AUTOMATION *in* FATIGUE *and* FRACTURE

TESTING AND ANALYSIS

Claude Amzallag

EDITOR

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Claude Amzallag, Editor

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The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of these peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution to time and effort on behalf of ASTM.

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Foreword

The International Symposium on *Automation in Fatigue and Fracture: Testing and Analysis,* was held 15–17 June 1992 in Paris, France. It was cosponsored by the: Societe Francaise de Metallurgie et de Materiaux (SF2M), Committee on Fatigue, France; and American Society for Testing and Materials (ASTM), Committee E9 on Fatigue, USA.

Also offering valuable cooperation were the: Society of Automotive Engineers (SAE); Fatigue Design and Evaluation Committee, USA; Engineering Integrity Society (EIS), UK; and National Research Institute for Metals (NRIM), Japan.

The Symposium was an extension of the series of International Spring Meetings of SF2M. This publication is a result of this symposium. Claude Amzallag, IRSID-Unieux, France, is the editor.

Acknowledgment

The Organizing Committee, who helped develop the program and provide session chairmen and reviewers, are acknowledged for their assistance. Ms. Gail Leese, (PACCAR Technical Center, USA) and Dr. Dale Wilson (Tennessee Technical University, USA) helped shape the symposium, provide reviewers, and graciously offered their time in reviewing papers.

In addition to the help of the technologists cited above, the editor wishes to express gratitude to the staff members of SF2M and ASTM, particularly Yves Franchot, SF2M, who handled the administration of the symposium.

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Overview

In the diverse and complex technology of fatigue and fracture, it is increasingly important for societies and engineers to exchange information of mutual interest. It is thus critical to provide forums, such as the subject symposium, to allow for open exchange. With knowledge of the needs of industry, researchers gain insight valuable in assuring their focus is on meaningful topics. Armed with the latest developments from the research community, engineers, in turn, are able to apply and validate these concepts and findings from the research community.

The goal of the Symposium on *Automation and Fatigue and Fracture: Testing and Analysis*, was to be just such a forum on an international scale. Developers of testing methodology, researchers and scientists who evaluate and predict materials response, and engineers who apply the results to current day challenges in industry joined together to reflect on recent achievements in the areas of:

1. Automated testing systems and methods,
2. Models and methods for predicting fatigue life under complex loading,
3. Fatigue and fracture analysis and simulation, and
4. Applications and prediction methods.

This collaboration resulted in the presentation of 45 papers to an audience of around 150 technologists, representing more than 18 countries and 5 continents. The broad range of topics describe how advancements in digital computer hardware and software have opened up new opportunities in mechanical testing, modeling of physical processes, data analysis and interpretation, and, finally, applications in engineering environments.

This volume is offered as a valuable source of information for all those interested in deepening their understanding of fatigue and fracture phenomena. It is the hope of all involved that this may spawn yet further ideas and innovations in applying multidisciplinary technologies to testing and analysis automation, which in turn may open new doors of understanding.

C. Amzallag

IRSID-Unieux, France;
symposium chairman and editor.

Automated Testing Systems and Methods

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Arthur A. Braun[1]

A Historical Overview and Discussion of Computer-Aided Materials Testing

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ABSTRACT: Consistency of test data has always been a key concern in any materials testing application. Test technique or method, operator skill and experience, and capabilities of the apparatus are all parameters that affect the consistency of the desired information. The arrival of testing automation has contributed significantly to improving the consistency of materials testing apparatus, modifying existing test methods, creating new test methods due to enhanced capability, and improving the productivity of testing systems.

This paper surveys the development of computer-aided testing over the last 20 to 25 years and includes a discussion of current systems implementations and the emerging area of laboratory-wide automation. The rapid development of materials testing automation capability has generally tracked the trends in the computer industry. Advances in microprocessor hardware technology have driven testing automation by allowing for embedded intelligence in key test system components and by allowing for high-performance supervisory computer subsystems to control or supervise the overall test rig. Software technology advances in concert with expanding hardware capability have provided truly useful real-time operating environments, more efficient applications development tools, and higher productivity through more intuitive user interface technology. All together, these technology improvements have allowed for more sophisticated, consistent, and higher performance testing automation. Further improvements will be realized through the true utilization of the emerging digitally based systems architectures and emerging networking technology. This discussion concludes with a brief look at where emerging capabilities such as these will allow for new types of experiments to be performed and where information management will be enhanced, thus allowing for greater productivity in the test laboratory.

