THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
345 E. 47th St., New York, N.Y. 10017

97-GT-252

A MECHANICAL START SYSTEM FOR U. S. NAVY DESTROYER GENERATOR SETS

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ABSTRACT

A mechanical start system has been developed to start the Ship's Service Gas Turbine Generators (SSGTG) on board U.S. naval destroyers. The current starting system uses either stored high pressure air or bleed air from another running turbine. The U.S. Navy has reviewed the high pressure air system and found it to be a costly system for both ship construction and maintenance. As a result, the Navy is requiring an alternative starting method that will replace high pressure air. It should be noted that any alternative that introduces compressed air to start the SSGTG depends on the start air regulating assembly and the pneumatic starter.

The Redundant Independent Mechanical Start System (RIMSS) consists of an Allison Model 250 turboshaft engine mounted above the SSGTG main reduction gearbox. The turboshaft power take off is connected to the pinion shaft of the reduction gearbox by means of a parallel shaft auxiliary transfer gearbox. The transfer gearbox connection to the reduction gearbox replaces the pneumatic starter adapter pad but provides a means to also connect the pneumatic starter. As a result, the pinion shaft can be driven either pneumatically by the air turbine or mechanically hy the Model 250 engine. This provides an alternative starting mode which is totally independent of the present means of starting. This will increase the reliability and availability of the SSGTG since it can still be started even if the pressure regulator or the pneumatic starter is not functional. This system has undergone testing at the Naval Surface Warfare Center Carderock Division facility in Philadelphia.

INTRODUCTION

When an Arleigh Burke class destroyer (DDG51) is at sea or in many foreign ports it is dependent upon an Allison Ship Service Gas Turbine Generator (SSGTG) set for all ship's electrical power. Three Model AG9130 or AG9140 SSGTGs provide all the power for weapon systems, machinery and hotel services for all conditions from normal operation to full battle conditions. Once the ship has disconnected from shore power, one or more of the SSGTGs must be operating.

Due to the critical availability of SSGTGs it is imperative that a reliable means of starting be provided, including a dark start when no shipboard power is available. SSGTGs are started using a pneumatic turbine starter installed on the pinion of the reduction gearbox. If one (or more) of the SSGTGs is operating, air from the gas turbine compressor fourteenth stage bleed manifold (compressor discharge) can be routed through ship's piping to the start air regulating system aboard another SSGTG to perform a crossbleed start.

An alternate source of starting air, especially during a dark start, is the shipboard high pressure air system, providing 21 MPa (3000 psi) air stored in bottles. This air is routed from the bottles through high pressure piping to a pressure reducing station adjacent to the SSGTG. While reviewing all shipboard systems, the U. S. Navy found the high pressure air system, especially the compressor capable of these pressures, to be costly for both acquisition and maintenance. It is also a safety concern due to the high pressure piping presence in manned spaces.

As a result, the Navy specified an alternative starting system to replace the high pressure air. Requests for proposal (RFP) were solicited. The RFP specified a separate

Presented at the International Gas Turbine & Aeroengine Congress & Exhibition
Orlando, Florida — June 2-June 5, 1997

