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400-Hz AIRCRAFT POWER-GENERATING SYSTEMS - ADVANCING THE BASELINE

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The weight evolution of the 400-Hz hydromechanical aircraft power-generating system (fig. 1) began in 1945 when the specific weight was of the order of 8 lb/kVA. This weight has steadily decreased with various advancements in particular technologies. Current hydromechanical systems typically weigh 1.3 to 1.4 lb/kVA. A 60-kVA system, including the generator and hydromechanical drive as an integrated package, at present weighs about 71 lb. The controls weigh about 9 lb and are getting to be a substantial part of the power system weight. Also over the years the reliability of hydromechanical systems has improved, the logical result of many millions of hours of experience.

This paper covers two areas: today's benchmark system for the 757/767/A310 airplanes and future trends. The 757/767/A310 system represents the commercial state of the art and the direction in which Sundstrand is headed, particularly in regard to weight reduction. Sundstrand introduced microprocessor control in an in-service system in the Boeing 767 and was the first to use databus communications between the controls. This paper briefly discusses Sundstrand's plans to develop this technology. Much of the rest of this conference is devoted to discussions of alternative ways to produce and use power in aircraft. Sundstrand has a few ideas to share with you about that and about the integrated starter drive.

757/767/A310 Systems - Today's Benchmark

The 757 and 767 are two-engine airplanes. They have an integrated drive generator (IDG) at each engine and an auxiliary power unit (APU) generator (fig. 2). All three generators are rated at 90 kVA.

Figure 3, a one-line diagram of the 757/767 bus arrangement, shows the number of components. There are three identical generator control units (GCU) and one bus protection control unit (BPCU). All of these control units use the microprocessor technology and communicate over the databus. A complete control system that is used in current aircraft is shown in figure 4, including a number of current transformers (CT's). Boeing chose to have a completely protected bus system, including the tie bus, and so there are some additional CT's.

Because of the microprocess system a new differential protection scheme was implemented wherein the bus connections could be adjusted in real time if there was enough CT information and enough communication between units. It was made possible by the microprocessor and the databus control.

Sundstrand introduced the microprocessor to aircraft power-generating system control. Figure 5 is a block diagram of the generator control unit. In this particular unit the voltage is regulated with analog circuits, but breaker control, protection, and built-in testing is controlled by an eight-bit microprocessor. Sundstrand uses the 8085 Intel system in a standard configuration with read-only memory, random access memory, independent watch-dog control for the microprocessor, and some nonvolatile memory, which is essential to the built-in test system. The built-in test system (BITE) for this particular airplane is a revolutionary system and the first of its kind.

Historically speaking, built-in testing has been an afterthought. It has not worked very well because it simply has not been very accurate. With the advent of the microprocessor Sundstrand has been able to incorporate active testing on a continuous and specific basis in order to address faults in the system and to isolate them on the basis of tests, not probabilities. The microprocessor processes almost all of the system information on a continuous basis anyway. Sundstrand took advantage of that and used it for the built-in test features. Any particular system malfunction is detected immediately, and an isolation routine is included in the fault-clearing operation. The non-volatile memory is used to store the information. (For example, for the first time we can seriously address problems such as intermittence.) This particular system contains a bus protection control unit and an alphanumeric display, which tells the flight-line mechanic in plain language exactly what is wrong, what the fault is, and what the line-replaceable unit (LRU) is. Boeing has found this to be very helpful in introducing the 767. Figure 6 shows, in a bar-chart form, that historically many parts have been removed that turned out not to be the problem. The common assumption is that systems consist only of an IDG and a GCU. This fails to take into account the 15 or 20 other significant parts that can also fail (e.g., wiring connectors and coolers). A BITE system that does not address those parts is inadequate. Therefore Sundstrand tried to address many of those parts in this new system. As a result the system should achieve a 95-percent confidence level in LRU identification - based on testing and not probability.

Future Trends

A typical assumption is that hydromechanical power-generating systems constitute a mature technology with little improvement possible. Nothing could be further from the truth. The technology is changing and being applied in the same way as the technologies for other approaches. By 1987 the weight of a typical system should be down to 0.8 lb/kVA. That is almost a 50-percent reduction from 1977 levels (fig. 7).

Weight reduction should come from the following technological advancements:

(1) Improved materials. Sundstrand is examining improved materials usage, particularly in the constant-speed drive area. We are testing a 24 000-rpm generator. Present generators run at 12 000 rpm, and therefore the increased speed should result in some generator weight reduction.