KEY WORDS: materials testing, test automation, controls, data acquisition, historical survey, fatigue (materials), fracture (materials), data analysis, testing methods

This paper describes the historical development of automation applied to fatigue and fracture testing. Automation capability for servohydraulic mechanical testing systems appeared in the late 1960s with the advent of lower-cost minicomputer capability and software options that allowed for the demanding real-time requirements of fatigue and fracture tests to be addressed. As computer hardware and software improved, gains in increased test control and data acquisition performance as well as options to use the automation facility for new types of tests emerged. This evolution occurred in several phases, which will be discussed here.

The first phase of early implementations was concerned primarily with interfacing lower-cost minicomputers with the system analog controls for data acquisition and program generation

[1] Group manager, Applications Engineering, Aerospace Structures and Materials Testing, MTS Systems Corporation, Eden Prairie, MN 55344.

(drive signal or function generation). This allowed for greater efficiency and some of the first generation of calculated variable control tests (tests in which the computer was used to control a secondary or indirectly calculated parameter such as true strain or stress intensity range by adjusting the primary control parameter, such as force or strain, during the course of the test).

The second phase was really a transition. Prior to the transition, the minicomputer solution was optimized for higher performance with more capable hardware and software. The transition began with the availability of very low cost personal computers (PCs) and the beginnings of microprocessor technology use in distributed system functions such as in data displays, servocontrollers, and control of peripheral devices such as temperature controllers. Applications software quickly used these enhanced capabilities and many types of tests were created that used computer control.

The third phase is the period we are currently experiencing where there has been a reintegration of system control functions with data acquisition, function generation, and peripheral control in the current digital control systems coupled with the use of higher-performance PC or workstation hardware and modern software technology. The emphasis is shifting from hardware orientation to software. The applications possibilities of some of these totally software-based systems remain to be realized in third-generation applications software. It is believed that the extension of this phase will be not necessarily in radical changes to the automation of the test system but rather in the connection of the test system to design, manufacturing, and modeling functions within a given enterprise through networking and enhanced software data sharing capability. Also, the software-based nature of the control systems will be utilized to implement truly adaptive control (autotuning systems or systems that optimize the control parameters in response to changes in the test specimen) and to implement new tests based upon the ability to use calculated parameters to control tests. Each of these periods will be discussed in more detail in terms of hardware, software, applications, and performance.

Early Implementations (1965 to 1975)

Servohydraulic test system technology emerged in the late 1950s and early 1960s with applications in structural testing and simulation being the first requirements. These systems used analog control based upon vacuum tube technology [*1*]. By the mid-1960s, servohydraulic test systems were becoming widely used for fatigue and fracture tests. Several evolutions of electronics technology were required before the vacuum tube-based controls were replaced first by discrete transistor logic and then by integrated circuit technology. Initial attempts using analog computers for test automation provided significant enhancements to the basic closed-loop capability [*2*]. The desire to utilize an easier-to-program digital computer could not be satisfied, however, until cost-effective digital computer hardware and software became commercially available. By the end of the decade, the commercial availability of minicomputer systems provided the first opportunity to marry computer control to these electrohydraulic systems.

These first implementations interfaced the minicomputer to the analog controller through an analog interface in which digital-to-analog (D/A) converters were typically used as a command reference (program source or function generator source) for the system and analog-to-digital (A/D) converters were used to acquire data (measure and store forces, strains, displacements, etc.) from the system. Figure 1 illustrates the typical system architecture functionally. Figure 2 shows a typical system configuration from this period. The computers used were, by today's standards, limited. The typical PDP 8 system manufactured by Digital Equipment Corporation utilized limited ferrite core memory typically in the 4 to 8-k word range, had limited processing power, and required a paper tape for program input and storage. Disk and tape technology usage became more viable as costs for these devices were reduced.

