EQUIPMENT QUALIFICATION TESTING - A PRACTICAL APPROACH

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1 ABSTRACT

When nuclear safety equipment is credited with a *Required Safety Function* it must properly perform that function to facilitate safe control and/or shutdown of the plant during a design basis accident. When such equipment is required to be *environmentally* (EQ) and/or *seismically* qualified (SQ) for safety related use in CANDU nuclear power plants, the preferred method of qualification is by type testing. The qualification testing process requires that the test specimen equipment be subjected to the aging stressors associated with the normal service conditions that it would experience during it's required qualified (or service) life. Following the aging process, the test specimen is in a condition representative of that in which it would be at the end of its service life in the plant. The test specimen is then subjected to a simulated accident during which it must satisfy *performance requirements* thereby demonstrating that it can perform its required safety function.

The performance requirements specified for the qualification testing must be designed to ensure that satisfactory performance of the safety function is demonstrated during the qualification program. This paper provides descriptions of practical methods used in the deriving and satisfying of relevant performance requirements during the qualification testing of safety related equipment.

2 DETERMINATION OF PERFORMANCE REQUIREMENTS FOR COMPONENT TESTING

Required safety function is initially specified at the safety system level however qualification testing of complete systems or in some cases complete assemblies is not always feasible or even possible. In these instances, individual components of the system or assembly are tested separately. In order to qualify individual components from a system, the specific role of each component in the performance of the system level safety function must be understood and documented so that meaningful performance requirements can be derived for use in the component testing. It is generally accepted that when qualification of individual components is achieved using appropriate performance requirements, the components can be interconnected in a functioning system. Qualification of the individual elements demonstrates qualification of the complete system.

It is often unnecessary to test complete devices, but to only test those components whose performance can possibly be effected by the normal and accident conditions. For example, many valve assemblies are composed of valve bodies having no non-metallic components while the mating actuators and accessories contain significant non-metallic components including pneumatic diaphragms and o-rings composed of elastomers or the polymeric components associated with electric actuators. As it is accepted that metallic components will not suffer aging related degradation, it is a common and cost effective practice, in these situations, to subject only the actuator and accessories to the qualification testing program. However, when taking this approach of testing a component such as an actuator, it is of vital importance that realistic performance requirements (related to the safety function of the complete valve assembly) be selected and demonstrated for that component.

One of the safety related functions specified for a control valve assembly might be that the valve operate within a certain time limit. In qualification testing of the actuator alone, it would not be sufficient to simply demonstrate that the actuator alone could operate in the required time. For true modelling of system operation, it is necessary to simulate all significant mechanical loads exerted by the valve components on the actuator. Satisfactory speed of operation of the actuator against the required load could then be demonstrated during the qualification program.

The methods used in qualification of a containment isolation butterfly valve actuator and a local air cooler motor are described in the following text.

3 QUALIFICATION OF PNEUMATIC SPRING RETURN ACTUATOR

As part of an order to supply actuators for use on the containment isolation butterfly valves for the Wolsong 2, 3 and 4 stations, Flo-Tork Inc. of Orrville, Ohio, undertook to gain generic EQ and SQ of their NMS line of pneumatic, spring return actuators by type testing of a single specimen. The test specimen was selected from the range of actuators methods outlined in the governing AECL specifications and in IEEE-382, Appendix D. Qualification parameters were defined in a specification issued by Flo-Tork to MEC while the test method was designed to meet the requirements of the AECL EQ and SQ specifications applicable to the Wolsong project. The primary objective of the test program was to gain EQ and SQ for service in the Wolsong stations. A secondary objective was to seismically qualify the line of actuators to the requirements of IEEE-344 and IEEE-382 such that they would be suitable for service in U.S. PWR and BWR plants. In order to satisfy this secondary objective, it was necessary to carry out a seismic test program on a test actuator of a different size and use the results of the two test programs to justify IEEE seismic qualification of the line.

3.1 Actuator Performance Requirements

The line of actuators for which qualification was desired contained actuators suitable for service on butterfly valves ranging in size from 6" to 36". The specific valves in the Wolsong plant which were to be fitted with the qualified actuators were 6", 10", 12", 16", 18", 30" and 36". The safety functions and minimum acceptable performance requirements specific to each of these valves were taken from the AECL valve specification sheets and an enveloping set of requirements was established for testing of a single actuator suitable for service on a 16" valve. In order to arrive at relevant actuator loading criteria, it was necessary to study the ultimate 16" host valve in order to determine the actuator output necessary to drive it at the required speeds against the anticipated internal pressures and flows. The performance which would be demonstrated during the ensuing qualification testing of the 16" actuator program was then extrapolated, using IEEE-382 guidelines and the extrapolated values were compared to the required output values for the other valve sizes in order to ensure that qualification of the entire actuator line could be justified by extension of the test results.

The performance requirements which were derived for testing of the single actuator were as follows;

3.1.1 Speed of Operation

The actuator was required to operate in pneumatic mode in 2.0 seconds or less against a load of 660 N-m (5800 in-lb) minimum and return in spring mode in 2.0 seconds against a load of 550 N-m (4700 in-lb) minimum under all normal service and accident conditions.

3.1.2 Output Torque

During operation under normal service and accident conditions, the actuator output torques curves, in spring and pneumatic modes, were to be within ±10% of the derived enveloping curves.

3.2 Actuator Qualification Method

During the course of the qualification testing program, the test specimen actuator was subjected to the testing summarized in Table 1.

3.3 Monitoring of Actuator Performance During Test Program

The test program included a variety of aging and accident simulations during which it was necessary to provide a means by which specific resistive torque loads could be imposed upon the test specimen actuator and by which the various performance parameters could be monitored. The monitoring equipment would be required to be readily adaptable for mounting to the actuator while the actuator was being subjected to the various simulations of normal and accident service conditions including those for harsh conditions (MSLB/LOCA) and seismic. In order to meet this requirement, the monitoring system (Figures 1 and 2) was developed. The following test equipment was employed;

- 65 mm D x 330 mm stroke hydraulic cylinder
- 75 mm D actuator output shaft with torque arm
- Mounting brackets and adaptors
- 110,000 N load cell
- Linear Voltage Differential Transformer (LVDT)
- Hydraulic controls
- 486 PC with A/D convertor board
- 25 mm solenoid air valve

The hydraulic cylinder and controls provided a means by which the actuator could be loaded and position controlled during output torque measurement tests in both the pneumatic and spring return modes of operation. The output torque at specific angles of rotation was calculated by software running on the computer using load output from the load cell, angular position output from the LVDT and taking into consideration the geometry of the loading set up. Operating speed times were calculated using the time difference between the initiation of pneumatic input to the actuator and indication from the LVDT that the desired output shaft position had been attained.

