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Automated Data Acquisition and Analysis in the Mechanical Test Lab

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Abstract

Computers and enhanced control technology have made it possible to perform more sophisticated mechanical tests than ever before, as well as to allow routine tests to be run and analyzed with much greater efficiency. Automated data acquisition, storage and analysis have become key ingredients in a mechanical test facility, especially in one which utilizes a wide variety of test equipment and techniques. This paper will discuss one such mechanical test facility where many different types of mechanical tests are performed utilizing automated data acquisition, centralized data storage and finally a complex system of automated data analysis. Various systems of data acquisition will be discussed, including those used on servohydraulic and screw-driven systems, as well as those used for higher-rate, formability and creep tests. Methods for networking equipment used in such a facility will be described. Networking is an important criterion for establishing a centralized data base, and for eventually building a system of automated data analysis.

1 Introduction

The charter of this mechanical test lab is to provide the highest possible quality mechanical characterization facilities for advanced materials development programs within the Los Alamos National Laboratory. Some of the advanced materials studied in these programs may require characterization at extreme environmental conditions, such as elevated and cryogenic temperatures.

This paper will focus on some of the unique features of this lab related to automated data acquisition, networking, and data analysis. These are three key ingredients which have made this lab a high quality, efficient mechanical test facility.

The first section will describe various pieces of equipment in this lab, and in particular, the data acquisition system related to each machine. In the next section, the network as a whole will be described. Finally, the data analysis system will be outlined.

2 Automated data acquisition systems

This mechanical testing lab provides mechanical characterization services on metals, ceramics, plastics and composites at temperatures ranging from 4 to 3273 °K. Typical strain rates are on the order of 10^{-8} per second to 5 per second.

These operations include but are not limited to tensile, compression, bend, impact, and fracture toughness testing of and on a wide variety of metals, ceramics and plastics. These tests are performed over a wide variety of environmental conditions that include gaseous atmospheres, vacuum, acidic and basic liquids as well as metal salts and liquid metals. Some test methods are performed to applicable ASTM standards. Other material characterization requirements may dictate that non standard, unique, test methods must be employed.

Some of the pieces of test equipment utilized are a Gleeble 1500/20, two Instrons, an MTS 880 55 kip test system, an MTS 886 metal forming system, creep testing machines, both constant stress and constant load, an impression creep test system, a charpy impact tester, an MTS drop tower, an MTS 442 600 kip test system, a fractometer, a fracture toughness tester, an "MTS-tren", which is an Instron servo-hydraulic load frame with an MTS controller

and a vacuum chamber, and an MTS 810 test system.

Key features which make a data acquisition system successful in a large networked environment such as this are the abilities to:

- provide high accuracy and reliability,
- be capable of high speed data acquisition,
- utilize standard format for data to facilitate networking and efficient analysis,
- provide data in a convenient form for use by the researcher to perform additional specialized analysis,
- and to provide direct digital data input for numerical modelling of materials and structures.

For the test equipment in this lab, each of the above features have been addressed.

2.1 MTS 880 55 kip servo-hydraulic load frame

The MTS 880 55,000 pound system has the greatest overall capability in the section. Tensile, compression, fracture mechanics, fatigue, and flexure testing is done on this system with applied loads ranging from a few pounds to 50,000 pounds. Some materials commonly tested are U-W, Be, and W-Ni-Fe. This system is equipped with dual servo valves. For most tests the 1 and 10 gpm valves are installed. For higher frequency or faster rate testing the 1 gpm servo valve may be replaced with a 10 gpm valve. In this configuration, with dual 10 gpm valves, the actuator is capable of traveling 240 inches per minute. Normal compact tension samples can be tested at 60Hz. With the 1 gpm valve in place the maximum ram speed is 12 inches per minute.

This machine can be used for elevated temperature testing, using a quartz lamp furnace capable of 1200 °C. In addition, a 10 KW RF induction heating unit and a resistance furnace are available for use on this load frame.

Up to 8 channels of strain gages may be recorded using the instrumentation attached to this load frame. Data acquisition and test system control is performed through a DEC Micro-PDP 11/23, interfaced to an MTS 448 series controller and function generator.