Figure 8 is a sketch of a 24 000-rpm two-pole generator that Sundstrand is building. It gives some idea of the rotor construction. There is nothing revolutionary about a two-pole machine: the idea certainly has been around for a long time. Several other people are building them. We are trying to build an extremely reliable one and we are spending some time to do that.

(2) Improved electromagnetic power density. Again, Sundstrand has been a pioneer in improving the power density of the electromagnetics in aircraft through spray-oil cooling and other means by integration into the system. This activity is continuing. Recall from figure 1 that the generator control unit is a significant part (more than 10 percent) of the power system weight. We think there is substantial room for improvement by using large-scale integration and increasing the role of the microprocessor in the power-generating system.

(3) Large-scale integration and expanded microprocessor role. In the generator control unit and the bus protection control unit, one of the obvious improvements is to include all of the system controls in the microprocessor. Sundstrand has an active program to do that. The kinds of controls that are

intended to be included are, for example, voltage regulation of the generator, frequency control, all of the parallel-system controls that might be used for those aircraft that require a parallel system, load management, and configuration management. In the 757/767 system Sundstrand began with load management, through the bus protection and control unit. We actually do remove loads based on the system configuration. Some studies show that management of more of the load system is desirable, and this can also be accomplished. In configuration management you can observe what is happening and configure the system for your particular mission arrangement. Any standard databus that is used on an aircraft can be used to interface and communicate between the units. Also remote display is probably an inevitable development since a central display is preferred over individual displays for each piece of equipment.

Figure 9 shows the architecture of a breadboard GCU that Sundstrand is presently working with. It uses two 16-bit 8086 Intel microprocessors and is an extremely powerful combination of equipment. However, it has fewer parts than, for example, the KC-135 re-engine GCU's. This decrease in parts with an increase in complexity is an expected result of a digital approach. The input-output conditioning is probably conventional. The two units are completely independent but can communicate back and forth and have their own local memories, watch-dog timers, and so forth. If one unit fails, the GCU can still operate to some extent with the other unit or use the other unit for other purposes.

(4) Alternative power. Presently most systems have 400-Hz power with some 28-V dc power. In 1978, Sundstrand suggested that 2000-Hz constant-frequency power be used as a possible approach for weight reduction. A number of aircraft have already been configured with double-voltage systems to reduce distribution system weight. More and different kinds of direct-current power, perhaps 270 V, 100 V, or just more 28 V, or maybe a mixture, could be used.

(5) Integrated starter drive. Sundstrand has been a pioneer in the field of integrated starter drives. In the early 1960's we introduced electric starting for aircraft on the 727. At that time the engine was in the design stage. As the required thrust increased, the engine outgrew the capability of the starter. Since that time we have been constantly studying this system and we feel that, with a simple change in the arrangement of the constant-speed drive components, an integrated starter drive can start the toughest engines.

Figure 10 is a block diagram of one arrangement of a 150-kVA integrated starter drive. In the start mode, alternating-current power is applied to the motor-generator, which would accelerate as an induction motor by using a patented static switch arrangement for the rotor. At that point the hydraulic drive is feathered (i.e., no torque is being transmitted through the transmission). So the motor is completely unloaded. Once it is at speed, it is converted to a synchronous motor, which has very high efficiency and certainly does not disturb the quality of power on the bus. The unit is then brought into stroke and the system can be started easily with working pressures not exceeding 5000 psid, less than, for example, the two-per-unit pressures in the hydraulic units and hence very conservative.

Figure 11 shows how the 150-kVA integrated starter drive system would work with a JT9D engine, a tough-to-start engine. The drag-torque curves are shown for 59° and -69° F. As you can see, the engine can be started hot or cold, under any condition, in 25 seconds with a very reliable torque margin.

Figure 12 is a diagram of the integrated starter drive system. Although the number of CT loops could be reduced, the basic point of this diagram is that, with the exception of pressure, which is fed back from the hydraulic units, and the real power limit, all of the control variables are normally found in a parallel generating system. The system includes electronic control of frequency (servovalve into the constant-speed drive area). This will be more prevalent and allow for presynchronized paralleling even in split-bus systems.

In summary, then, I have attempted to share with you the state of the art of the 757/767/A310 hydromechanical aircraft power-generating systems: that Sundstrand has 1.3- to 1.4-lb/kVA systems in service, has introduced databus communications, and has introduced the microprocessor. Further substantial weight reductions are possible, to 0.8 lb/kVA in the foreseeable future. The microprocessor control is a powerful, flexible, dual 16-bit system that can handle any parallel-generating-system or starting arrangements that are envisioned. And, of course, the BITE is a landmark system and will continue to be so. Alternative forms of power are not excluded by considering this approach. Higher frequency, higher voltage, and mixed direct-current power can be used if needed. Finally, this system provides an extremely high torque margin for reliable engine starting.