3.3.1 Monitoring of Actuator Performance During Harsh Environment Simulation

During harsh environment testing it was required that the actuator demonstrate its full range of performance while being subjected to the specified (150°C, 400 kPa(g), 100% humidity) accident steam environment. In order to accomplish this it was necessary to locate the monitoring equipment outside the test chamber so that it would not be subjected to the harsh conditions. This was facilitated by fitting an extended output shaft to the actuator. The shaft passed through a sealing o-ring in the chamber bulkhead and was connected to the monitoring equipment outside the chamber. A schematic of the set up for the harsh environment test is presented in Figure 3.

At intervals during the harsh environment test, the performance of the following functions was evaluated;

- Output torque - pneumatic operation (for both 550 kPa(g) and 860 kPa(g) air supply)
- Output torque - spring return operation
- Speed of operation - pneumatic actuation (against minimum load of 660 N-m)
- Speed of operation - spring actuation (against minimum load of 550 N-m)

Plots of the output torque demonstrated during the harsh environment simulation can be seen in Figure 4.

A plot comparing the harsh conditions actually imposed during the test to those required under the specifications is presented in Figure 5.

3.3.2 Monitoring of Actuator Performance During Seismic Testing

In order to provide justification for both line and hard mounted applications the test specimen actuator was subjected to two types of seismic qualification tests.

3.3.2.1 Single Frequency (Sine Beat) Tests

For line mounted equipment, the predominant earthquake motion will be single frequency. The sine beat test method simulates this effect by subjecting the test specimen to a series of single frequency sine beat tests at one third octave intervals between 2 and 32 Hz. Following the test, the adequacy of the simulated seismic motion is evaluated by comparing the Table Input Motion (TIM) for the test to the Required Input Motion (RIM) specified in the governing documents. The sine beat test is acceptable if the RIM is enveloped by the TIM at all test frequencies and if the required performance of the test specimen is demonstrated satisfactorily.

It is a requirement of the governing IEEE specifications to demonstrate the function of the test specimen actuator at all test frequencies but, as the test duration at each frequency was relatively short, it was not possible to demonstrate the full range of performance of the actuator, at each beat frequency, without repeating the sine beat tests four times. This would have introduced undue conservatism into the test program. It was therefore determined that the performance testing at each frequency would be limited to the demonstration of satisfactory speed of operation against a constant torque load. Figure 6 contains a graphical presentation of the results of the performance testing carried out during sine beat seismic testing.

3.3.2.2 Multi Frequency (Broadband Random Vibration) Tests

The earthquake motion to which a component hard mounted to the plant structure would be subjected is most closely simulated by a random multifrequency test during which, for SQ of the test specimen to be justified, the Table Response Spectrum (TRS) must envelope the Required Response Spectrum (RRS) and the required performance must be demonstrated. As the governing specifications required a minimum test duration of 30 seconds, it was possible to demonstrate the full range of performance of the test specimen actuator while subjecting it to seismic motion exceeding the required levels. Figure 7 contains a plot of the TRS relative to the RRS.

3.4 Results of Actuator Qualification Test Program

The test specimen actuator successfully demonstrated the specified required performance during all phases of the testing summarized in Table 1. The results of this testing were used in conjunction with extrapolation analysis to justify seismic and environmental qualification of the Flo-Tork NMS series of actuators to Wolsong 2,3 and 4 requirements and, in addition, to justify seismic qualification of the actuators to the requirements of IEEE-344 and IEEE-382.

4 QUALIFICATION OF LOCAL AIR COOLER MOTORS

In 1995 MEC Ltd carried out a test program designed to provide EQ of the replacement Local Air Cooler motors for New Brunswick Power, Point Lepreau GS (PLGS). Analysis carried out by PLGS had concluded that the air densities in containment following Design Basis Accidents (DBA's) would result in greater motor loads than were originally postulated. The upgrade to larger horsepower motors was deemed necessary to power the LAC fans against these higher loads. The DBA's under consideration were;

a) Loss of Coolant Accident (LOCA)
b) Main Steam Line Break (MSLB)

These accident scenarios were considered to be independent of each other and, as such, were not postulated to occur simultaneously.

The proposed replacement LAC motors were Westinghouse Type HSB, 30 horsepower , 600 Volt, 3-phase induction motors. The equipment specification was as follows;

Design class	TEFC	Full load current	27.5 Amps
Insulation class	H	Full load speed	1765 rpm
Horsepower	30 HP	Full load torque	89.2 lb-ft
Volts	575 V	Service factor	1.15

The electrical protection of the LAC motors was carefully designed, by PLGS, to coordinate the following modes of operation;

a) Normal Operation - Motor running at 70% full load
b) LOCA Operation - Motor running at 120% full load
c) MSLB - Motor tripping below motor damage curve

One motor was supplied by PLGS as a test specimen, along with a spare set of bearings and seals.

4.1 LAC Motor Qualification Requirements

The qualification requirements were stated by PLGS in a test specification.

4.1.1 Environmental Conditions

Normal Environmental Conditions	Temperature	40 deg.C
	Pressure	100.6 kPa(a)
	Radiation	3.0 MRad
	Humidity	2%

The accident conditions representing the postulated environmental conditions *including margin* during the LOCA and MSLB accident scenarios were specified as,

LOCA Environmental conditions	Temperature	126 deg.C (peak)
	Pressure	140 kPa(g) (peak)
	Radiation	7.0 MRad
	Humidity	100%
MSLB Environmental conditions	Temperature	143 deg.C (peak)
	Pressure	290 kPa(g) (peak)
	Humidity	100%

4.1.2 Safety Related Function

The safety related function of the LAC motors for a LOCA event was to continue to operate at a load of 37 amps without tripping or sustaining significant damage which would reduce the life of the motor. This would fulfil the two major objectives of the local air cooling system which were,

a) to prevent hazardous hydrogen concentrations
b) to provide long term Reactor Building heat removal

An MSLB creates a rapid increase in temperature, pressure, and humidity within the containment building, in excess of that related to a LOCA event. This results in an increase in the loading on the LAC motors which when combined with the hostile operating environment will cause the motor to trip at the set overload current of 55 amps. The safety related function of the LAC motors during an MSLB was to be capable of being restarted (assuming that they tripped during the initial peak conditions of the MSLB accident), after the peak environmental transient conditions had subsided and to stay operational for the remaining mission time. This would meet the objective of ensuring long term reactor building heat removal.