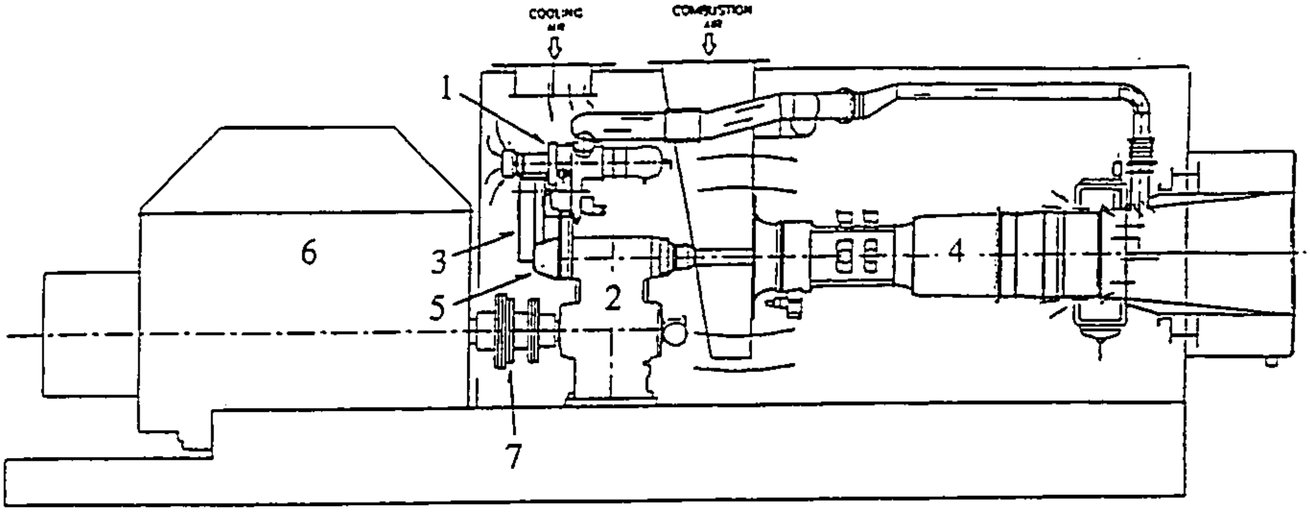

Figure 1 - Layout of RIMSS installed in a Naval Destroyer SSGTG

gas turbine auxiliary power unit (APU) module to supply adequate bleed air to the SSGTG start air regulator for accomplishing an air start. After reviewing the Allison small engine models (Model 250 class) it was determined that an adequate supply of air could not be bled from the compressor and still maintain engine operation.

Instead, a proposal was submitted to use the Model 250 engine as a source of shaft power for a mechanical start. The Model 250 engine is mounted inside the SSGTG module, over the reduction gearbox, eliminating the need for a separate module. Connection to the pinion shaft, downstream of the existing pneumatic starter, is by means of an auxiliary parallel shaft transfer gearbox. This allows the pinion shaft to be driven by either the pneumatic starter or the mechanical input. The Model 250 engine can be started from a battery supported by the shipboard no-break power supply and controlled by the SSGTG local control operator's panel (LOCOP).

This configuration provides a totally independent mode of starting the SSGTG. A start can be accomplished when any part of the pneumatic start system is inoperative, even if isolated from the crossbleed system. Thereby the Redundant Independent Mechanical Start System (RIMSS) increases the reliability and availability of the total electrical power supply system.

OVERVIEW OF CONCEPT

See Figure 1 for an illustration of RIMSS as installed on a AG9140 SSGTG. The main reduction gearbox (2) takes the power from the prime mover, a Model 501-K34 gas turbine engine (4) and reduces the speed to drive the electric generator (6) through a flexible coupling (7). The motive starting power is provided by a Model 250-C20B turboshaft engine (1) rated at 310 kW (420 SHP). The engine output is transferred to an auxiliary pad on the main reduction gearbox by means of a parallel shaft speed increasing transfer gearbox (3). The transfer gearbox contains an overrunning clutch of the self shifting synchronous (SSS) type. As the prime mover's speed accelerates past the mechanical starter input speed, the clutch disengages and the Model 250 returns to idle. This arrangement also allows the prime mover to run totally independently of the Model 250 with the clutch overrunning continuously. This is the mode of operation when the air turbine starter (5) is used. The Model 250 is a free power turbine engine and therefore no torque converter or slip clutch arrangement is necessary in the transfer gearbox.

Control of the Model 250 engine is accomplished by a Woodward NetCon 5000 based operating system which controls the prime mover engine as well as all other skid functions. The control is tuned to provide all operating functions; motoring and crank wash of the Model 250 as well as starting, motoring and crank wash of the prime mover engine using the Model 250 or the air turbine starter for cranking power. Both engines employ the same electric fuel valve with only orifice size differences required for the each engine's flow range. Standard naval marine diesel fuel has been used in testing to date but JP-5 is scheduled to be used in subsequent testing. A 24 VDC starter is mounted to the Model 250 accessory gearbox for starting and motoring of the Model 250 engine. Temperature monitoring of the Model 250 engine is accomplished by means of four chromel-alumel thermocouples located between the gas generator turbine and the power turbine.