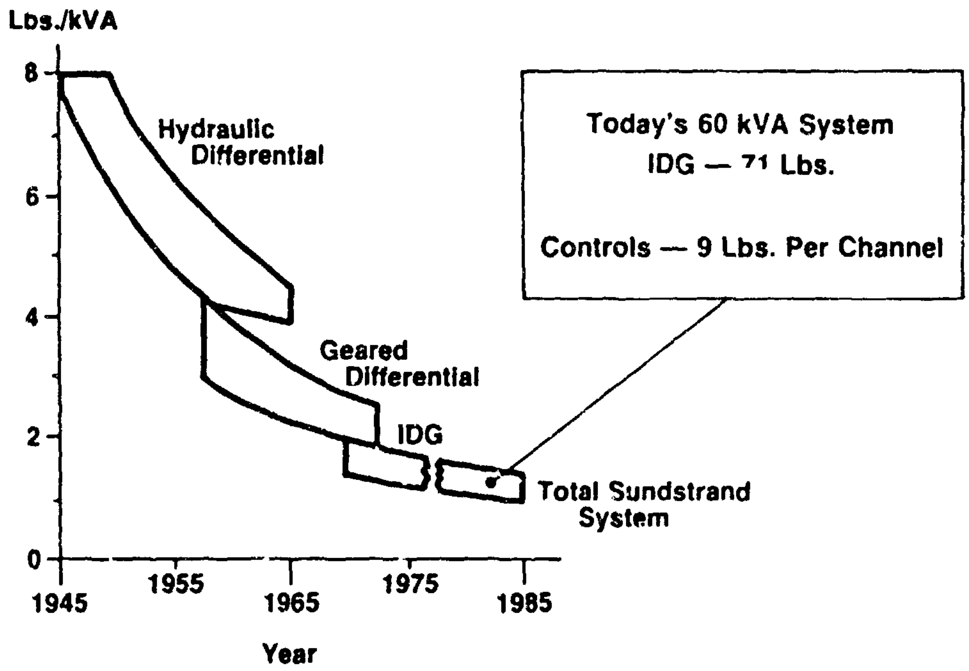

Figure 1. - Integrated-drive generator weight evolution.

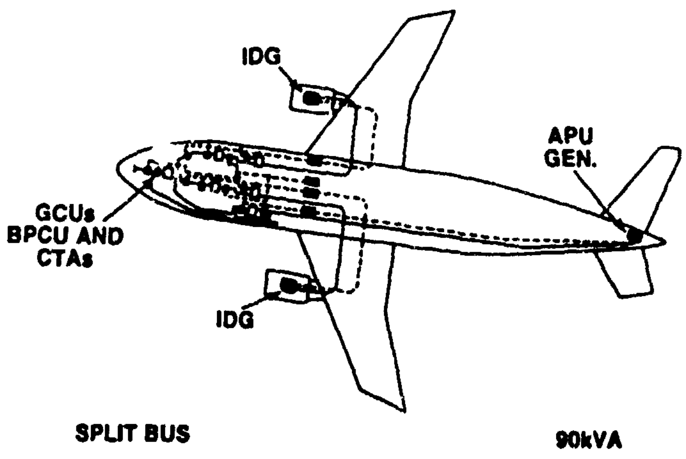

Figure 2. - 757/767 generating system.