4.2 LAC Motor Qualification Method

The qualification test program was designed to demonstrate that the Local Air Cooler Motors would maintain acceptable performance during their qualified life when subjected to the service conditions consistent with normal operation and design basis accident conditions inside containment of the PLGS. To demonstrate this, a type test was performed in which the test motor was artificially aged to the end of its qualified life before exposure to the design basis accident environmental conditions. During the accident simulation, sufficient monitoring was provided to evaluate the performance of the test motor.

During the course of the qualification testing program the test specimen motor was subjected to the testing summarized in Table 2.

The motor was disassembled prior to thermal aging, and the rotor and stator thermally aged separately from the remaining motor components.The bearings and shaft seals were mounted to a dummy shaft which was rotated for the duration of the thermal aging using a 1.5 HP, 1725 rpm motor.

Factory trained technicians from Westinghouse were contracted for disassembly of the motor prior to, and re-assembly, following thermal aging. Tests conducted by Westinghouse at these times indicated that the operating parameters of the motor (vibration, megger, current draw, etc.) were within acceptable limits.

The harsh environment simulation test was conducted with the LAC motor mounted in the MEC harsh environment chamber as shown in Figure 9. PLGS provided qualified splice kits which were used for the motor electrical connections. These connections were bottom entry to help prevent moisture ingress to the motor.

Although the LOCA and MSLB events were not postulated to occur simultaneously, NB Power elected to combine the two events into one test profile. While this conservatism had obvious cost advantages in that only one test was required, there was also a risk that the possible failure of the motor during the MSLB simulation would not be conclusive as the effects of the LOCA simulation alone could not be assessed. The harsh environment test profile, *including margin*, derived by PLGS to incorporate both LOCA and MSLB is presented in Figure 8.

4.2.1 LAC Motor Performance Requirements

The performance requirements were expressed in terms of a motor load curve which is included in Figure 8. The test specimen's performance was required to equal or exceed (i.e. envelope) this load curve during the harsh environment test. The determination of motor load during these two accident scenarios was carried out by PLGS and reflects the changes in atmospheric density and pressure and the effect upon the operation of the LAC fans. The effect of an increase in pressure in the reactor building was assessed by monitoring the current draw on the LAC motors presently installed at PLGS during a leak test of the reactor building at 124 kPa(g). The increase in load on the motors was determined to be directly proportional to the increase in air density.

Additional criteria were provided to evaluate changes in the electrical properties of the test specimen motor;

- Phase to ground IR was required to be in excess of 1.0×10^7 Ohms
- Leakage current was required to be no greater than 1.6 times the baseline value (Baseline leakage current = 0.01 mA @ 1280 VDC)

These were not intended as pass/failure criteria but rather flags for the generation of a notice of anomaly should the load curve acceptance criteria not be satisfied. PLGS were responsible for investigating the impact of any such anomalies upon the qualification program.

4.2.2 Monitoring of LAC Motor Performance During Harsh Environment Simulation

MEC was required to devise a method of loading the LAC motor to enable variation of the load in a manner representative of that which would be experienced by the LAC fans during accident conditions (Figure 8).

The method selected for applying a variable load to the motor during the harsh environment simulation was to mount a hydraulic pump to the motor inside the test chamber. Hydraulic supply lines were piped through the test chamber access cover plate and connected to a hydraulic control system and reservoir. Figure 9 presents a schematic of the hydraulic control system used to provide the variable loading to the motor. For a constant shaft speed, the load placed on the motor by the hydraulic pump was proportional to the hydraulic system pressure. The motor load was therefore modulated as required by changing the position of the variable position hydraulic relief valve and hence altering the hydraulic system pressure.

The monitoring of the test motor electrical load was achieved by installing current sensors on each of the three phase supply lines. Load data was continuously displayed, and recorded, on the data acquisition system computer. Variable setting current relays were used to monitor phase current and provide the motor trip signal when current draw exceeded 55 amps. A pressure transmitter was used to monitor the hydraulic system pressure and hence provide an indication of the physical load on the motor.

In order to use the hydraulic system pressure as an indication of motor load it was first necessary to establish a baseline loading curve which related the system pressure to the current draw of the motor. This baseline curve was established prior to the harsh environment test by increasing the hydraulic system pressure and recording the corresponding current draw of the motor until it reached 37 amps.

Prior to the initiation of the harsh environment simulation the test motor completed four hours of continuous operation at full load of 27.5 amps. Harsh environmental conditions in the chamber were then imposed by the injection and venting of saturated steam in a controlled manner such that the required pressure and temperature profiles were enveloped. Relative humidity was maintained at 100%. The pressure and temperature within the chamber were monitored using a pressure transmitter and two type T thermocouples. The output from these instruments was recorded and displayed on the data acquisition system computer. Figures 10 and 11 present the temperature and pressure profiles applied to the test motor for the initial periods of the LOCA and MSLB portions of the harsh environment simulation.

The baseline loading curve generated prior to the test was used as a guide for the load application. The load was increased up to 37 amps as the chamber conditions were ramped up to the maximum LOCA temperature and pressure. This load was maintained throughout the cyclic (dousing) portion of the environmental profile followed by a return to full load (27.5 amps) for the next 5.5 hours. At the six hour point the motor load was increased to 55 amps as the chamber conditions were ramped to the maximum MSLB temperature and pressure . At 55 amps the current relays activated, tripping the motor. The motor was successfully restarted at 6 hours and 14 minutes and run at 22.5 amps for the remainder of the twelve hour test. Figures 10 and 11 also present the average phase current draw during the initial periods of the LOCA and MSLB portions of the harsh environment simulation.

Comparison of the information used to generate the baseline load curve and the current draw during the harsh environment simulation showed that the hydraulic system pressure for a given motor current draw in the harsh environment simulation exceeded the baseline values. This increase in performance of the system was attributed to the increase in the temperature of the hydraulic oil. As the oil temperature increased the viscosity decreased resulting in greater pressure for the same mechanical input.

4.3 Results of LAC Motor Test Program

Conclusions based upon the results of the testing performed, were that the Westinghouse 30 HP motor would have a qualified life of 20 years when installed as the Local Air Cooler motor at Point Lepreau Nuclear Generating Station in an environment not more severe than the service conditions specified for the qualification program. To maintain qualification would require the replacement of the bearings and shaft seal at an interval not exceeding 5 years.