Much of the specialized test software used in controlling tests is supplied by MTS. For most tests, however, a simple function generator routine is used, and the data is acquired by software written in-house. This software, which is separate from the data acquisition software, is written to acquire the raw data and to store it using a standard format. By writing our own data acquisition software for each piece of equipment, the data file format can be standardized so that it can be easily read by the data analysis software, which will be described later. Some of the commercial software has been modified to provide the standard data file output.

2.2 Two Instron screw-driven load frames, 10 and 20 kip

Two Instron screw-driven machines, with capacities of 10,000 and 20,000 pounds are used for tensile, compression and flexure tests. The crosshead on these frames have a minimum speed of 0.0002 inches per minute and a maximum speed of 20 inches per minute.

The 20,000 pound load frame has a cryostat for low temperature tensile and compression testing to 4 °K. A variety of materials are tested cryogenically, including Be, Cu, and Al. The 10,000 pound frame is used for tensile and compression tests at ambient test conditions. An environmental chamber can also be installed on this frame. The temperature range on this chamber is -70 to +315 °C.

The two screw driven Instron load frames are operated by one controller in the lab. Data is acquired by commercial software on an IBM personal computer through an HP-IB interface to the Instron controller. This computer is on the network, as are all of the computers in this lab. In this manner, the data can be stored directly onto the main file server.

2.3 MTS 810 600 kip servo-hydraulic load frame

This load frame is designed primarily for compression testing. Loads applied to the sample can range from a few pounds to 600,000 pounds, based on the size of the sample being tested. Testing is performed at ambient conditions.

2.4 Charpy impact tester and MTS drop tower

A standard instrumented Charpy impact machine capable of providing 300 ft·lbs of impact energy to the sample is used for testing to the ASTM E23 standards. In addition, several novel tests have been developed to measure coating spall behavior using this impact tester.

The MTS drop weight tower can deliver 4000 ft·lbs of impact energy to the sample. This device uses a guided drop hammer to fracture the sample.

Impact testing is performed using standard ASTM techniques. The drop tower has had an instrumented tup added. Data is collected from both the Charpy impact machine and the drop tower using a high-speed data acquisition board in an IBM personal computer which is networked. This data can be plotted as absorbed energy as a function of time.

2.5 Four creep frames

Creep tests are used to determine low strain rate, high temperature material properties. Two constant stress, one constant load, and one impression creep frame are used to perform creep tests at elevated temperatures. This involves loading the sample essentially with dead-weights, and recording the behavior of the material over long periods of time, normally hundreds of hours.

Modifications to the extensometers have been made so that dual high precision LVDT transducers can be mounted on each specimen. This allows for bending moments in the linkages to be averaged out of the strain signal that is recorded by the computer. Current sensitivity allows displacements of 1 μm to be measured easily. This resolution corresponds to strains of 0.01% in the current buttonhead specimen.

Data acquisition is performed by an IBM personal computer, which can monitor and acquire data from all four frames simultaneously. The computer is interfaced to a data logger through an HP-IB interface. Creep data is stored directly onto the main file server. Because of this, one can monitor the progress of a creep test using the data analysis software from a computer in any office, or even by logging into a workstation from home via a modem. This is especially useful for creep tests, which normally have long durations.

2.6 "MTS-tron" 20 kip servo-hydraulic 4 post load frame

This is a 20,000 pound Instron 4 post load frame controlled by an MTS 458 series controller and micro-profiler. It is equipped with a cryo-pumped vacuum chamber with a 100 KW RF induction heating power supply, directly coupled to the hot zone of the rams. The rams are 2.75 inch diameter stainless steel, with alumina insulation between the stainless steel and the hot zone, which is normally made from TZM. The design allows for replaceable platens which can be made from different materials, depending on the test temperature.

The system is used primarily for hot deformation studies on materials and for diffusion bonding. The micro-profiler can be programmed for any type of test, including a constant true strain rate tensile or compression test. The controller and micro-profiler are connected to an IBM personal computer using an MTS interface card.

2.7 MTS 810 22 kip servo-hydraulic load frame

This load frame is configured primarily for fracture mechanics and fatigue testing. The dual 10 gpm servo valves described for the 880 system above are installed on this frame. However, due to the smaller actuator, the maximum travel speed of the actuator is 300 inches per minute with no load or 60 Hz operation with a 10,000 pound load through a 0.01 inch stroke. This load frame is also configured to accept the cryostat from the 20,000 pound Instron load frame.