Combustion air for the Model 250 engine is drawn from the cooling air within the SSGTG module through a screened inlet. For test purposes, the exhaust from the Model 250 engine is ducted within the module to the prime mover exhaust. This does not represent the production exhaust configuration. The production units will duct the Model 250 exhaust directly through the roof and connect to the prime mover exhaust uptake.

The rated speed of the Model 250 gas generator is 50,970 rpm. A two stage helical gear set in the power and accessory gearbox reduces the rotational speed of the power turbine from 33,290 rpm rated speed to 6016 rpm at the output shaft for standard airframe applications. For the RIMSS application, the transfer gearbox uses a gear ratio of 2:1 which raises the speed at which RIMSS can drive the reduction gearbox pinion to 12,032 rpm. This represents a significant increase above the 9100 rpm starter cutout required by the pneumatic starter.

THEORY OF OPERATION

The RIMSS start cycle is represented in Figure 2. Upon initiation of a start signal from the LOCOP (Time = 0 seconds) the electric starter of the Model 250 engine starts to spin the gasifier until the engine lights off and its speed (N1) accelerates. The control switches to temperature limiting after light off and remains so until approximately 31,000 rpm. During this time the power turbine is locked because not enough torque has been created to breakaway the generator set gear train. As N1 increases, torque is increased on the power turbine and torque control becomes the limiting factor on fuel supplied to the Model 250 engine. When the torque reaches the breakaway point (Time = approx. 25 seconds), the power turbine (N2) begins to rotate, driving the generator set geartrain and causing the prime mover to accelerate. The control keeps maximum allowable torque applied to the prime mover engine during its acceleration. When the prime mover reaches a set point between 11,000 and 12,000 rpm or approximately 30,000 rpm for N2 (Time = approx. 58 seconds), the fuel control pulls back sharply, reducing torque to the point that the clutch overruns and the Model 250 returns to idle. The prime mover continues to its rated speed of 14,341 rpm under its own power and the Model 250 enters a three minute period at idle speed before shutdown.

This cycle is significantly different from the flight cycle in that a "ground idle" period of sixty seconds is standard for helicopters before going to takeoff power. The RIMSS cycle eliminates the ground idle warm up period in order to meet the goal of having electric power available from the generator set within sixty seconds. For this reason the thermal cycle effects were a primary concern in the evaluation that was done during the endurance testing performed at the Naval Surface Warfare Center - Carderock Division, Ship's Service Engineering Station (NAVSSES). Depending on the final results of additional endurance testing, the Navy can weigh the engine life benefits that would be achieved from having a less aggressive start schedule against the disadvantage of a longer overall SSGTG start time. If a cycle were selected for routine starts that included an idle time before full power application, it would approximate a standard flight cycle with its more favorable effects on turbine wheel life. The cycle represented in Fig. 2 could still be performed in emergency start situations to preserve the sixty second goal when needed.

While the start cycle will be the most common use for the RIMSS unit, a starting mechanism for SSGTGs must also provide the motive force for motors and crank washes of the prime mover engine. The requirements for a crank wash of the prime mover are in many ways more stringent than those of the actual start cycle. During a crank wash the prime mover engine must be held at a speed of approximately 4000 rpm for two minutes or more. During a start the prime mover lights off at about 2200 rpm and begins to assist in its own acceleration. During a motor, the compressor requires increasing torque above 2200 rpm. When water is added during the motoring process to wash the compressor, the torque requirements are even greater. The Model 250 engine is required to provide 200 n-m (150 ft-lbs) of torque at the output of the transfer gearbox throughout the two minute motor depicted in Figure 3. It is well capable of this and has completed fifty consecutive crank washes of the prime mover. This requirement is what makes an engine with lower power and torque ratings such as aircraft jet fuel starters marginal for performing this mission.

As can be seen from Fig 3., additional tuning of the speed control gain is required for a smooth crank washing speed. This will be accomplished in Phase 2 of testing which is scheduled for May 1997.

