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**DESIGN AND FABRICATION OF A UNIQUE ELECTROMECHANICAL MACHINE
FOR LONG-TERM FATIGUE TESTING**

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DESIGN AND FABRICATION OF A UNIQUE ELECTROMECHANICAL MACHINE FOR LONG-TERM FATIGUE TESTING*

K. W. Boling

ABSTRACT

An electromechanical machine has been designed and fabricated for performing long-term fatigue tests under conditions that simulate those in modern power plants. The machine is now commercially available. Its advantages over current electrohydraulic machines are lower initial cost, minimum maintenance requirements, and greater reliability especially when performing long tests. The machine operates in closed-loop fashion by utilizing continuous feedback signals from the specimen extensometer or load cell, and it is programmable for testing in strain or load control. The maximum run rate is 0.056 mm/s (0.134 in./min), maximum ram travel is 102 mm (4 in.), and load capacity is ± 44 kN (± 10 kips). Induction heating controls specimen temperatures to 1000°C.

INTRODUCTION

Fatigue tests with long strain or load hold times in tension and/or compression at minimum strains with variable strain rates are required to simulate the service conditions of materials in some power plant applications (Fig. 1). The machine described herein meets this requirement. It is well suited for long operation (6 months or more per test) because its electromechanical constituents require minimum maintenance. The oil used in the present electrohydraulic machines must be changed periodically, and there is no assurance that the test specimen will not be damaged if the hydraulic pump fails or power is lost. The objective of our effort was to design an improved test system for conducting long-term, time-dependent fatigue tests or creep-fatigue interaction tests.

BASIC OPERATION

A jactuator (worm-gear jack) driven accurately by a stepping motor through a reductor (reduction gearbox) applies strain or load to the test

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Fig. 1. Typical loading conditions for fatigue testing with long hold times. (a) Tension and compression hold. (b) Tension hold only.

specimen (Fig. 2). The stepping motor is controlled by a position controller, which drives the motor to produce a strain or load rate equal to the programmed rate of a DATA-TRAK function generator. The position controller also allows manual up and down operation for inserting and removing specimens.

CONSTITUENTS

FRAME, GEAR TRAIN, AND DRIVE MOTOR

The basic mechanical constituents of the machine are diagrammed in Fig. 3. The H-type frame is simply constructed, with the gear train, drive motor, and ram located in the bottom section and with a crosshead at the top adjustable for height. The gear train includes a spool that is driven up and down by the jactuator. Four equally spaced shafts maintain axial alignment of the spool and the attached ram by means of eight Thomson

Fig. 2. The closed-loop control system compensates for elastic strain in the load train, thereby accurately controlling the strain or load applied to the test specimen.

Fig. 3. The ram is attached to a spool in the lower part of the machine's frame, and a stepping motor drives the spool up and down by means of a jackulator. Four alignment shafts restrain the spool radially.

linear ball bushings (four in the top of the spool and four in the bottom). The alignment is equivalent to that of a die set. Adjustable ball nuts bolted to the center of the spool (one at the top and one at the bottom) connect the spool to the ball-screw shaft of the jactuator. The spool moves axially when the jactuator shaft is rotated by the stepping motor. The stepping motor drives the jactuator through a reductor, with a ratio of 5 to 1. The gear-train and ram rate functions obtainable are shown in Fig. 4 along with component specifications.

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STEPPING MOTOR		REDUCTOR		JACTUATOR	SPECIMEN
SERIES M12-FD-06 MAXIMUM TORQUE = 6 N·m (52.5 in·lb) MAXIMUM SPEED = 0.0075 s/STEP (40 rpm)		MODEL T-133 RAT 3:5:1 EFFICIENCY = 0.8		MODEL KDM-2806 LOAD CAPACITY = 44 kN (10 kip) WORM GEAR RATIO = 24:1 TURNS FOR 25 mm (1 in) RAISE = 50.667 REQ'D TORQUE FOR 44 kN (10 kips) = 10 N·m (90 in·lb)
1. TORQUE CAPACITY FOR 44-kN (10-kip) LOAD ON SPECIMEN	2.5 N·m (22.5 in·lb)	2.5 (15:108)	10 N·m (90 in·lb)		$P_{max} = 44 \text{ kN (10 kip)}$ $\sigma_{max} = 2192 \text{ MPa (318 ksi)}$
2. SPEED CAPACITY FOR 44-kN (10-kip) LOAD ON SPECIMEN	34 RPM	$\frac{34}{5}$	6.8 RPM	$\frac{6.8}{50.667}$	0.056 mm/s (0.134 in/min) MAXIMUM RAM RATE

Fig. 4. Summary of component specifications and of the component interactions that provide the machine's capabilities.