2.8 MTS Cup-forming and formability testing machine

This unique machine is used to evaluate the formability of sheet materials using a hydraulic bulge test. This system is also used to fabricate small sheet metal components to very tight tolerances.

2.9 Gleeble 1500/20

Samples of various configurations are tested under tension or compression in the Gleeble. The samples are enclosed in a vacuum controlled atmosphere chamber during testing. The testing cycle typically consists of subjecting the sample to a programmed thermal cycle (achieved by passing a controlled electrical current through the specimen) and simultaneously deforming the specimen in tension or compression. The sample is held in or between interchangeable water cooled jaws.

The load frame is capable of applying 20000 lbs force to the sample with crosshead speeds of 2800 inches per minute. Heating rates to 105 °C per second are possible with the direct resistance heating employed on this system. The maximum controlled temperature of the system is 3273 °K.

The Gleeble is interfaced with a Compaq personal computer for both control and data acquisition. This computer is on the network, and so data can be stored directly on the main file server.

3 Mechanical testing systems network

A DEC Microvax II has been utilized to form the foundation of a network which consists of mechanical testing equipment, personal computers, workstations, and many different peripherals. This network allows researchers to access both mechanical test data and data analysis software from their own personal computer or workstation. The network started out as a small thinwire ethernet system, connecting only the mechanical test lab and the Microvax II, as well as a couple of personal computers. It has quickly grown to a large network of over 30 personal computers and workstations, a central file server, and a variety of printers and output devices. It now spans our entire facility, including labs and offices in almost every section of our group. The network is also connected to the rest of the world via Internet. This allows us to transfer data and reports to customers and collaborators in any part of the world, which has proven to be very useful in a number of ongoing programs. The computing power has been substantially upgraded with the addition of a number of DECstations, which are very fast RISC-based workstations. These are used for data analysis, as well as various modelling activities which previously required Cray super-computers. A diagram of the

network is shown in Figure 1. Since the network is constantly growing, this figure is only a partial representation.

Figure 1: Network configuration diagram

The widest line on this diagram represents the backbone ethernet, which spans the entire building. There are a number of computers in the mechanical test lab interfaced to the various pieces of mechanical test equipment, some of which is shown in this figure. In other areas of the building, personal computers in most offices are networked. The Cisco is the local network's interface to the Internet, which is our link with the rest of the world. The computers are represented by boxes, each having its own Internet name and address. The computers are named after cars.

All of the data collected on the various mechanical test machines (as well as data collected in other labs in the building) is stored on the central file server, named Mustang, which has a current capacity of approximately 3 gigabytes. This can be accessed by any of the computers on the network.

Figure 2 is a graphical representation of this concept, showing how the various data is collected and stored on the central file server, for access by the rest of the network.

Figure 2: Data from tests stored on central file server for access by personal computers and workstations

One method of access is through the data analysis system, which will be outlined in the following section. Data can also be accessed directly by any of the workstations or personal computers. For example, one could perform a specialized analysis, by loading the data into a spreadsheet. This sharing of data and software is represented graphically in Figure 3.

The network has been very successful so far. Members of the group in all sections of the building have utilized both its vast file storage capabilities and the computing power of the DECstations. The network allows the transfer of large data files quickly and easily from one machine to another. It also allows information such as data and reports to be shared easily among researchers, both within the group and outside the lab.

Figure 3: Personal computers and workstations share data and software via the central file server

4 Data analysis software package

The data analysis software package allows data to be analyzed in a very efficient, accurate manner. It is flexible enough to analyze many different types of tests, and, because of its modular structure, is easily changed to analyze data using any test techniques that may be developed in the future. The software is extremely user-friendly, so that anyone may analyze their own data, whether or not they have ever used a computer. This way, the researcher requesting the test has the opportunity to analyze their own results if they wish, since they sometimes know best what they are looking for in the data.

The software is easily accessible throughout the building by any of the personal computers or workstations on the network. The program uses two libraries of graphical routines called CGS and CGSHIGH which were developed at Los Alamos National Lab. The analysis software runs on the

DECstations, so any computer with the appropriate graphics terminal emulation software may access it. Currently, the user interface uses Tektronix graphics calls, and so every computer uses a Tektronix 4105 emulator to run the software. There are plans to include an X windows user interface as well. Most user input can be provided with a mouse pointing device or arrow keys.