EVALUATION OF CONCEPT

In order to prove the RIMSS concept, a prototype was constructed and then tested at NAVSSES from 03 June 1996 to 14 August 1996. The test requirements were to complete 500 starts of the SSGTG as well as several motors and crank-washes of the SSGTG prime mover engine. The mission cycle of a Model 250 engine in the RIMSS application differs significantly from Model 250 flight applications. For this reason a complete teardown of the Model 250 engine was conducted to ascertain the effects of the RIMSS cycle on Model 250 engine life. Special attention was directed to thermal cycling effects which are the life limiting factor for turbine wheels.

Thermal cycles induce fine crack indications in the wheel hubs of the turbine wheels. These are measured and recorded in a mapping process done under fluorescent dye penetrant inspection to determine the size and location of all indications. To predict crack propagation and thereby wheel life, a baseline has been established by Allison. The baseline engine was cycled to an equivalent of 2400 flight cycles with mapping performed at 800, 1600 and 2400 cycles. The mapping of the RIMSS engine was then compared to the baseline mapping and the results indicated in the test report

The engine was torn down on September 4, 1996, at Allison Engine Company. Upon visual inspection, it was determined that the condition of the hardware was consistent with experience of other engines with similar accumulated cyclic life. All seals appeared to be working satisfactorily based on residue evident only in the appropriate locations. Airflow passages were coated with a black residue similar to that found in the exhaust ducting on the SSGTG module.

The compressor unit was first removed from the engine. The case halves were then separated and laid out for inspection. Concern of reported indications found during a borescope inspection of the case at NAVSSES was alleviated upon visual examination. The indications under suspicion were located in the plastic coating around the vane bands. The indications seen in the borescope inspection were found exclusively in this coating, not in the vanes. The coating is designed to act as a rub tolerant flowpath seal as well as provide corrosion resistance for the compressor case. Indications in this material are normal and are experienced by other engines in the field after use. They are not detrimental to performance, however, without proper rinsing or flushing of the compressor, corrosion of the base metal through the indication may occur. The plastic lining may be replaced at an approved repair facility throughout the life of the engine. The six stages of the compressor rotor and the impeller all looked satisfactory. There were no indications in the compressor blades.

The outer combustion case was removed and inspected. The igniter appeared normal. Despite apparent build-up on the fuel nozzle (heavier than operation with JP-5, but consistent with diesel fuel use), the engine successfully started on every attempt during testing except one. This case was an initial start overtemp that was corrected via a minor change in control software. The combustion liner was also removed for inspection . The liner was in excellent condition, without any evidence of hot spots or louver damage.

The turbine unit was disassembled for inspection. No visual discrepancies or abnormalities were noted throughout the turbine. All four wheels and nozzles were visually inspected and found to be satisfactory. There was no evidence to suggest any sealing or other mechanical problems existed. The gearbox was not torn down for inspection. Routine inspection of the magnetic plugs during testing did not indicate a need for further analysis.

Following teardown of the engine, the compressor rotor (all axial stages and the impeller) and the four turbine wheels and nozzles underwent zyglo inspection. The turbine wheels from the RIMSS engine were mapped based on zyglo indications. Photographs were taken of the hardware which exhibited florescent penetrant indications.

All time/cycle limits on the Model 250 engine are derived from field experience. It appears that the RIMSS cycle is more severe than the actual flight cycle, however the magnitude of the difference will only be accurately quantifiable with additional testing. Turbine wheel cracking is the result of stresses induced into the wheel rim as the rim heats faster than the web of the wheel during starting/upward power transients. A second thermal gradient is present during downward power transients and shutdowns as the rim cools before the web. Overall, the RIMSS initial thermal gradient is probably worse than typical installations due to "cold iron" to full power start versus a typical flight start to ground idle before acceleration to full power. However, the reverse thermal gradient for RIMSS is probably better because there isn't time in the RIMSS cycle to fully heat the entire wheel before power is reduced to an idle condition.

SUMMARY AND CONCLUSIONS

The RIMSS engine successfully completed the testing at NAVSSES. No indication limits were exceeded and no hardware replacement is required for continued service. Figure 4 shows the start cycle for start number 500 which can be compared to Figure 1 to demonstrate that no significant engine degradation occurred during the endurance testing. The test regimen included 500 starts and 50 SSGTG prime mover motors and crank washes. Total cycles on the engine exceed 600 when including development testing done before the NAVSSES series. The Model 250 engine will meet the SSGTG starter life requirement of 7000 cycles. However, the RIMSS cycle is somewhat more demanding than the flight cycle as far as thermal cycling is concerned. This means that maintenance activity may be required more often than the 3000 cycles of flight applications. This maintenance activity, called a "mini-turbine", consists of a on site operation to replace the first and second stage turbine wheels.

