

CASE HISTORY

Accelerated fatigue testing

*David Spenciner**

*Thielsch Engineering
Cranston, R.I.*

Muhammed Ovase

*United States Postal Service
Norman, Okla.*

Postage stamps on every first-class mail item forwarded by the United States Postal Service (USPS) are canceled using an Advanced Facer Canceler System, or AFCS, which incorporates a highly mechanized clutch-brake assembly. Because the clutch-brake assembly is prone to failure and needs to be serviced about every six months, several million dollars are spent each year to maintain these machines.

To trim costs, USPS is developing a brushless, servomotor-based system called Smart Servo, which has an estimated ten-year life span. The development program for this component involved accelerated fatigue testing and failure analysis of machine prototypes developed by two different vendors.

The testing program was undertaken to provide both a basis to predict the life expectancy of the new equipment, and a baseline against which vendor-supplied products could be evaluated and compared. Accelerated fatigue testing was used to simulate the actual service loading conditions experienced by stamp-canceling equipment.

System design criteria

A brushless servomotor provides more acceleration capacity than any other motor type, while minimizing the need for maintenance. In addition, better heat dissipation results in an increase in the "mean time between failures" (MTBF), and the absence of brushes eliminates carbon buildup. The motor drive is required to index a load inertia of 291 g·m² (1.5 oz·in.²), with each revolution taking no more than 36 msec. Maximum velocity is 1900 rpm, and the

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maximum time allowed for the acceleration and deceleration portions of the rotation is 5 msec. This constrains the system to have a torque-to-inertia ratio that allows an acceleration of 40 krad/sec².

To ensure that the die and envelope speeds are equal, it is necessary to electronically gear the die to the AFCS transport clock during the constant velocity portion of the cycle. Each indexed cycle repeats once every 50 msec so that up to 20 envelopes can be processed every second.

The motor-drive assembly communicates with AFCS controls via several signal inputs, including machine start, canceler service, clutch fire, lead/trail, transport tachometer, jog up, jog down, and home. It must also provide Smart Servo output based on move progress.

Because the signals have different voltage characteristics, optical isolation is required, and the system must have the capability of knowing its position on power up without making any homing-type moves. In addition, the home reference must be adjustable.

The postal service required that the new system be a drop-in replacement for the current system, conforming to all dimensional constraints both above and below the deck.

Also, a guard was deemed necessary to prevent excess ink and/or dust from penetrating to the front bearing.

Required service life was set at a minimum of ten years with a MTBF greater than 15,000 hours.

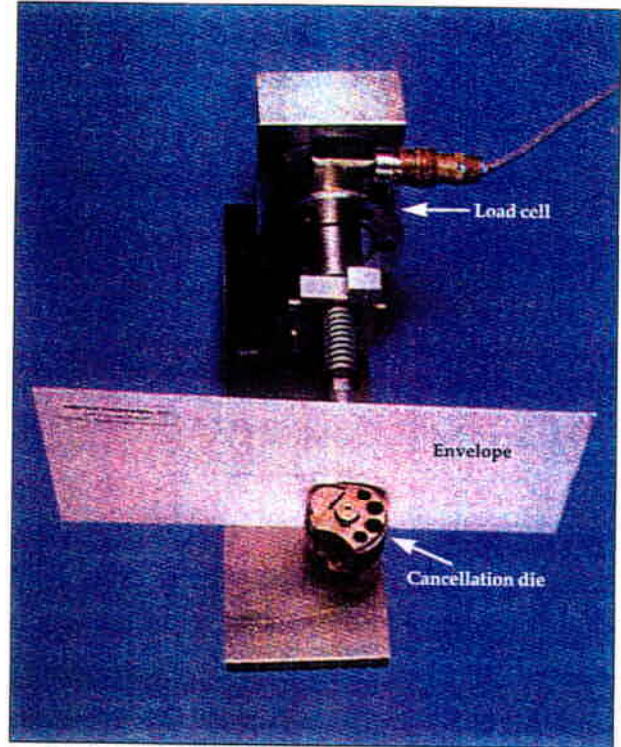


Fig. 1 — Loads imposed by envelopes on a postage-cancellation roller-die assembly are measured by passing an envelope through an assembly from an actual advanced facer canceler system (AFCS) that is connected to a strain-gaged load cell.

Model cancellation system

A model cancellation system was constructed before testing to determine loading imposed on the equipment by envelopes of varying thicknesses. The model consists of a roller and die assembly from an actual AFCS connected to a strain-gaged load cell, as shown in Fig. 1.

By preloading the system, a peak load of 59 kg (27 lb) is produced by simply spinning the die against the rubber roller. Load profiles for envelopes of various thicknesses were recorded by passing the envelopes through the assembly. Thicknesses were selected to provide the full size range encountered by the AFCS; from 0.25 mm (0.01 in.), which is equivalent to an empty envelope, to a maximum of 6.35 mm (0.25 in.). Loads on the Smart Servo were accurately simulated in fatigue testing based on these data.