In this section, a sequence of steps performed to analyze a simple data file from a tensile test will be described. It is assumed that the user has logged in using the mechanical test analysis account password, which starts the program automatically. In screen 1 below, the initial screen prompts the user to input the type of test they would like to analyze; a stress-strain or creep test. In this and all further cases, the user makes their selection by pointing with the mouse and clicking, or moving the cursor with the arrow keys and hitting space. The creep analysis routines, which will not be described here, have very similar options to the stress-strain analysis routines. However, under the creep menu there are some additional analysis routines such as "theta-projection" programs, which use sophisticated curve fitting formulas.

After the user selects the type of test to analyze, screen 2 prompts the user for a directory in which to find the file they would like to choose. These directories are normally organized by project, or sometimes by material. Screen 3 prompts for the file name within the chosen directory.

DATA ANALYSIS MAIN MENU	CHOOSE DIRECTORY OR FILENAME WITH CURSOR	CHOOSE DIRECTORY OR FILENAME WITH CURSOR
STRESS-STRAIN DATA	ARCHIVE/	1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100. 101. 102. 103. 104. 105. 106. 107. 108. 109. 110. 111. 112. 113. 114. 115. 116. 117. 118. 119. 120. 121. 122. 123. 124. 125. 126. 127. 128. 129. 130. 131. 132. 133. 134. 135. 136. 137. 138. 139. 140. 141. 142. 143. 144. 145. 146. 147. 148. 149. 150. 151. 152. 153. 154. 155. 156. 157. 158. 159. 160. 161. 162. 163. 164. 165. 166. 167. 168. 169. 170. 171. 172. 173. 174. 175. 176. 177. 178. 179. 180. 181. 182. 183. 184. 185. 186. 187. 188. 189. 190. 191. 192. 193. 194. 195. 196. 197. 198. 199. 200. 201. 202. 203. 204. 205. 206. 207. 208. 209. 210. 211. 212. 213. 214. 215. 216. 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1014. 1015. 1016. 1017. 1018. 1019. 1020. 1021. 1022. 1023. 1024. 1025. 1026. 1027. 1028. 1029. 1030. 1031. 1032. 1033. 1034. 1035. 1036. 1037. 1038. 1039. 1040. 1041. 1042. 1043. 1044. 1045. 1046. 1047. 1048. 1049. 1050. 1051. 1052. 1053. 1054. 1055. 1056. 1057. 1058. 1059. 1060. 1061. 1062. 1063. 1064. 1065. 1066. 1067. 1068. 1069. 1070. 1071. 1072. 1073. 1074. 1075. 1076. 1077. 1078. 1079. 1080. 1081. 1082. 1083. 1084. 1085. 1086. 1087. 1088. 1089. 1090. 1091. 1092. 1093. 1094. 1095. 1096. 1097. 1098. 1099. 1100. 1101. 1102. 1103. 1104. 1105. 1106. 1107. 1108. 1109. 1110. 1111. 1112. 1113. 1114. 1115. 1116. 1117. 1118. 1119. 1120. 1121. 1122. 1123. 1124. 1125. 1126. 1127. 1128. 1129. 1130. 1131. 1132. 1133. 1134. 1135. 1136. 1137. 1138. 1139. 1140. 1141. 1142. 1143. 1144. 1145. 1146. 1147. 1148. 1149. 1150. 1151. 1152. 1153. 1154. 1155. 1156. 1157. 1158. 1159. 1160. 1161. 1162. 1163. 1164. 1165. 1166. 1167. 1168. 1169. 1170. 1171. 1172. 1173. 1174. 1175. 1176. 1177. 1178. 1179. 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the type of test being run, the name of the test, and some other crucial information, such as test sample dimensions. The first line of this header relays to the data analysis program how many header lines there are, how to interpret the information found in the rest of the header, how many columns of raw data to look for in the file, and what each column represents. By storing the data in this fashion, the user of the data analysis software need not know any information about the data file, how it was taken, or even which machine was used to acquire the data, since the data analysis software can interpret this information from the data file.