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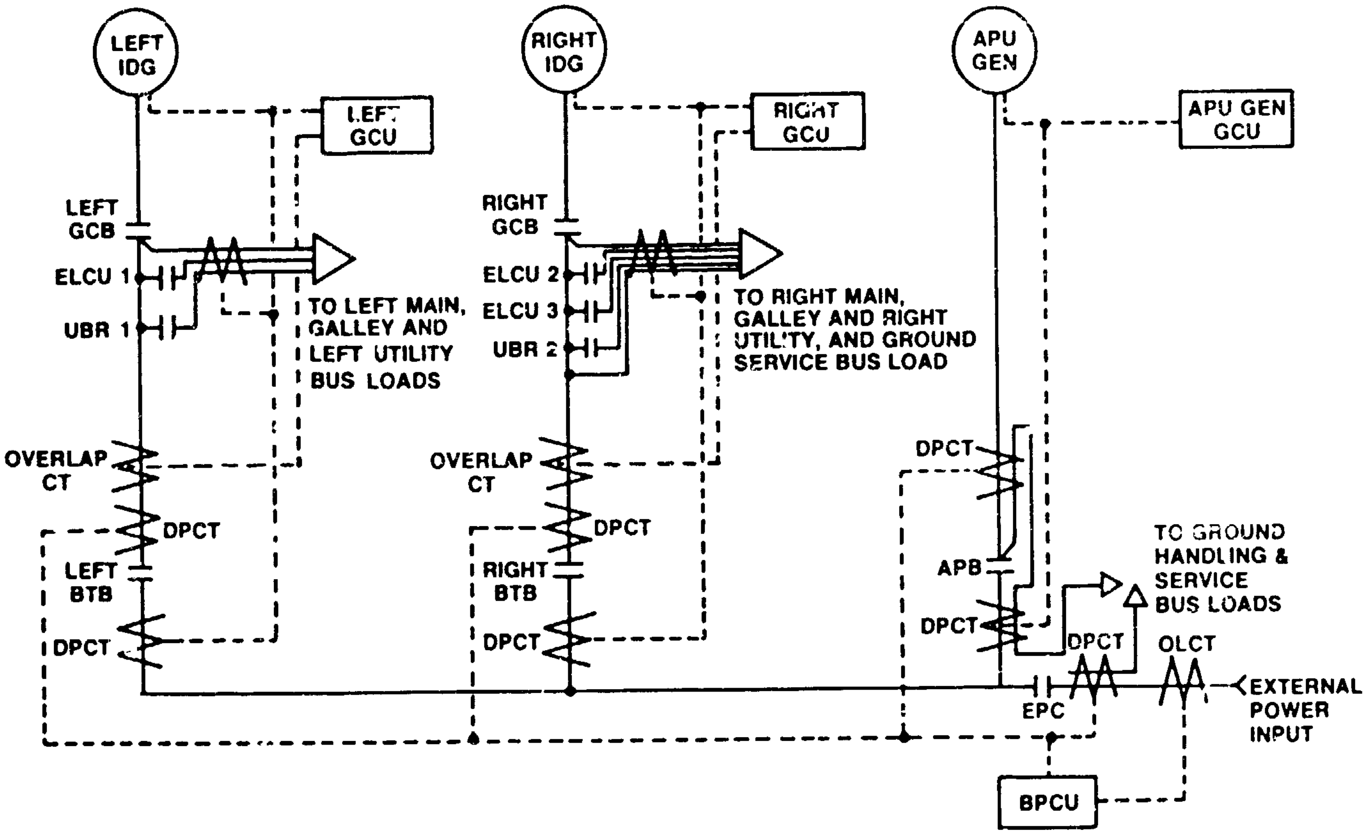

Figure 3. - Schematic of 757/767 EPGS.

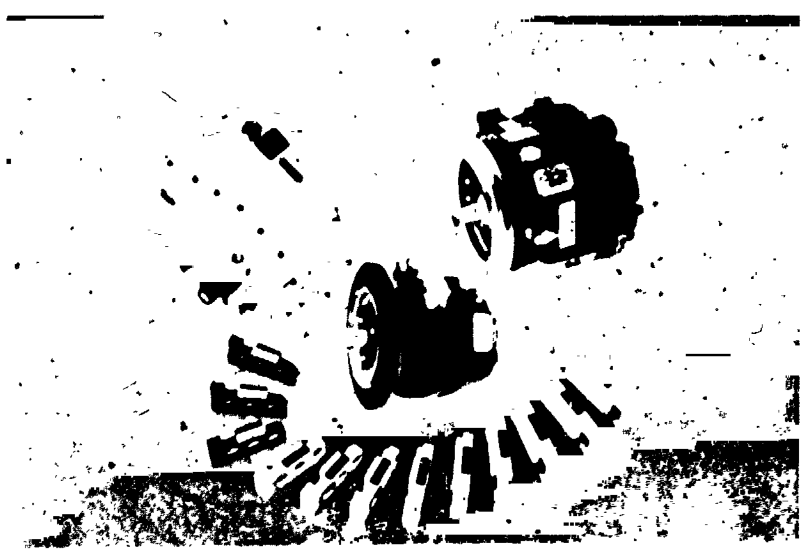

Figure 4. - Complete control system used in current aircraft.