SPECIMENS, EXTENSOMETER, GRIPS, AND LOAD CELL

Figure 5 shows our recommended uniform-gage specimen, which meets standard E 606 of the American Society for Testing and Materials (ASTM). Specimens with other shapes or dimensions or with tubular cross sections also can be tested successfully within the scope of the ASTM recommended practice. Care must be taken in machining the uniform-gage specimens to blend the shoulder radius with the gage diameter to avoid undercutting. The shoulder radius should be as large as possible within the limitations of the specimen length to minimize the stress concentrations.

Fig. 5. A specimen with concentric diameters is required to avoid bending moments and thereby produce valid test data. Dimensions in millimeters.

The particular hinge-type axial extensometer that we use is shown in Fig. 6. It has ceramic probes and a linear variable differential transformer (LVDT) for strain measurement with a magnification ratio of 1 to 1.

Any standard fatigue grip system and high precision tension-compression load cell that meet ASTM requirements should produce valid fatigue data. We recommend the use of a load train with minimum length and with a Wood's-metal pot to obtain the required axial alignment of the grips. Figure 7 shows the conventional load train used on the machines in our laboratory.

PROGRAMMER

The programmer used is the Model 73211 DATA-TRAK purchased from Research, Inc., Minneapolis; however, similar programmers that interact suitably with the other components could be used. The Model 73211 DATA-TRAK is a microprocessor programmer with programmed profiles (single or dual analog set points) for process control versus time. The outputs are industry standard control signals 0 to 5 V, 0 to 10 V, 0 to 15 V, or 4 to 20 mA. Programs are generated by best-fit straight-line segments to

Fig. 6. Typical axial extensometer used in long-term creep-fatigue tests.

the desired stored profile and then accessed as required. Program capacity up to 51 segments is available and is used for the best straight-line fit of the analog program desired. Groups of segments can be looped back to recycle portions of the program and then continued on. The time duration of the segments is 0 to 1999, which can be programmed in seconds, minutes, or hours. The crystal-controlled clock also includes the time of day and can be used to start the program at a preset time.

STRAIN OR LOAD CONDITIONER

The strain or load conditioner was designed by J. T. Hutton, Instrumentation and Controls Division, Oak Ridge National Laboratory. The strain channel consists of LVDT sensor and conditioning components purchased from Automatic Timing and Controls Company, King of Prussia,

Fig. 7. The load train includes a Wood's-metal pot to obtain the required axial alignment of the specimen grips.

Pennsylvania. The load channel has standard analog integrated circuits that function with a strain-gage-type load cell purchased from Strainert Company, West Conshocken, Pennsylvania.

POSITION CONTROLLER

The position controller was designed by J. T. Hutton and D. L. Thomas, Instrumentation and Controls Division, Oak Ridge National Laboratory. It compares a programmed command signal from the DATA-TRAK programmer with a conditioned feedback signal (load or strain) from the strain or load conditioner; the resulting dc error signal is an input to the stepping-motor translator, which in turn drives the motor. A selector switch is

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Fig. 8. One of the long-term fatigue machines with $\pm 44\text{-kN}$ ($\pm 10\text{-kip}$) capacity used at Oak Ridge National Laboratory for testing specimens in air to 950°C .

available for strain or load control, and a manual up-down function is used for changing specimens. This closed-loop operation eliminates concern for elastic strain in the system and provides very accurate control of the strain or load on the specimen.

TEMPERATURE CONTROL

We use induction heating to provide the desired specimen test temperature; however, a resistance-type furnace can be used if access for the extensometer is provided. The method of heating the specimen depends on the shape and size of the specimen, test temperature, grip type, and test environment.

CONCLUSION

The electromechanical long-term creep-fatigue machine is a unique testing machine. It is excellent for performing mechanical properties tests that simulate the cyclic creep and fatigue conditions imposed on materials in some high-temperature energy-conversion plants. It requires minimum maintenance, provides rigid alignment with zero backlash on load reversal, and appears to fill a need in the creep-fatigue field as longer hold times are required. It is also well suited for long-term relaxation testing.

The machine's load capacity is ± 44 kN (± 10 kips), its ram rate is 0 to 0.056 mm/s (0 to 0.134 in./min), and its maximum ram travel is 102 mm (4 in.). It is being used in our laboratory (Fig. 8), and units based on our design are commercially available.

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