5 REFERENCES

[1] MEC Document 08160-FTR, Rev. 01, March, 1996
Seismic and Environmental Qualification of Flo-Tork NMS-1640-3 Pneumatic Actuator for Wolsong 2 NGS

[2] MEC Document 09120-FTR, Rev. 00, March, 1995.
Qualification Testing of Local Air Cooler (LAC) Motors

[3] IEEE Std 323-1974
IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations

[4] IEEE Std 334-1974
IEEE Standard for Type Tests of Continuous Duty Class 1E Motors for Nuclear Power Generating Stations

[5] IEEE Std 382-1985
IEEE Standard for Qualification of Actuators for Power Operated Relief Assemblies with Safety Related Functions for Nuclear Power Plants

[6] IEEE Std 344-1987
IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations

[7] AECL Candu Technical Specification 86-30060-TS-001
Wolsong 2, 3 & 4, Environmental Qualification of Equipment

[8] AECL Candu Technical Specification TS-XX-30830-002
Seismic Qualification of Valves

[9] NB Power Test Specification 60010-EQTS-002, Rev. 00, March, 1995
Qualification Testing of Local Air Cooler Motors for Use at Point Lepreau Nuclear Generating Station

6 ACKNOWLEDGEMENTS

The co-operation and assistance of Flo-Tork Incorporated and New Brunswick Power in the production of this paper is gratefully acknowledged.

TABLE 1

QUALIFICATION TEST SEQUENCE - FLO-TORK ACTUATOR

Sequence	Test	Facility	Description of Test Conditions
1	Pre-Test Inspection	MEC	Assessment of test specimen condition and conformance to relevant specifications and drawings.
2	Exploratory Test (Resonance Search)	MEC	Determination of resonant modes of vibration below 40 Hz.
3	Baseline Function Testing	MEC	Performance of test specimen actuator in "new condition" assessed as per section 3.1.1 - Speed of Operation and 3.1.2 - Output Torque.
4	Mechanical Wear Aging (900 cycles under load)	MEC	Actuator cycled 900 times at a rate of 1 cycle/min against a minimum load of 550 N-m.
5	Radiation Exposure	Isomedix	Actuator received a minimum air equivalent dose of 24.5 MRad at a maximum dose rate of 0.4 MRad/hour. This is representative of 20.0 MRad LOCA dose plus 50 Rad/hr normal dose for 5 years service plus 10% margin on total.
6	Accelerated Thermal Aging (400 mechanical wear cycles during thermal aging)	MEC	Actuator thermally aged, using Arrhenius techniques, at 104°C minimum for 102 hours to justify 5.5 year qualified life for elastomers. Actuator cycled 400 times against a minimum load of 550 N-m.
7	Mechanical Wear Aging (900 cycles under aging)	MEC	Actuator cycled 900 times at a rate of 1 cycle/min against a minimum load of 550 N-m.
8	Post Aging Function Test	MEC	Performance of test specimen actuator in "end of normal service life condition" assessed as per section 3.1.1 - Speed of Operation and 3.1.2 - Output Torque.
9	Harsh Environment Simulation (MSLB & LOCA)	MEC	Test Specimen subjected to test profile enveloping Wolsong 2 MSLB and LOCA. 150°C, 400 kPa(g) peak conditions, 100% humidity, 6 month mission time at 60°C. Performance of test specimen actuator assessed, while under accident conditions per section 3.1.1 - Speed of Operation and 3.1.2 - Output Torque.
10	Post Harsh Environment Function Test	MEC	Performance of test specimen actuator in "post accident condition" assessed as per section 3.1.1 - Speed of Operation and 3.1.2 - Output Torque.
11	Seismic Aging (OBE)	MEC	Simulation of operating basis earthquakes. Required for U.S. seismic qualification to IEEE-344
12	Seismic Qualification Testing	MEC	Actuator qualified for both line and hard mounted applications by testing using single frequency (sine-beat) and random multifrequency methods. Performance of test specimen actuator assessed during seismic simulation as per section 3.1.1 - Speed of Operation and 3.1.2 - Output Torque.
13	Post Seismic Function Test	MEC	Performance of test specimen actuator in "post seismic condition" assessed as per section 3.1.1 - Speed of Operation and 3.1.2 - Output Torque.
14	Post-Test Inspection	MEC	Test specimen inspected to assess any damage or degradation occurring as a result of the qualification process.

TABLE 2

QUALIFICATION TEST SEQUENCE - LAC MOTORS

Sequence	Test	Facility	Description of Test Conditions
1	Pre-Test Inspection	MEC	Assessment of test specimen condition and conformance to relevant specifications and drawings.
2	Baseline Function Testing	MEC	Insulation resistance and hypot testing of test specimen assessed as per section 4.1
3	Radiation Exposure	Isomedix	Motor received a minimum air equivalent dose of 11.8 MRad at a maximum dose rate of 0.25 MRad/hour.
4	Post-Radiation Aging Function Test	MEC	Insulation resistance and hypot testing of test specimen assessed as per section 4.1
5	Accelerated Thermal Aging	MEC	Motor and stator thermally aged, using Arrhenius techniques, at 190°C minimum for 227 hours for 20 year qualified life at operating temperature of 120°C (including 80°C heat rise) Bearings and shaft seals thermally aged at 100°C minimum for 266 hours for 5 year qualified life at operating temperature of 50°C (including 10°C heat rise)
6	Post-Thermal Aging Function Test	MEC	Insulation resistance and hypot testing of test specimen assessed as per section 4.1
7	Harsh Environment Simulation (LOCA followed by MSLB)	MEC	Test specimen subjected to profile defined in Figure 1 (LOCA followed by MSLB) Performance of test specimen motor assessed, while under accident conditions.
8	Post Harsh Environment Function Test	MEC	Insulation resistance and hypot testing of test specimen assessed as per section 4.1
9	Post-Test Inspection	MEC	Test specimen inspected to assess any damage or degradation occurring as a result of the qualification process.