Fatigue testing and analysis

Accelerated fatigue tests were con-

Envelope loading on AFCS roller-die assembly

Sample	Envelope thickness, mm (in.)	Peak load, kg (lb)
1	0.25 (0.010)	13 (28)
2	1.58 (0.063)	15 (33)
3	3.18 (0.125)	18 (39)
4	4.76 (0.188)	20 (43)
5	6.35 (0.250)	21 (46)

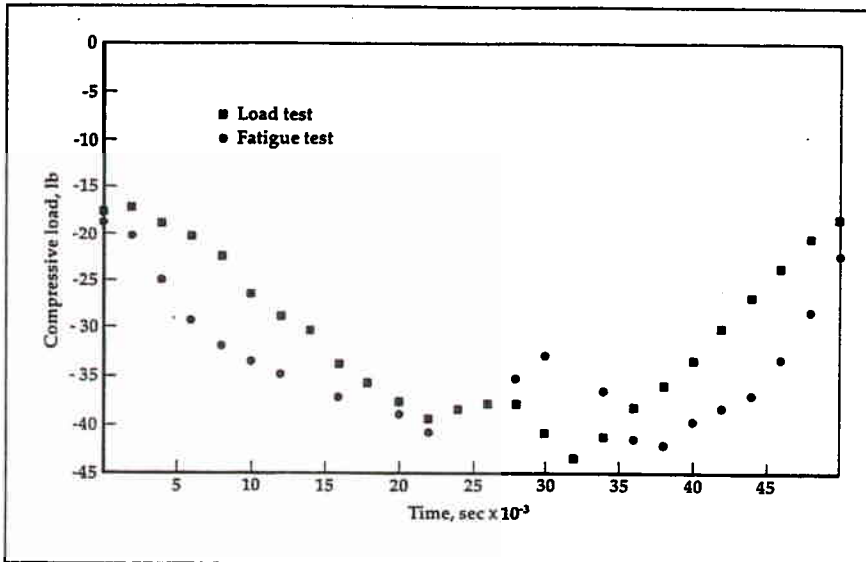


Fig. 2 — A plot of envelope load (compressive stress) vs. time for a load test and typical fatigue cycle shows that the load profile is closely duplicated in the fatigue test.

ducted on an Instron Corp. servo/hydraulic load frame with digital data acquisition. Test fixtures were designed to allow simultaneous testing of two servomotors, ensuring that both motors were exposed to exactly the same load profile. The servomotor shafts rotated at 20 Hz while being loaded in a cantilever mode by the hydraulic actuator. Figure 2 shows a typical plot of compressive load vs. time for a load test and a fatigue test, indicating that the load profile is closely duplicated in fatigue testing. The amplitude of the waveform varies to simulate the entire range of envelope widths canceled.

An AFCS cancels several envelopes per second and operates an average of four hours per day, which is equivalent to about 20 million envelopes per year and about 200 million envelopes over a ten-year period. However, due to time constraints, the motors in the test program were subjected to only about 160 million cycles, or a simulated eight years of use.

The shaft and bearings typically are the weakest parts of the motor, and two of the motor shafts failed in

fatigue at the intersection of a step in shaft diameter and a keyway. The shafts were tested for hardness and chemical composition, and the shaft microstructure was evaluated to determine material type and heat treatment.

The shaft material from both vendors was AISI 1144 steel in the normalized condition with hardnesses of 28 and 31 HRC. The microstructure of both shafts consisted of islands of ferrite in a matrix of pearlite, which is typical of a normalized 1144 steel (Fig. 3). This material is relatively inexpensive, but has lower fatigue properties than those of more highly alloyed steels, such as AISI 4140 or 4340.

The motor internal bearings and races were examined for wear, spalling, and fretting. Three sets of bearings were analyzed: unused, at about 20 million cycles, and at about 160 million cycles. Although the bearings were packed with grease, they squealed intermittently during fatigue testing.

However, examination by a stereomicroscope and a scanning electron microscope did not indicate any condition that would cause the bearings

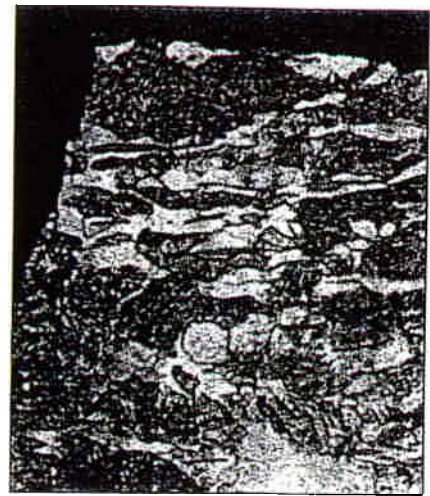


Fig. 3 — Microstructure of the AISI 1144 servomotor shaft consists of islands of ferrite in a pearlite matrix, typical of a medium-carbon steel in a normalized condition. Shaft hardness is about 30 HRC. Magnification: 500%. Etchant: 2% Nital.

to be a limiting factor in the ten-year life span of the motors.

Recommendations

Several recommendations were made based on the results of the fatigue-testing program:

- Make the shaft from a more highly fatigue-resistant alloy, such as AISI 4340, preferably in the quenched and tempered condition.
- Redesign the keyway that provides a connection to the cancellation die to reduce stress concentrations.
- Eliminate stress raisers (crack-initiation sites) at the sharp corners located at changes in shaft diameter by incorporating a minimum fillet radius of 1.5 mm (0.06 in.).
- Redesign the shaft overall to minimize other stress concentrators.

Incorporation of these recommendations led to design changes and lower costs, and resulted in an improved product. ■

For more information: Mr. Spenciner is a mechanical test engineer, Fatigue Testing Laboratory, Thielsch Engineering Inc., 195 Frances Ave., Cranston, RI 02910; tel: 401/467-6454; fax: 401/467-2398. Mr. Ovase is an engineering analyst, Maintenance Technical Support Center, United States Postal Service, 600 West Creek Rd., Norman, OK 73070-6708; tel: 405/573-2327; fax: 405/573-2327.

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