Additional testing is scheduled at NAVSSES that will include another 500 starts and 50 crank washes. The engine will be reassembled and will undergo this testing with no parts replaced to gain additional life on the current major components. Additional data generated from the scheduled testing will allow a better prediction of the actual cycle limit.

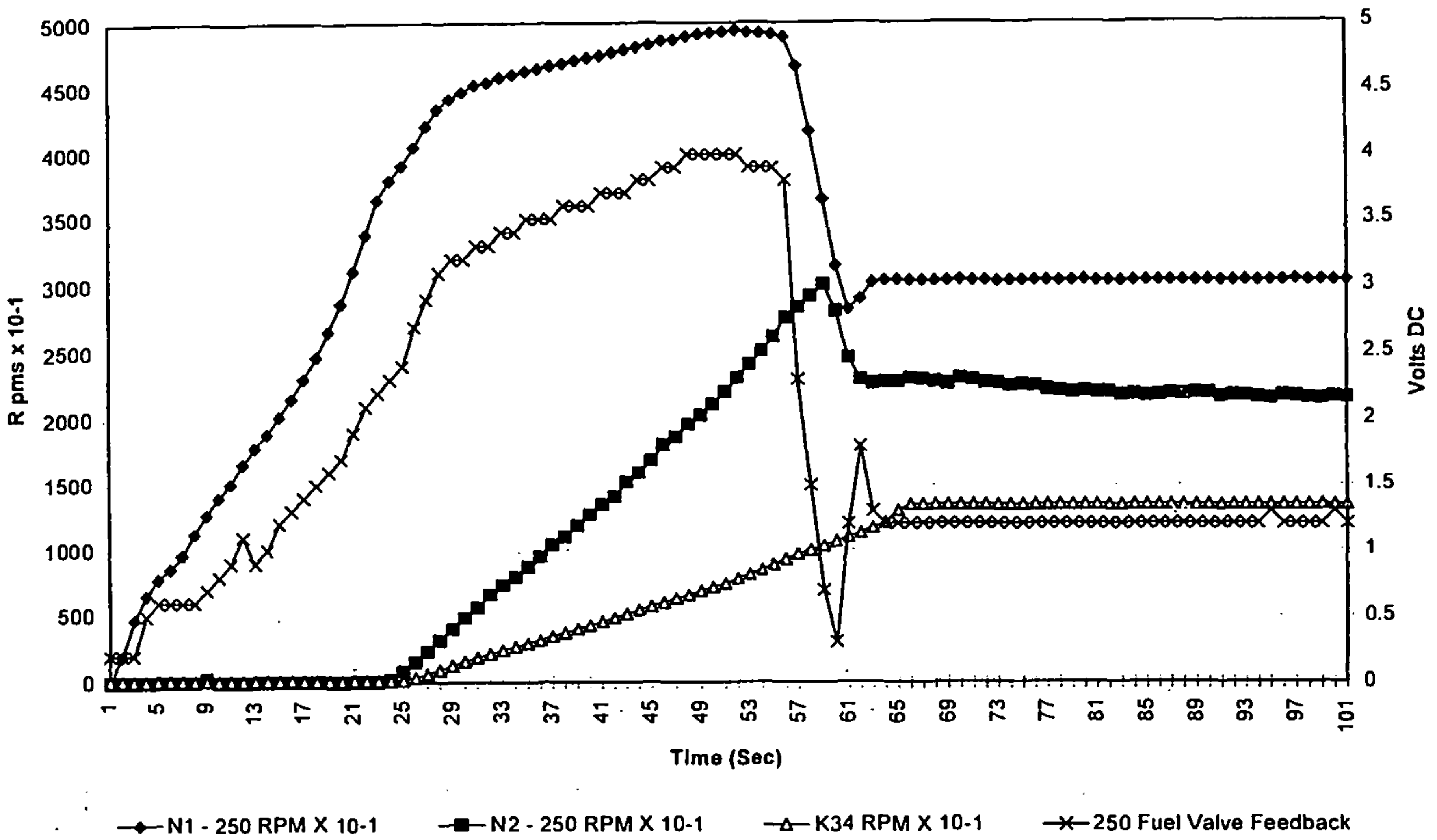