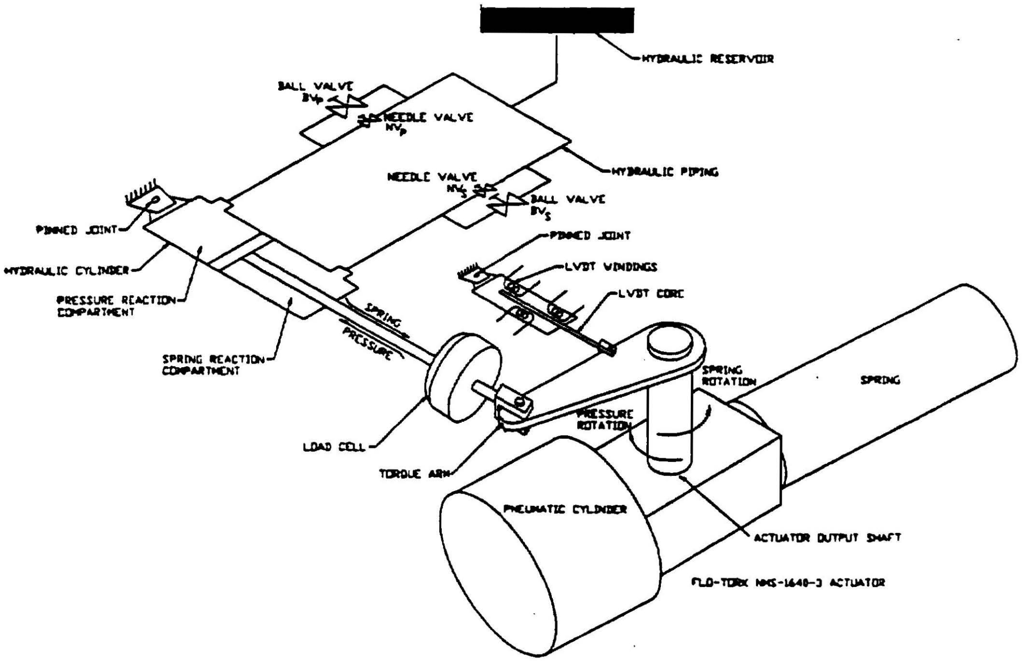

FIGURE 1

ACTUATOR PERFORMANCE MONITORING EQUIPMENT

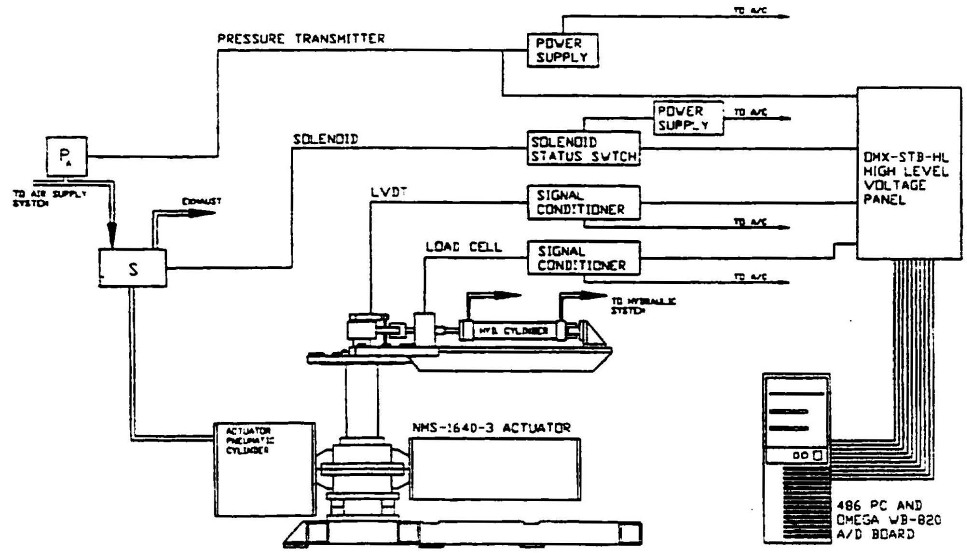

FIGURE 2

ACTUATOR PERFORMANCE MONITORING SCHEMATIC

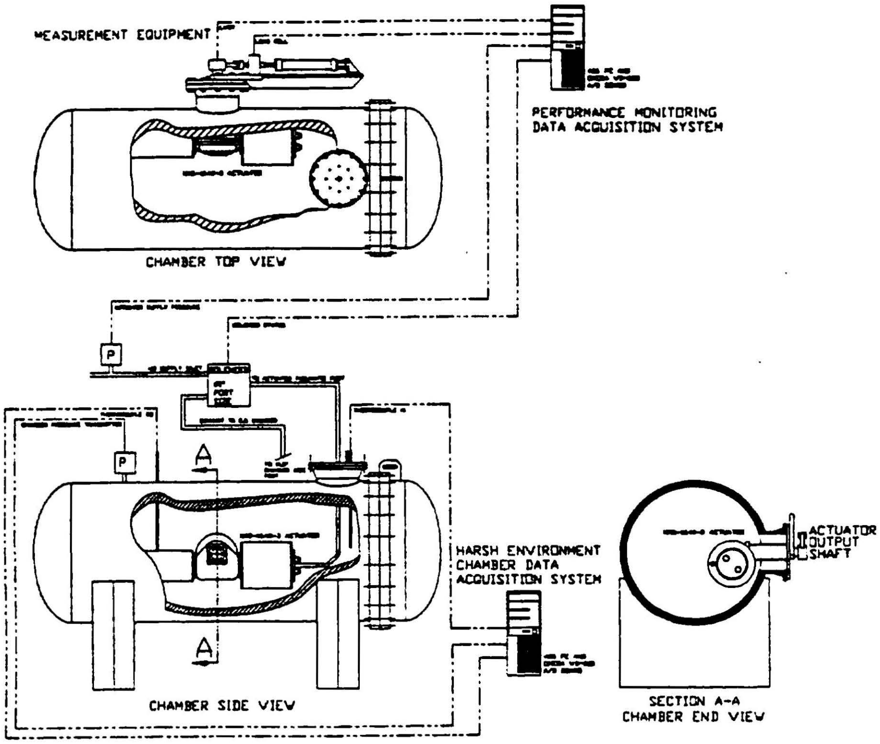

FIGURE 3