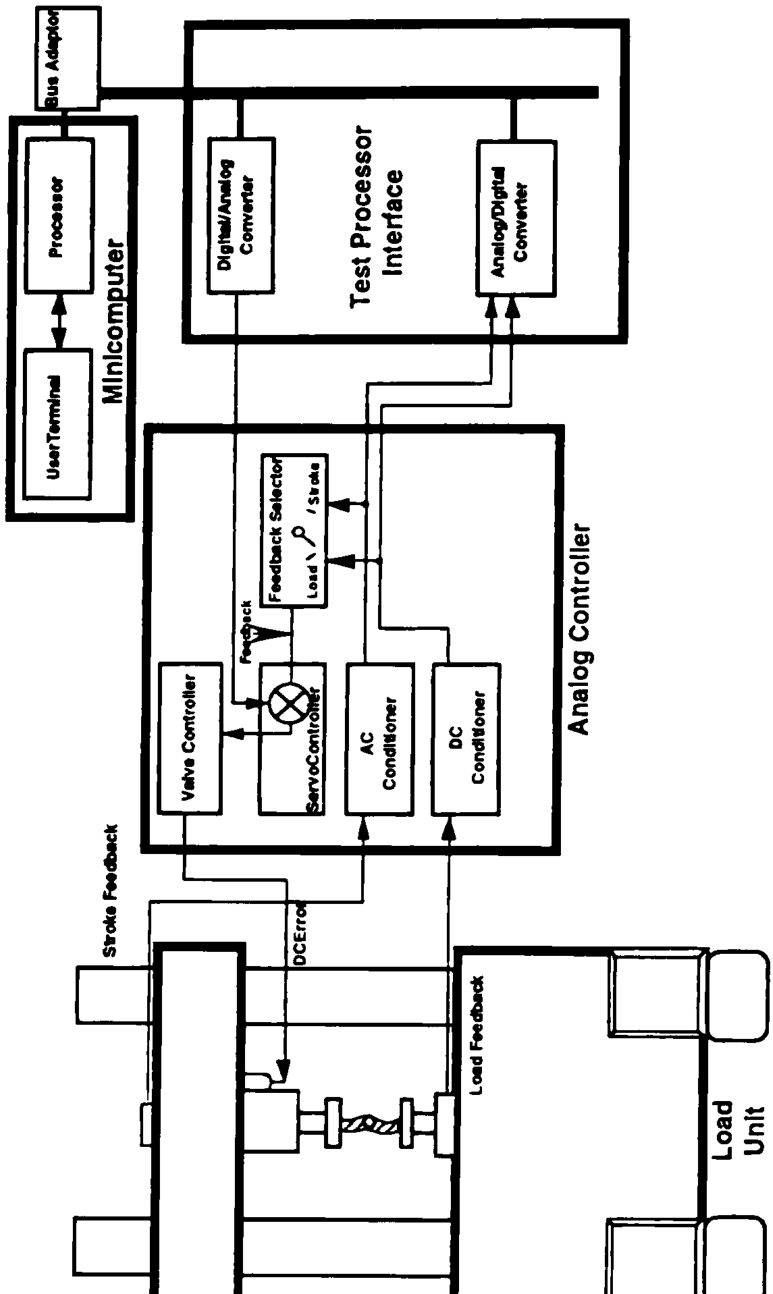

FIG. 1—*Typical first-generation automated system block diagram.*

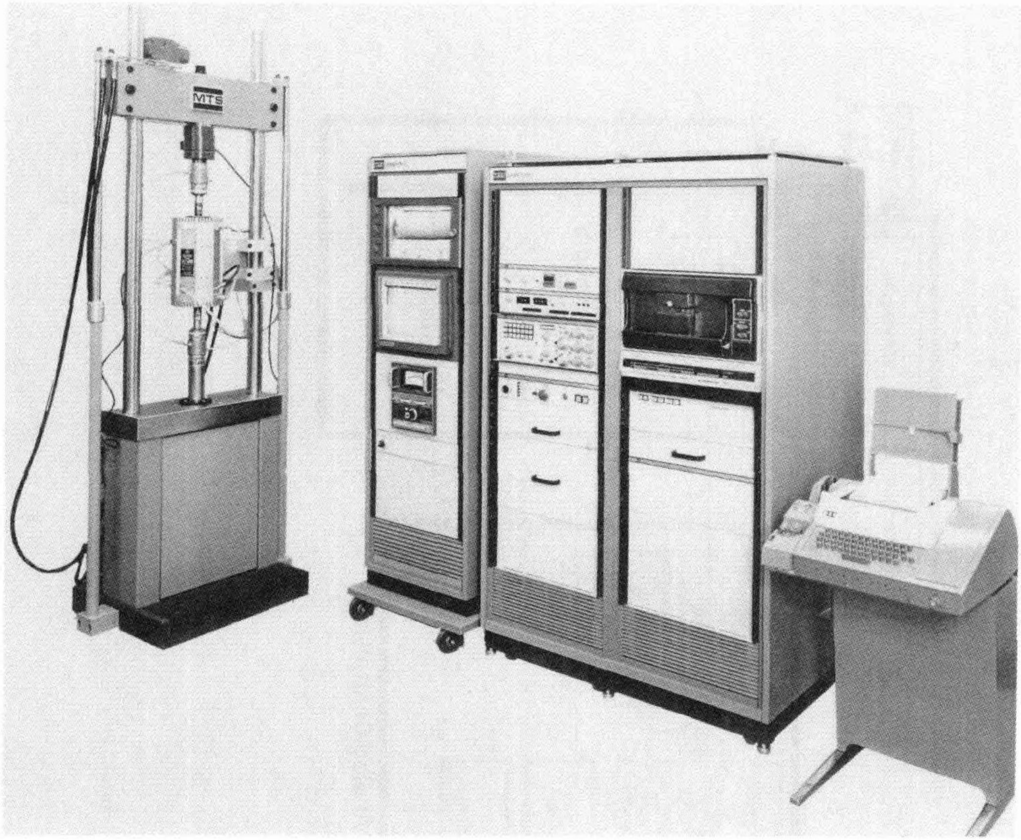

FIG. 2—*Example of a first-generation PDP 8 automated test system.*

The A/D and D/A converters used were typically 12-bit devices providing one part in 4096 resolution over ±10 V. The software in the earliest systems was either machine language based making programming the system a major ordeal, or a specialized assembly developed for materials testing. The "MTL" language developed by MTS Systems Corporation is an example of one of these proprietary languages. Much progress was made in this mode as exemplified by the work of Conle and Topper [*3*], Richards and Wetzel [*4*], and Martin and Churchill [*5*]. Significant advances were made in performing strain-controlled fatigue tests with calculated variable limit programming for load, strain, or inelastic strain. A significant advance common to all of these works was the introduction of the computed variable control capability discussed previously. A good example of this approach is the tests that were developed for axial strain control where the axial strain was calculated from the diametral strain [*6*].

The most significant limitations of these early systems were the severe memory limitations and the primitive programming environment for creating testing applications programs. By the middle of the 1970s, metal oxide semiconductor memory, MSI (medium scale integration), and the use of higher level languages such as BASIC and FORTRAN brought about the next phase of development in testing automation.

The Minicomputer Refinement Period (1972 to 1980) and the Transition to Personal Computers (1980 to 1985)

The advent of cheaper memory and higher performance processors as exemplified by the early members of Digital's PDP 11 family of minicomputers allowed for higher level language use on these systems to become feasible. Languages such as FORTRAN and especially interpretive BASIC required another level of performance in the computer. This additional performance was not required in the machine