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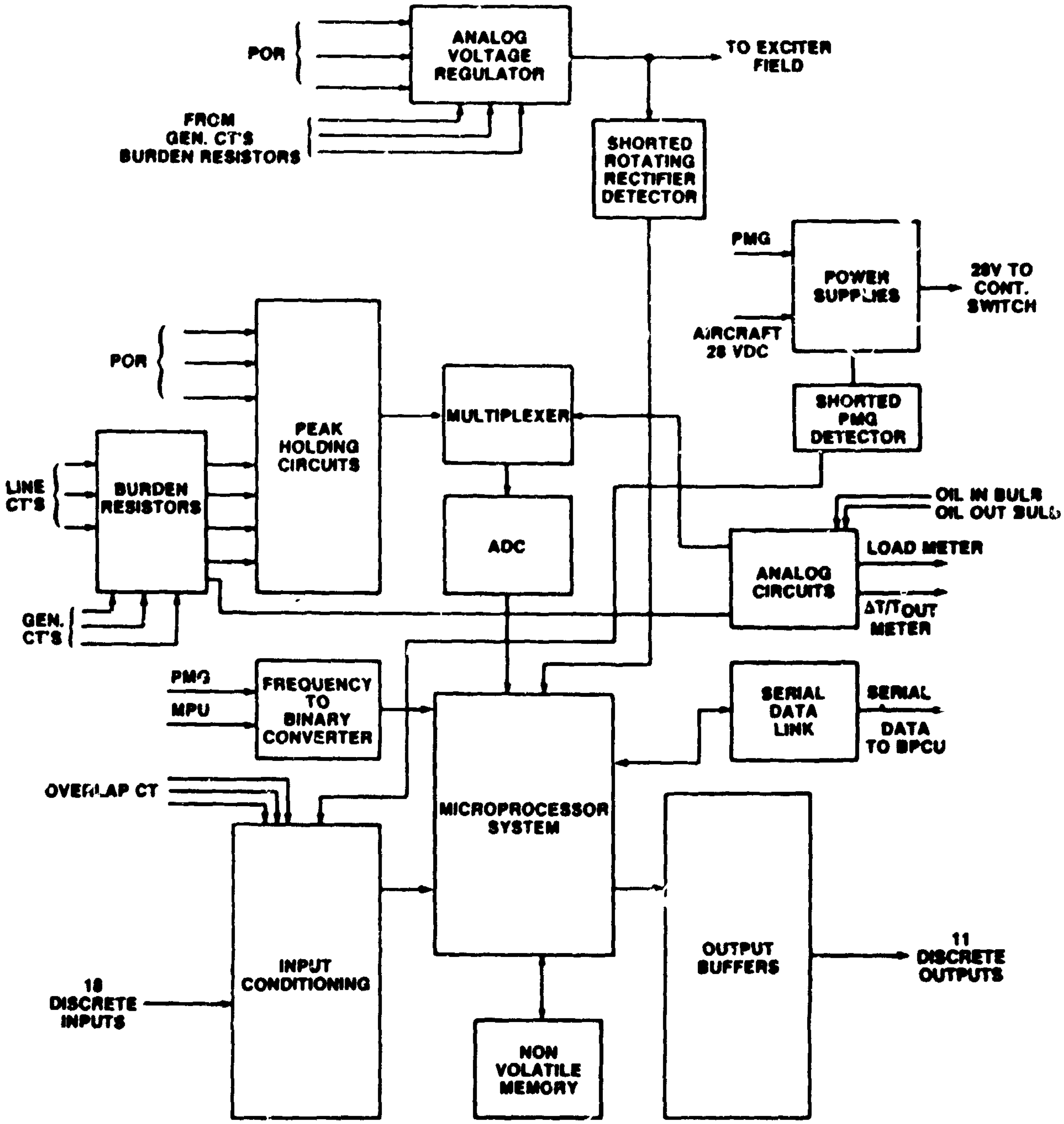

Figure 5. - Block diagram of 757/767 generating system.

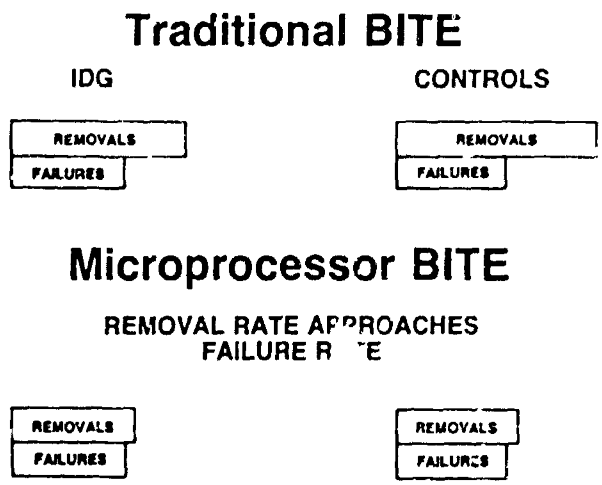

Figure 6. - Tranditional and microprocessor BITE'S.