SET UP FOR ACTUATOR HARSH ENVIRONMENT TEST

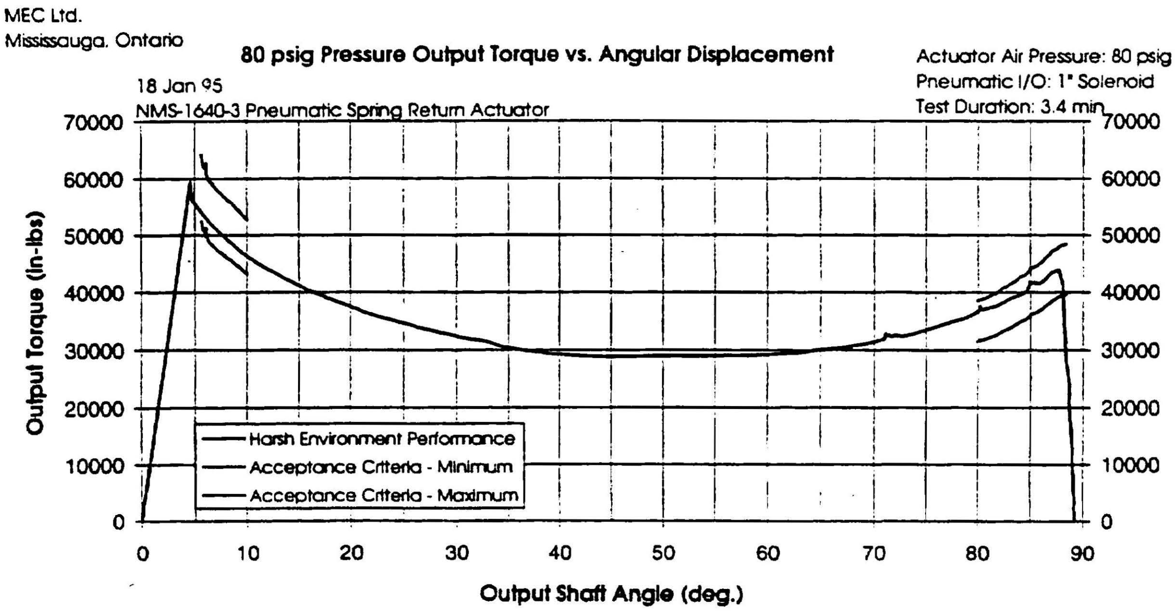

FIGURE 4

PERFORMANCE TEST OF ACTUATOR DURING HARSH ENVIRONMENT SIMULATION

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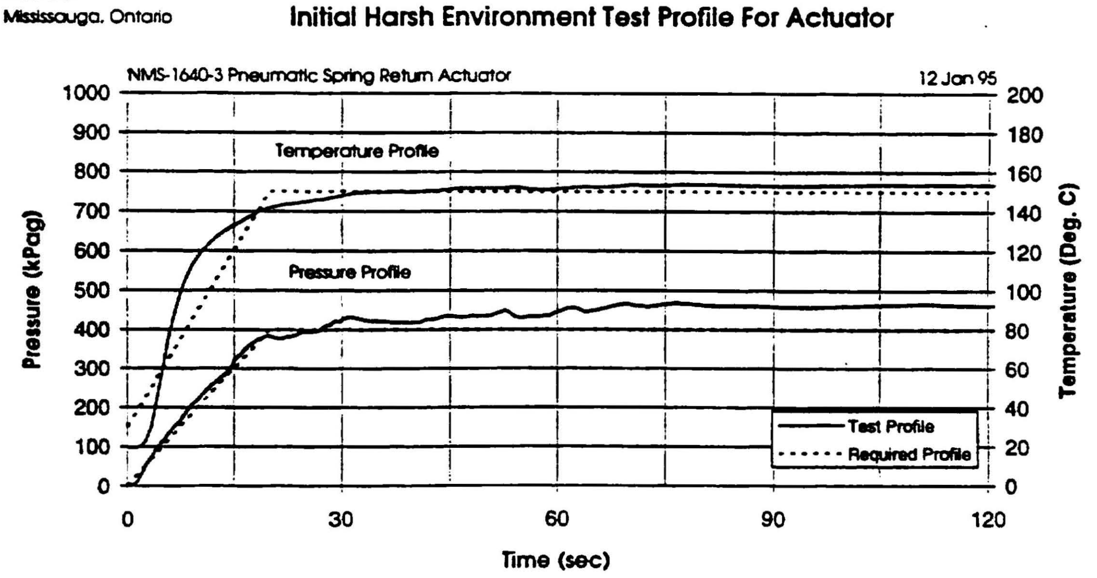