language/assembly language implementations. This added complexity also required more memory in addition to a more powerful processor. The early 1970s brought hardware meeting these requirements from companies such as Digital Equipment, Data General, and Hewlett Packard. Mass storage had developed to the point where magnetic tape and disk subsystems were usable and the paper tape based systems were disappearing. Computer manufacturers were also providing "operating systems" that managed system peripherals and memory and provided a structure upon which to build and use higher level programming tools.

The basic system hardware architecture of the systems implementation did not change radically during this time. A "processor interface" continued to bridge the space between the analog control system and the computer. There were, however, some attempts to eliminate the analog controls also in some of the earliest direct digital control (DDC) systems at this time [*7*]. Processor performance, however, severely limited the sample rate of these systems and forced the majority of implementations to use analog controllers. A/D and D/A resolution initially was limited to 12 bits but increased to 14 and 16 bits in the late 1970s and early 1980s as higher-resolution higher-performance components became available. Improvements in function generation were developed that provided more localized hardware control of the D/A converter such as "segment generation" (where a local clock steps the D/A through a wave table and provides scaling), thus off-loading the computer from generating every D/A step and freeing up time for other tasks. Similar developments were provided through local clocking of A/D input channels. Also, other hardware features were developed for the "processor interface." Computer-controlled control mode switching, system monitoring, voltage sensing, digital input/output (I/O) logic, and computer hydraulic system shutdown capabilities were refined and then put under software control through callable library routines accessible in the high level programming language used with these systems.