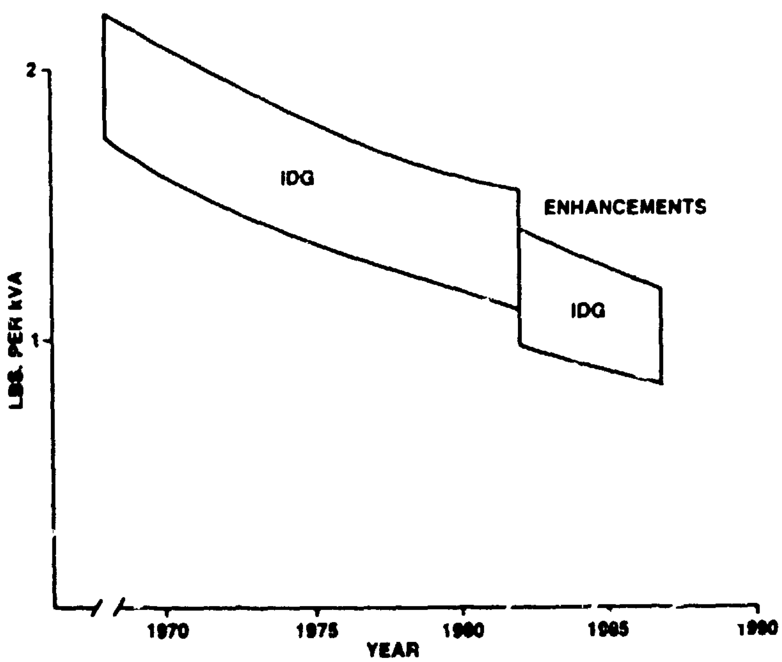

Figure 7. - Future IDG weight trends.

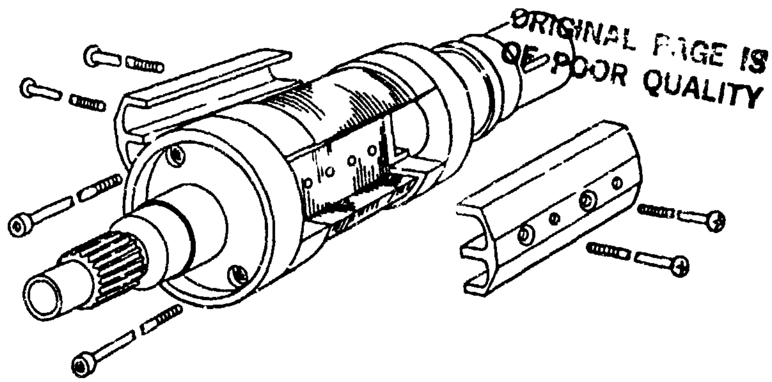

Figure 8. - Two-pole, 24 000-rpm generator rotor.