MEC Ltd.
Mississauga, Ontario

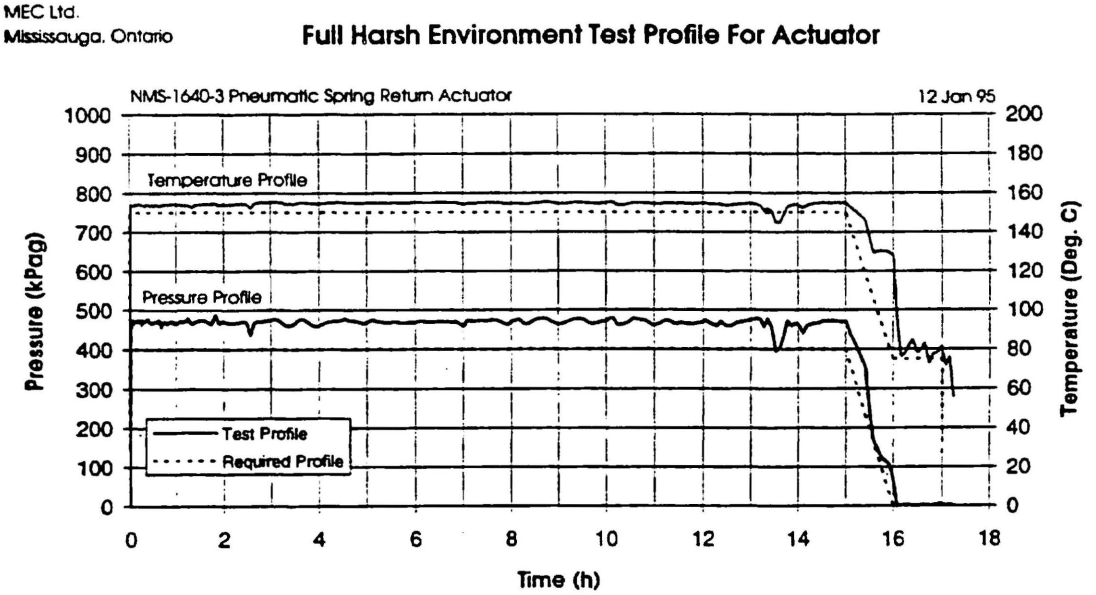

FIGURE 5

HARSH ENVIRONMENT TEST PROFILES

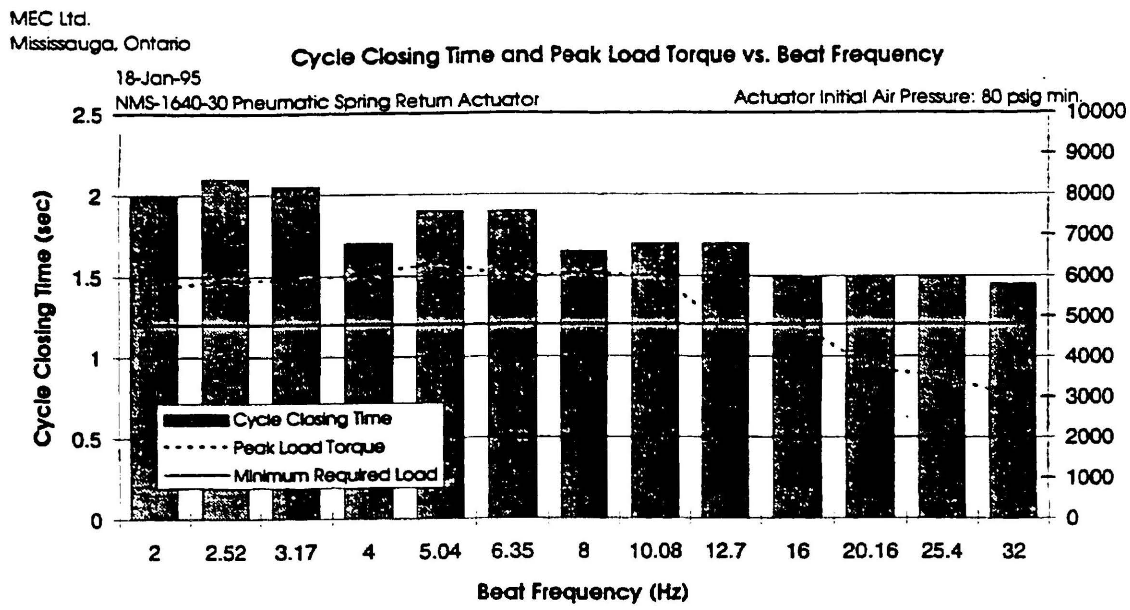

FIGURE 6

ACTUATOR PERFORMANCE DURING Z EXCITATION SINE BEAT TEST

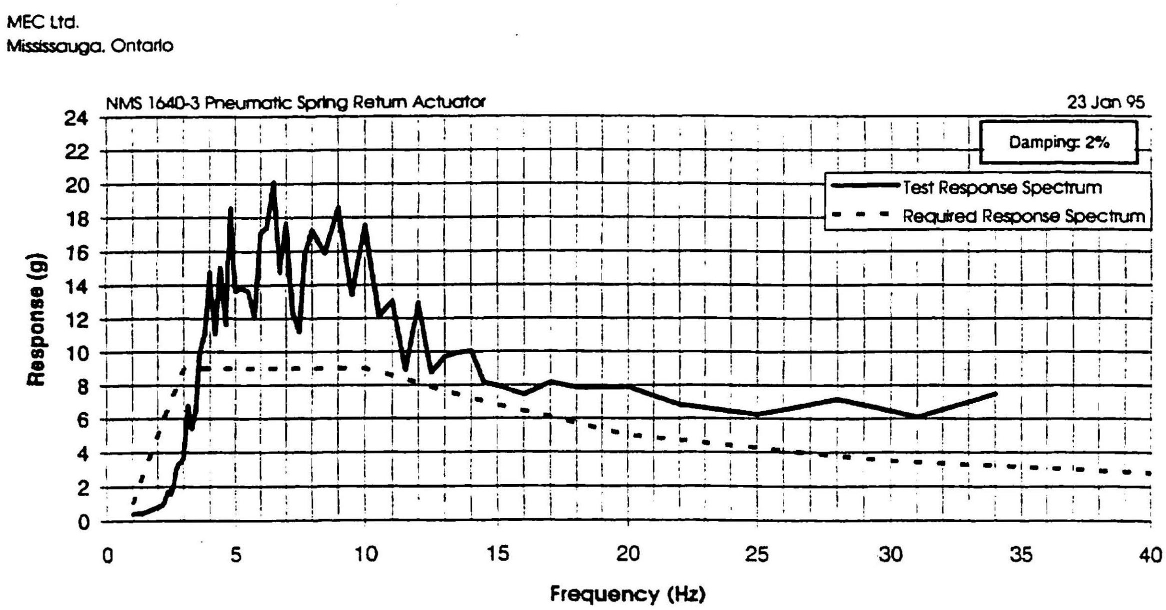

FIGURE 7

TEST RESPONSE SPECTRUM FOR X EXCITATION

BROADBAND RANDOM VIBRATION TEST OF ACTUATOR

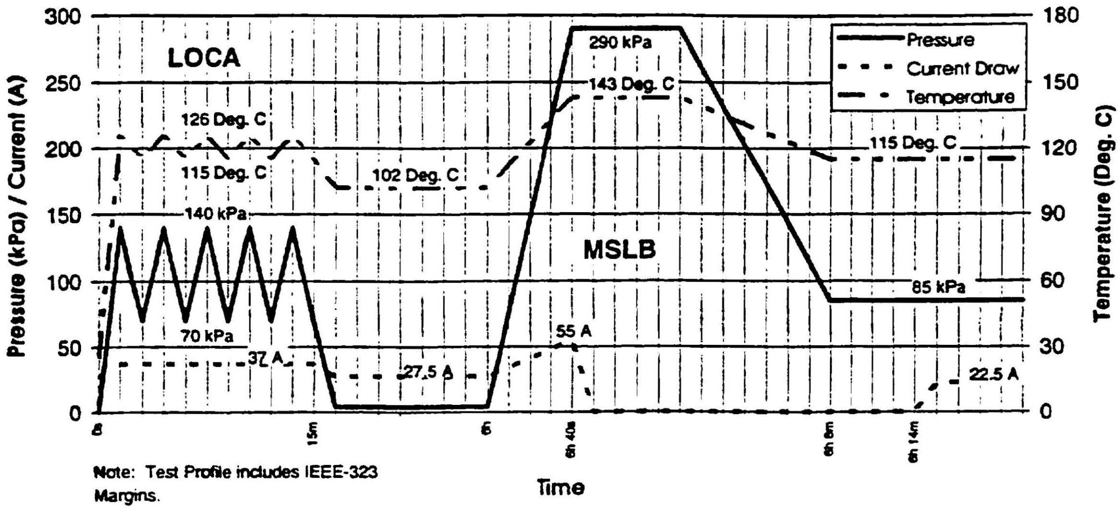

FIGURE 8

SPECIFIED HARSH ENVIRONMENT PROFILE AND LAC MOTOR LOAD

