is the program's self-explaining tutorial.

Chapter 4

How To Use RS/hyper

This chapter describes the organization of information contained in RS/hyper and the navigation tools used to guide the user through the program. After reading this chapter, you should understand the function of icons and how to operate the program.

You may skip this chapter and follow the tutorial describing the operation of the program by clicking the mouse cursor on the HELP icon (it looks like a question mark) on the title screen. The information presented in the program's tutorial and the information presented in this chapter are similar.

The hypertext system is organized in three sections each with four levels of information. This is a natural result of the logical presentation of information from the most general to the most specific.

4.1 Program Tutorial

The first section contains the tutorial describing the operation of the program. Here, you are introduced to the manner in which hypertext screens are accessed, how underlined words indicate the existence of a definition, and how italicized words indicate a branch point where related information pertaining to the topic at hand can be reached. Additionally, the tutorial explains the color coding of the text, red for safety and blue for key ideas, and the use of the icon menu and hyper-index. The purpose of the tutorial is not only to teach about the operation of the program, but also to reduce any "computer shyness" which operators with little or no computer experience may have.

4.2 Safety Screens

The second section contains safety information. This information describes the National Bureau of Standard (NBS) guidelines for the operation of x-ray producing equipment. The user must pass through this section and acknowledge that the information was read and understood before proceeding to section three.

4.3 Information Screens

The third section contains the icon menu, from which the four levels of information may be accessed. The top level contains, among other things, the hyper-index which will be discussed in a later section.

4.4 Levels of Information

The first level contains the title screen, the tutorial, the safety section, the icon menu, and the exit screen. The second level contains the help screens, the hyper-index, and the menu screens under the maintenance, theory, sample preparation, hardware, and experiment icons. The third level contains general information regarding the aforementioned menu screens. The fourth level contains graphics, tabulated information, and detailed information. The user is unaware of the information level which is presented, since it is not important that the user know this. However, the written text provided with the software does describe the four levels of information, to satisfy curiosity about hypertext.

4.5 The Icon Menu

The icon menu is a feature of the program which sets the logical order of information presentation into eight separate topics. These topics are accessed by clicking the mouse cursor on the icon which describes the topic selected.

Icons were chosen at the top information level to decrease the time spent at this level. Written text requires the user to read and then perform the mental process of interpreting the words into an idea. The icons used simply require that the user associate a symbol with an idea. Icons also are intended to add to the attractiveness of the software, as they have been drawn with interesting designs and colors.

4.5.1 The HELP Icon

Proceeding left to right and top to bottom on the icon menu screen, the first icon is the HELP icon, which is in the shape of a question mark. In the icon menu

and at lower levels, the HELP icon accesses a screen which provides the user with information pertaining to the operation of the hypertext program. From this help screen, the user can branch to the tutorial section if more detailed help is required. When finished with the tutorial and the help screen, the user is sent back to the screen from which the help screen was accessed.

4.5.2 The MAINTENANCE Icon

The MAINTENANCE icon, which is in the shape of a sprayer and paper towels, accesses a menu which presents topics of information pertaining to the machine upkeep, consumable parts, and warranty information.

4.5.3 The THEORY Icon

The THEORY icon, which appears as a mortarboard and tassel, accesses a menu which presents topics of information pertaining to XRDRS theory, single and multiple exposure techniques, preferred orientation and grain size effects on the data, and corrections made to the data by the system software.

4.5.4 The HYPER-INDEX Icon

The HYPER-INDEX icon, which appears as the index in a written textbook, accesses an alphabetical listing of all topics covered in the manual, much like the index in a conventional text. The advantage of the hyper-index is that it may be accessed on virtually any screen, then return the user to that screen when the information has been located. In this way, the program sets an invisible bookmark when the user branches to the hyper-index, then returns to that bookmark as necessary.

4.5.5 The SAMPLE PREPARATION Icon

The SAMPLE PREPARATION icon, which appears as the Proto Model 8188 electropolishing unit, accesses a menu which covers sample preparation, electropolishing, and surface coating removal.

4.5.6 The HARDWARE Icon

The HARDWARE icon, which appears as a screwdriver and pliers, accesses a menu which covers information pertaining to the manipulation of machine hardware such as x-ray tube and filter installation, detector positioning, and computer software operation.

4.5.7 The EXPERIMENT Icon

The experiment icon, which appears as a diffraction head, accesses information pertaining to experimental design and implementation such as the calibration procedure, powering the x-ray tube up and down, and how to measure stress gradients. It is closely linked with the hardware and theory icons, as both these topics directly relate to experimental set-up and performance.

Chapter 5

Troubleshooting

This chapter provides possible solutions to software errors that you may encounter.

Out of Environment Space

The message “Out of environment space” may appear during installation. If you see this message, try adding the DOS **SHELL** command to your system’s CONFIG.SYS file:

```
SHELL=COMMAND.COM /E:360.
```

If the **SHELL** command already exists, add 200 to the number after **/E:**. After modifying the CONFIG.SYS file, reboot the computer and restart the installation procedure. For more information about the **SHELL** command, see your MS-DOS documentation.

Memory Parity Errors

On certain computers, the message “Memory Parity Error” may appear during operation of RS/hyper. To avoid this problem, reboot the computer, load the Windows 3.1 Program Manager, and follow the instructions in your Microsoft Windows 3.1 Operation Manual to turn off the swapfile. With the swapfile off, be sure that you still have enough free RAM memory to run RS/hyper by exiting Windows, and using the **MEM** command¹. The available contiguous extended memory must exceed 2 MB to insure that RS/hyper will run properly.

¹See your MS-DOS manual for more information about the **MEM** command.

Memory Parity errors have been observed while running RS/hyper and a variety of other Windows Applications not related to RS/hyper. The programmers of RS/hyper believe that the Memory Parity Error occurs because the swapfile incorrectly uses areas of memory allocated for other purposes. Although this may not be the problem, turning off the swapfile has prevented the Memory Parity Error from occurring while running RS/hyper and other applications.

LOGiiX Errors

If you see a box entitled LOGiiX, displaying an error message, you have found a software bug. Immediately call Proto Technical Assistance, and inform us of the error and the screen on which it occurred. Proto will correct the problem and send a corrected version of the software as soon as possible.

Proto Technical Assistance: (519) 737-6300

If you think a problem exists with the hypertext software which is not described in this chapter, or if the recommended remedies do not solve the problem, please call Proto Technical Assistance.

If you damage or lose the installation disks, replacements are available for a small fee and will be shipped immediately.