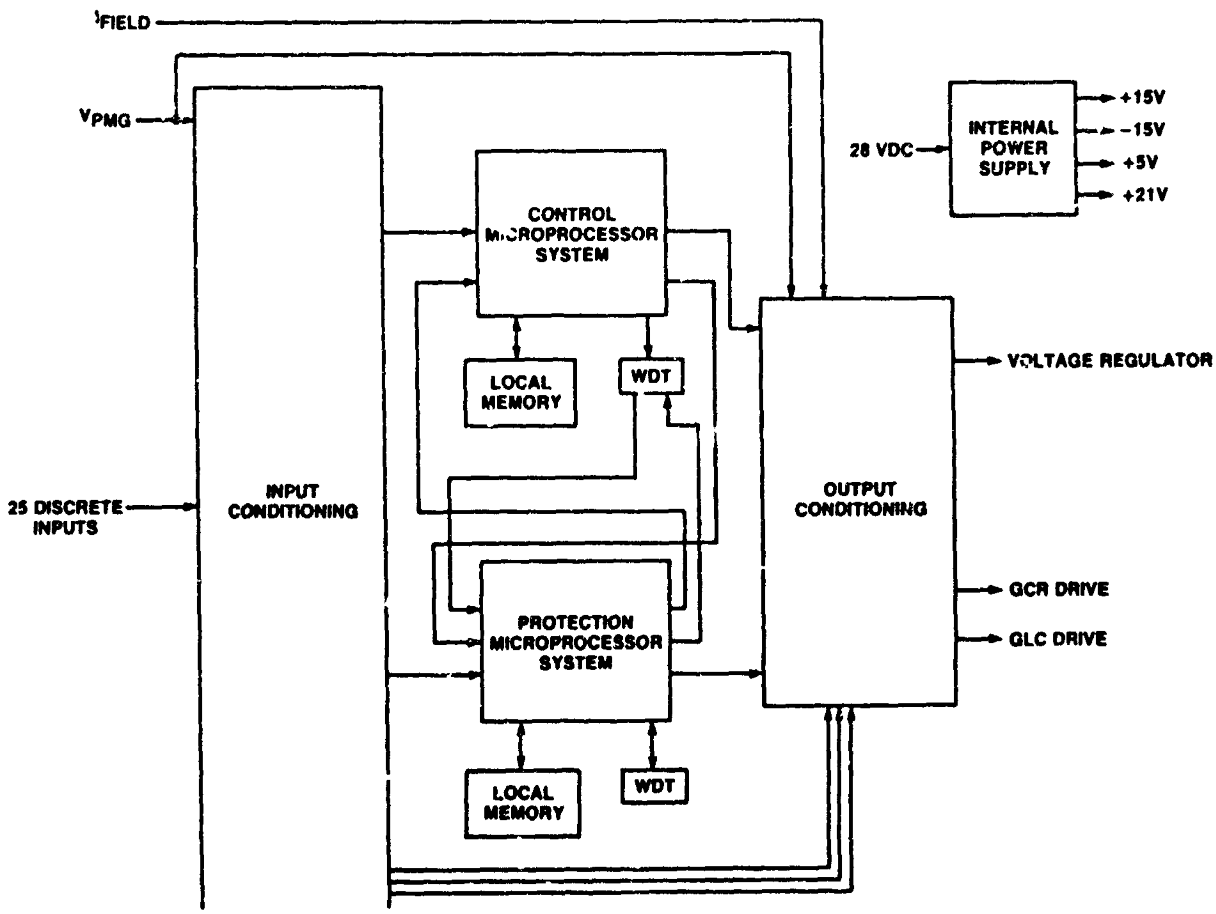

Figure 9. - Block diagram of advanced-architecture generator control unit.

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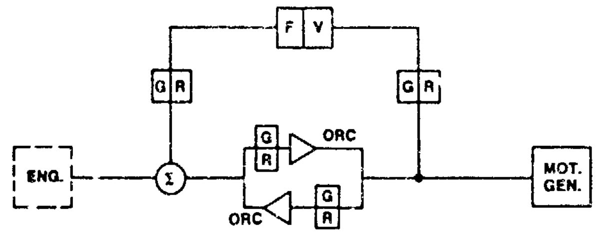

Description of Operation

- V Unit Feathered, Induction Motor Start Up
- V Unit Stroked, Hydromechanical Engine Start Up Controlled at 5,000 PSID
- Working Pressure Decreases With Increasing Input Speed When in CSD Mode

Figure 10. - 150-kVa integrated starter drive.

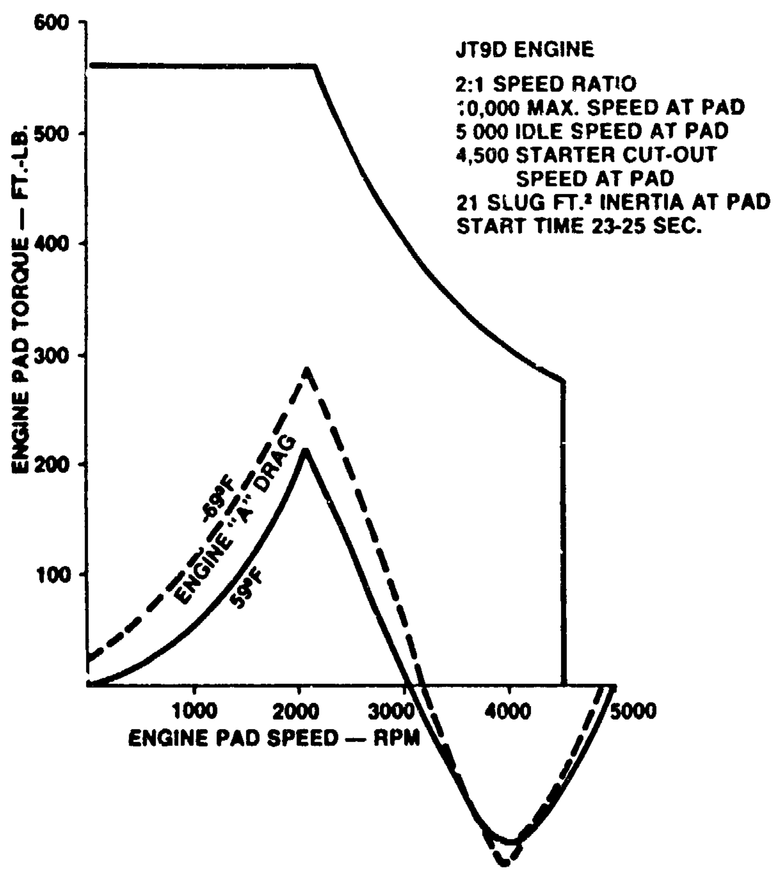

Figure 11. - Torque as a function of speed for 150-kVa integrated starter drive on JT9D engine.