The most notable advances were accomplished in the software environment where higher level programming languages with built-in function calls to assembly language hardware control routines were used to make the task of developing test software somewhat easier. The work of Donaldson et. al described in Ref *8* is typical of the state of the art in the mid 1970s. These systems at first were typically single station, that is, there was one computer and processor interface per test system. Graphics capability emerged in the early 1970s allowing for data acquired to be plotted on a terminal screen and for plots to be outputted to plotter and hard copy units for reporting. Figure 3 shows a typical system from this period of refinement. The programming languages typically had a set of callable routines for graphics that allowed for "on-line" graphics to be shown during the course of a test. To obtain the best real-time response possible, the operating systems for these computers were typically memory resident, nonswapping, and did not dynamically reallocate memory. Digital's RT11 operating system was a typical example of this type of operating system. This changed as hardware, peripheral, and memory performance increase toward the end of this period.

During this time, test technology advanced with the enhanced computer power being utilized to perform multiaxial test control with data acquisition [*9*] and stress intensity range controlled fatigue-crack growth tests [*10*] among many others. The hallmark of this period, however, was that software technology was expanding to use the higher performance processors, addi-

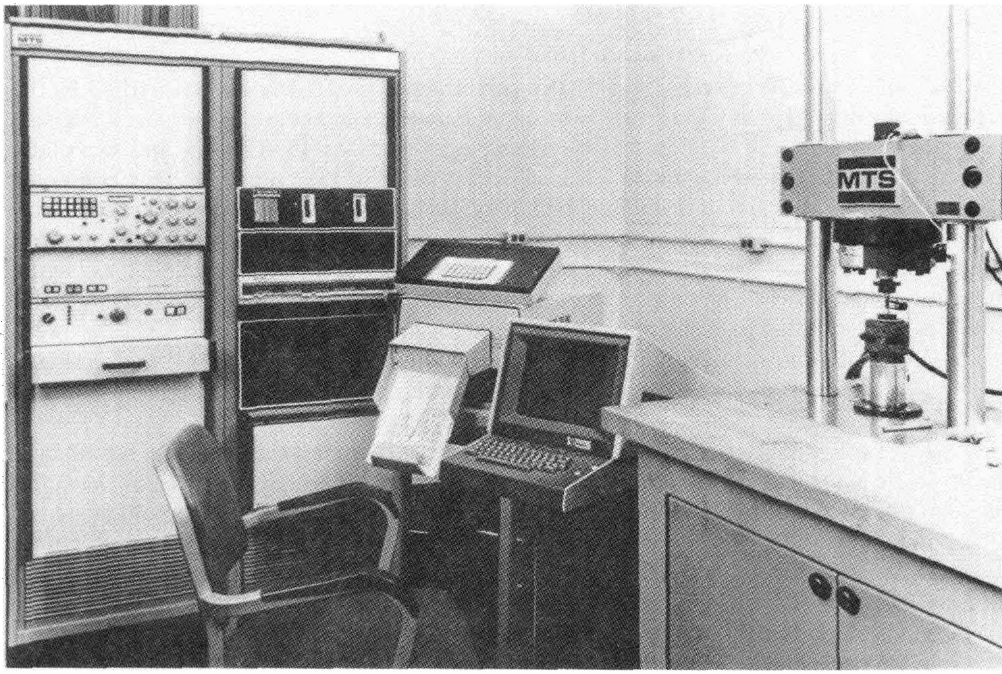

FIG. 3—*Automated test system from the early 1970s.*

tional memory and more readily available mass storage capability while, in general, maintaining the need for a single computer to be dedicated to a single test system. The predominant computer suppliers were Digital Equipment Corporation, Data General, and Hewlett Packard.

Transition Period

Increased performance in minicomputers, additional memory, and less expensive higher performance mass storage facilitated the transition from single-station systems to multistation and multiuser systems. This is the culminating period of the development and use of minicomputer systems in materials testing applications. The subsequent availability of microprocessor technology caused the next real evolution to occur. It is interesting to note that during the period from the late 1960s to the early 1980s the emphasis consisted of using a single processor for all tasks on a single system and then on multiple systems. Processor interface technology, programming languages, and operating systems concentrated on this philosophy.

The multistation/multiuser systems that evolved in the late 1970s and early 1980s used the highest performance minicomputer technology available. The Digital PDP 11/34 became, for example, a common platform upon which to implement some of these systems. Figure 4 shows a typical system configured to control five test stations performing fatigue-crack growth tests. Extended addressing allowing for increased memory (the 11/34, for example, used 18-bit memory addressing), faster disk drives (allowing for swap oriented operating systems operating systems to be usable in real time), and operating systems designed for real time multi-user activity allowed the extension to multistation systems.

Applications software did not necessarily change greatly during this time but rather was refined to utilize the higher performance. The availability of microprocessor technology prior

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