Figure 2 - RIMSS Start Cycle - Number 1 of 500

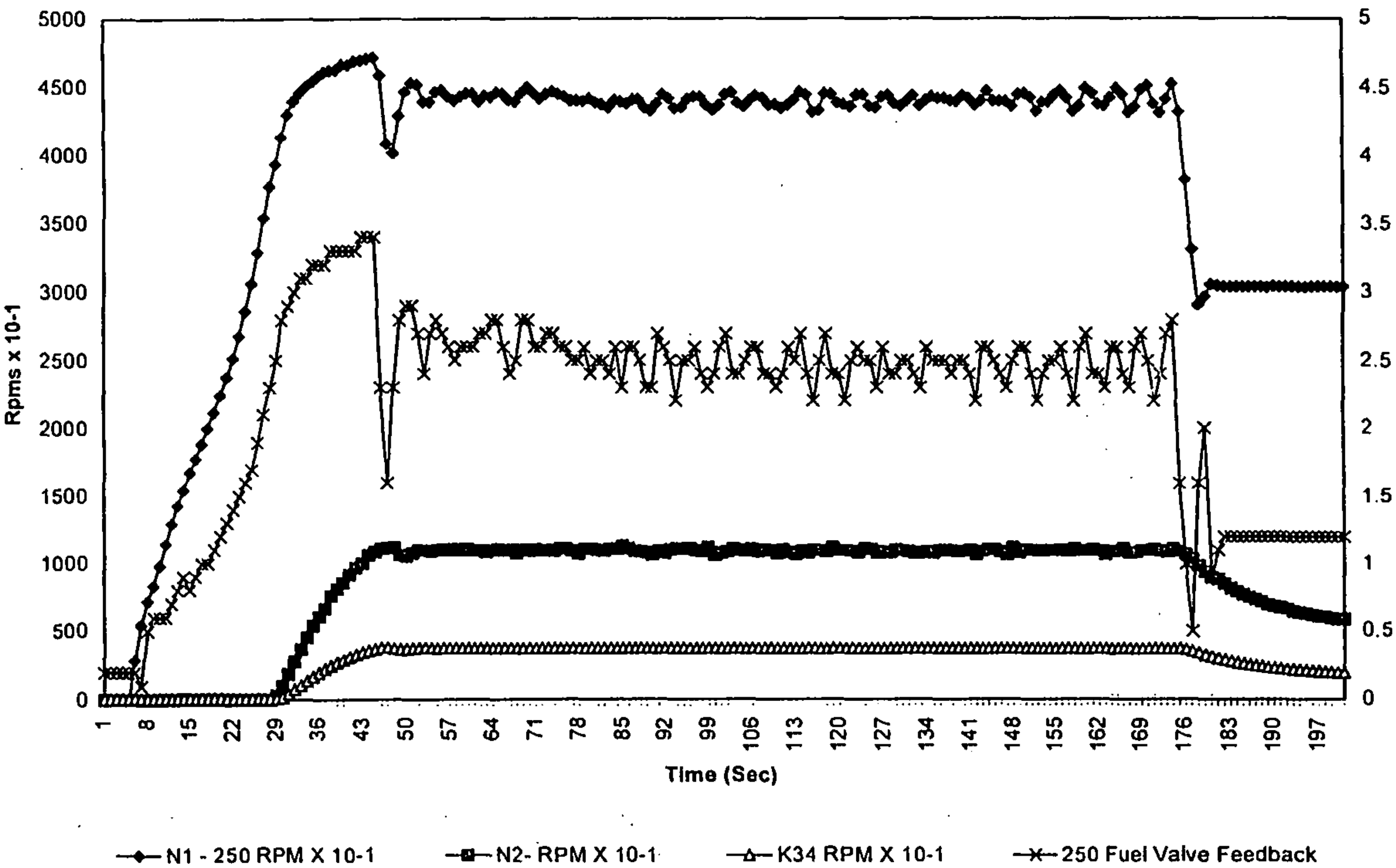

Figure 3 - RIMSS Crank Wash Cycle

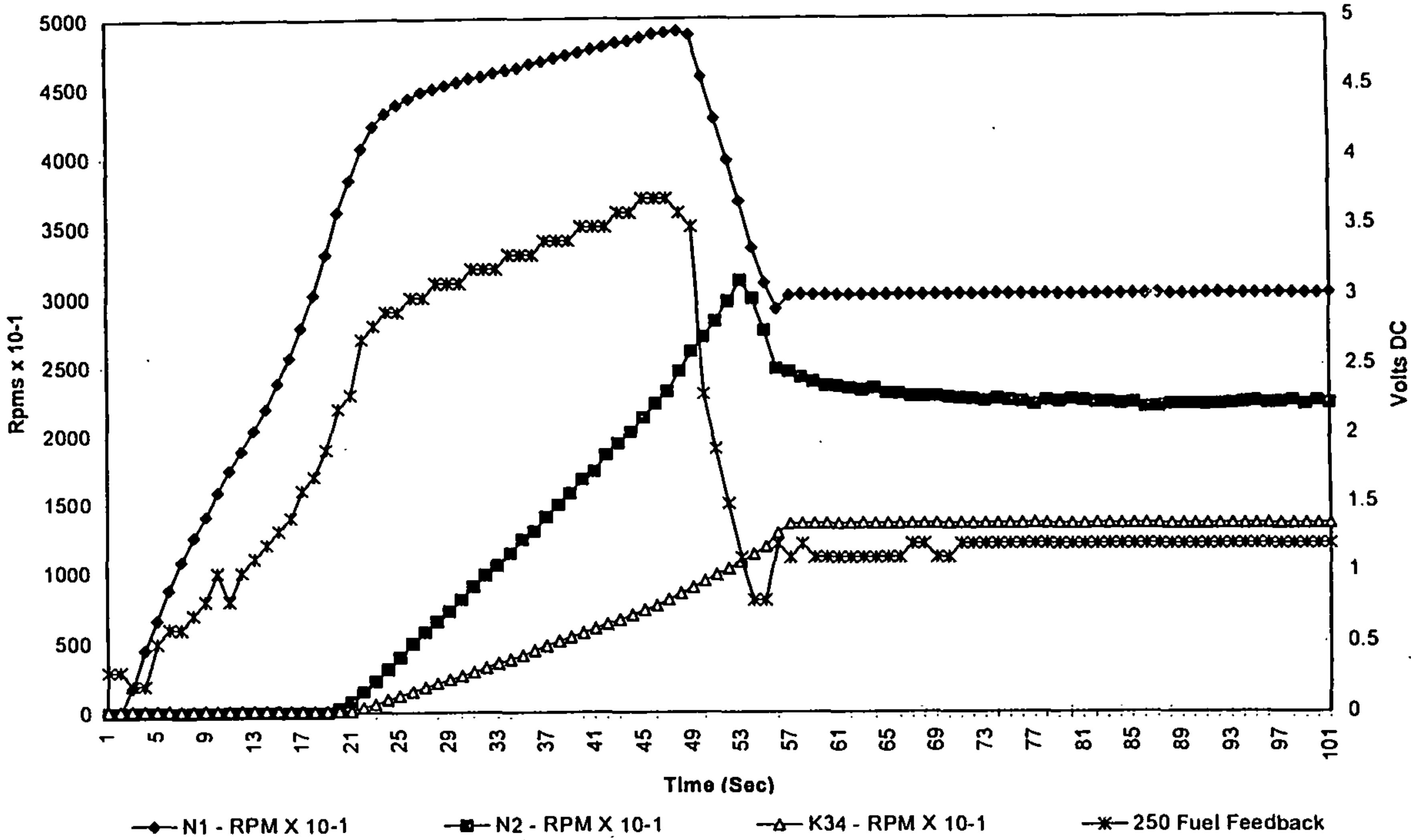

Figure 4 - RIMSS Start Cycle - Number 500 of 500