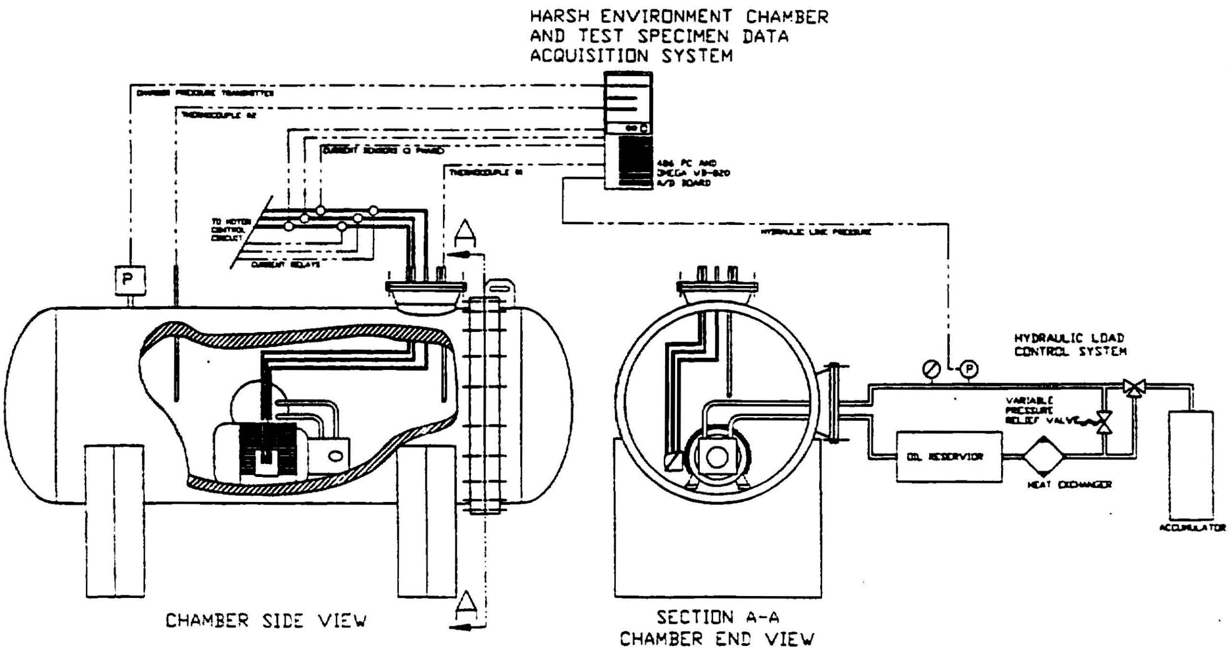

FIGURE 9

SET UP FOR LAC MOTOR HARSH ENVIRONMENT TEST

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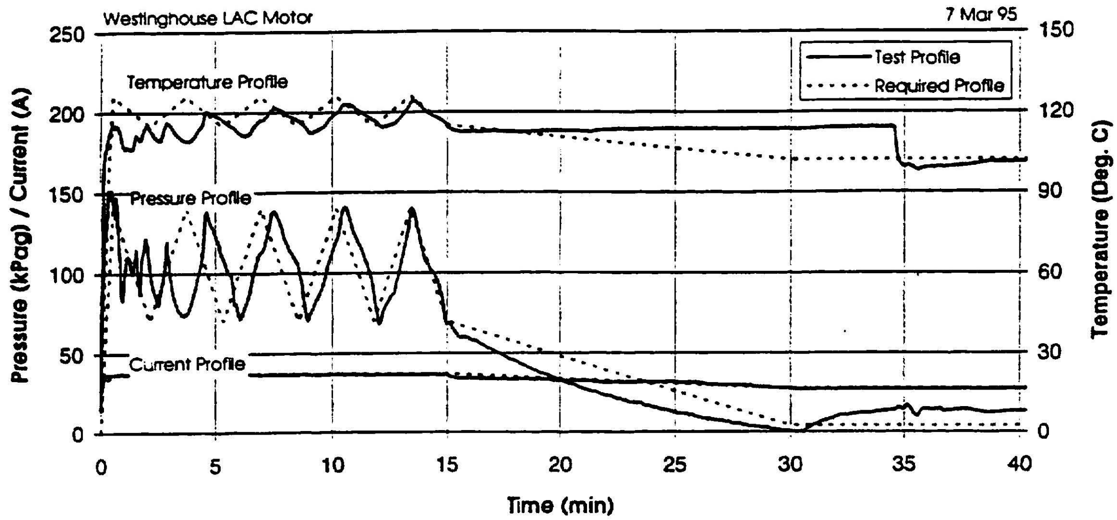

FIGURE 10

INITIAL LOCA HARSH ENVIRONMENT TEST PROFILE FOR LAC MOTOR

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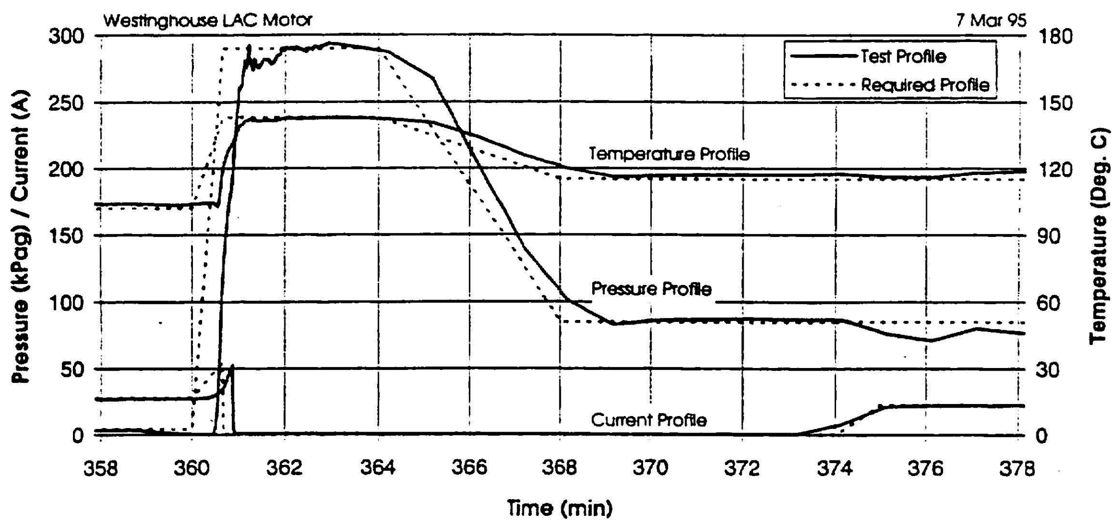

FIGURE 11

INITIAL MSLB HARSH ENVIRONMENT TEST PROFILE FOR LAC MOTOR