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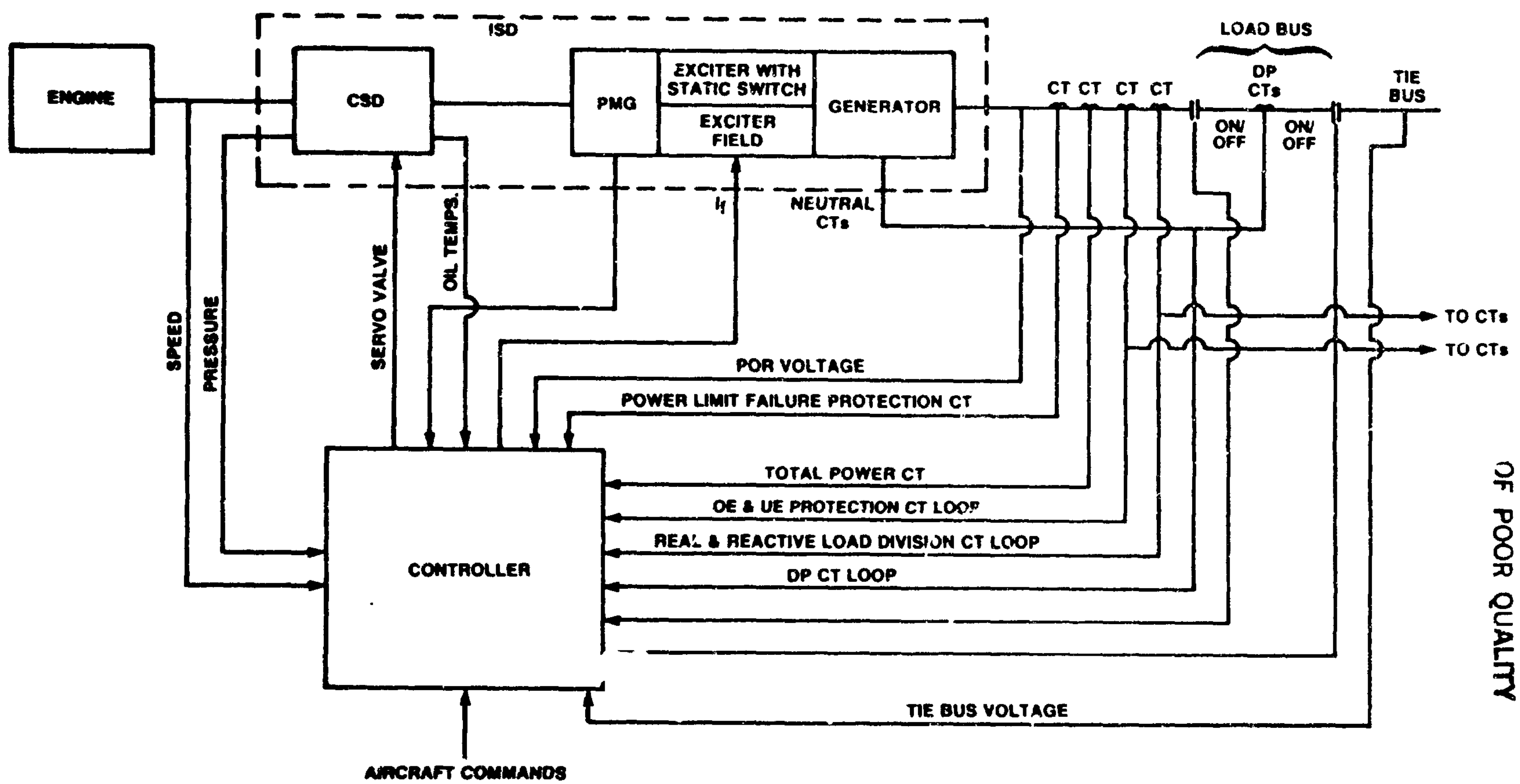

Figure 12. - Block diagram of integrated starter drive system.