Screen 4 shows the main menu for analyzing data from a stress-strain curve. Before analyzing the data, it is sometimes required to edit the stress-strain data file. This is because there is sometimes erroneous data in the file after the test is over, for example. There can also be electronic "glitches" which cause erroneous data points. Rather than editing the data by hand, or by importing it into a spreadsheet, this program allows the data to be edited graphically. The next few screens show the sequence of steps involved in one such edit operation. By clicking on "edit stress-strain data file", screen 5 prompts for a variety of edit operations. This particular data file appears normal, except for some extra data after the test was over. By clicking on "set min and max for curve" in screen 5 the stress-strain curve can be easily cleaned up. Screen 6 prompts for the minimum and screen 7 prompts for the maximum real data point. Note that in all of these operations, the program will choose the point closest to the cursor location—the user does not have to click on the precise location of the point.

Screen 4

Screen 5

Screen 6

Screen 8 assures that the program has chosen the correct data points by marking them with red asterisks and prompting the user to make sure that

Screen 7

Screen 8

Screen 9

this is really what they want to do. The user is also given the option to redo this operation. Screen 9 brings the user back to the edit menu, and displays the edited data file. At this point, the user may continue editing, or return to the main menu. If the user chooses to exit, the program asks if the data file should be stored in a "standard" format. This saves the edited data, so that the edits do not have to be repeated every time the file is analyzed. It also stores the data as stress-strain data, so that the raw load-displacement data does not have to be reduced again.

Now that the data has been edited, the program brings the user back to Screen 10. The next few screens show the steps involved to calculate elastic modulus and yield strength. We have found that the best way to calculate modulus is through a graphical approach. There are many computer programs available to calculate modulus using a variety of numerical approaches. The modulus calculated by this program, however, is done purely based on the user choosing the correct limits between which the program calculates a linear fit to the data. We have found that this approach normally provides just as accurate results as most of the numerical approaches.

In screens 11 and 12, the user is prompted for the minimum and maximum data points between which to calculate the modulus. The program marks these choices with red asterisks, and in screen 13, plots the calculated modulus. The minimum and maximum values chosen in this example are marked with asterisks in screen 13. The program also prints the value of the calculated modulus at the top of the screen. The user can choose to repeat this operation as many times as needed, to assure that the calculated value is accurate. If it is, the program then asks if a yield strength should be calculated. The user is given a choice as to the offset to use in this calculation

(normally 0.2%). In screen 14, the stress-strain curve is replotted, showing the modulus and yield strength lines, and the calculated values of the elastic modulus, yield strength, and ultimate strength, as well as the test name, at the top of the screen. The user is given an opportunity to output this to a pen plotter or other graphics output device, and then returned to screen 15.

The third option on screen 15 allows the user to simply plot the stress-strain curve without the modulus and yield strength lines, as in screen 16. If the modulus and yield strength has been calculated through option 2, the program will provide those values at the top of the screen.

The remaining menu options shown in screen 15 will not be discussed here, as they are fairly self-explanatory. The creep data analysis main menu is fairly similar to the stress-strain data analysis main menu shown in screen 15. The creep portion of the program does include some additional curve fitting routines, which use theta projection analysis techniques. This is one

Screen 15

Screen 16

method which can be used by the researcher to predict long term creep behavior from relatively short term creep experiments.

5 Concluding remarks

This laboratory has quickly grown from a few pieces of test equipment and a couple personal computers to a large network connecting many machines, computers, and other devices. This progress has proved extremely valuable in maintaining efficient operations. One example of the usefulness of this network is a certain program which is a collaborative effort with an industrial partner on the opposite side of the country. The researcher involved is able to analyze the data from their tests while sitting in their office. They can then write a report incorporating this data, and e-mail the report across the country. In this manner, the partner on the opposite side of the country can have instant access to not just an "executive summary" of their results, but to the actual raw data from their mechanical tests.

It has been shown how this particular laboratory has integrated automated data acquisition, networking, and data analysis into an extremely efficient, high quality mechanical test facility. Although this laboratory may differ from others in the details of its network configuration and analysis software, it is very important to address these three key factors when planning such a laboratory, especially a facility which utilizes a wide variety of test equipment and techniques.