



AEROSPACE INFORMATION REPORT

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Superseding AIR1739A

Information on Antiskid Systems

RATIONALE

AIR1739B has been reaffirmed to comply with the SAE five-year review policy.

INTRODUCTION

The summary of experience in antiskid system usage will be used by design personnel to avoid the pitfalls experienced by others in application of antiskid to retrofitted and new systems. The information will be presented as General System Description and Operation, Hardware Details and Functions, System Performance Evaluation, System Development Process, and Service Problems.

Need and Requirements:

While antiskid system, component, and feature problems and limitations are well known to the designer and specific user, there is no documentation available which describes the broad field of applications. This document is a compendium of field experience and can form the basis for establishing system requirements. The requirements should reflect the intended operating surfaces, the desired performance, required system efficiency and the method of determining this efficiency. Required system characteristics or features should be initially established along with performance requirements prior to contracting for a system.

Antiskid control systems originated in response to the inability of the pilot to maintain control of the brake system and to avoid inadvertent wheel lockup and possible tire failure. With most power brake systems, the "feel" of the overall aircraft system to the pilot is inadequate to maintain knowledge of the state of rotation of all the aircraft wheels. This is especially true for large multi-wheel aircraft. Therefore, some degree of assistance was needed to detect and react to deep skids and wheel lockups. This initial basic need resulted in the inclusion of an antiskid system. As antiskid systems evolved, their primary purpose shifted from lockup prevention and tire saving to optimal stopping performance. All modern brake control systems include highly efficient stopping performance as one of their primary goals.

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1. SCOPE

This SAE Aerospace Information Report (AIR) has been prepared by a panel of the SAE A-5A Committee and is presented to document the design approaches and service experience from various applications of antiskid systems. This experience includes commercial and military applications.

1.1 Purpose

The purpose of this document is to describe antiskid system configurations, features, modes of operation and to define various methods used to calculate antiskid system performance.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org

AS483B	Skid Control Equipment
AIR764C	Skid Control System Vibration Survey
ARP862B	Skid Control Performance
AIR1064D	Braking System Dynamics
ARP1070C	Design and Testing of Antiskid Brake Control Systems for Total Aircraft Compatibility
AIR5372	Information on Brake-by-Wire (BBW) Brake Control Systems

2.2 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>

14 CFR 25.735e	Antiskid Systems
14 CFR 25.109	Accelerate-Stop Distance
14 CFR 25.1301	Function and Installation
14 CFR 25.1309	Equipment, Systems and Installations
AC 25-7B	Flight Test Guide for Certification of Transport Category Airplanes
AC 25.735-1	Brakes and Braking Systems Certification Tests and Analysis
MIL-W-5013L	Military Specification Wheel and Brake Assemblies, Aircraft General Specification for
MIL-PRF-5041K	Performance Specification, Tires, Ribbed Tread, Pneumatic, Aircraft, General Specification for
MIL-B-8075D	Brake Control Systems, Antiskid, Aircraft Wheels, General Specification for



2.3 Other Documents

AFFDL-TR 74-118 "Test and Performance Criteria for Airplane Antiskid Systems," October 1974

Boeing Report D6-41115, "Research Study on Antiskid Braking Systems for the Space Shuttle," NASA Contract 8-27864

ASD-TR-74-41, FAA-RD-74-211, Vols. I and II, "Combat Traction II, Phase II," October 1974

ASD-TR-77-6, Vols. I and II, "An Extended Prediction Model for Airplane Braking Distance and a Specification for a Total Braking Prediction System," March 1977

NASA TP-1051, "Behavior of Aircraft Antiskid Braking Systems on Dry and Wet Runway Surfaces - A Slip-Velocity-Controlled, Pressure-Bias-Modulated System", December 1979

NLR-TP-2001-242, "Hydroplaning of Modern Aircraft Tires," Nationaal Lucht- en Ruimtevaartlaboratorium NLR, November 1999

3. GENERAL SYSTEM DESCRIPTION AND OPERATION

3.1 General System Configuration

Antiskid Control System is defined as a group of interconnected components which interact to prevent inadvertent tire skidding and contribute to shorter aircraft stopping distances by controlling excessive clamping force on the brakes. The basic system normally consists of a wheel speed transducer, a control circuit and a brake pressure control valve or electric motor actuation controller as shown in Figure 1. The antiskid system is a sub-system of the braking system which also includes the pilot control, parking brake functions, and the wheel/tire/brake assemblies. The braking system may also include other features such as automatic and gear retract braking. In some cases, the pilot's control function uses the antiskid system hardware, as is the case in many brake-by-wire systems. All are subsystems of the gear, and they are all interrelated.

3.2 System Operation

The basic purpose of the antiskid system is to modulate pilot commanded clamping force on the brakes, modulating it to levels compatible with optimum aircraft deceleration, while preventing excessive wheel skidding. In hydraulic systems this clamping force is produced by hydraulically driven pistons. In electric brake systems this force is produced by electrically driven actuators. Typical operation is as follows. The pilot applies brakes by applying force to the brake pedals resulting in an increase in clamping force in the brakes. As the clamping force increases, the wheel begins to slow down and the force between the tire and the runway increases. When the available friction force between the tire and the runway is exceeded, the wheel begins to decelerate rapidly. This is sensed by the antiskid system which in response outputs a signal to reduce clamping force. With release of clamping force, the wheel accelerates to a speed somewhat less than synchronous speed while maintaining as much braking force as possible, the release signal is removed and clamping force is reapplied. This sequence then repeats as needed.

3.3 Antiskid Control Classification

Many different antiskid systems are in use today. They represent a broad spectrum of an evolving technology from the late 1940's and different approaches to the solution of a complex problem. The very early systems utilize on-off control concepts, while later systems provide different degrees of brake pressure modulation in response to wheel speed changes.

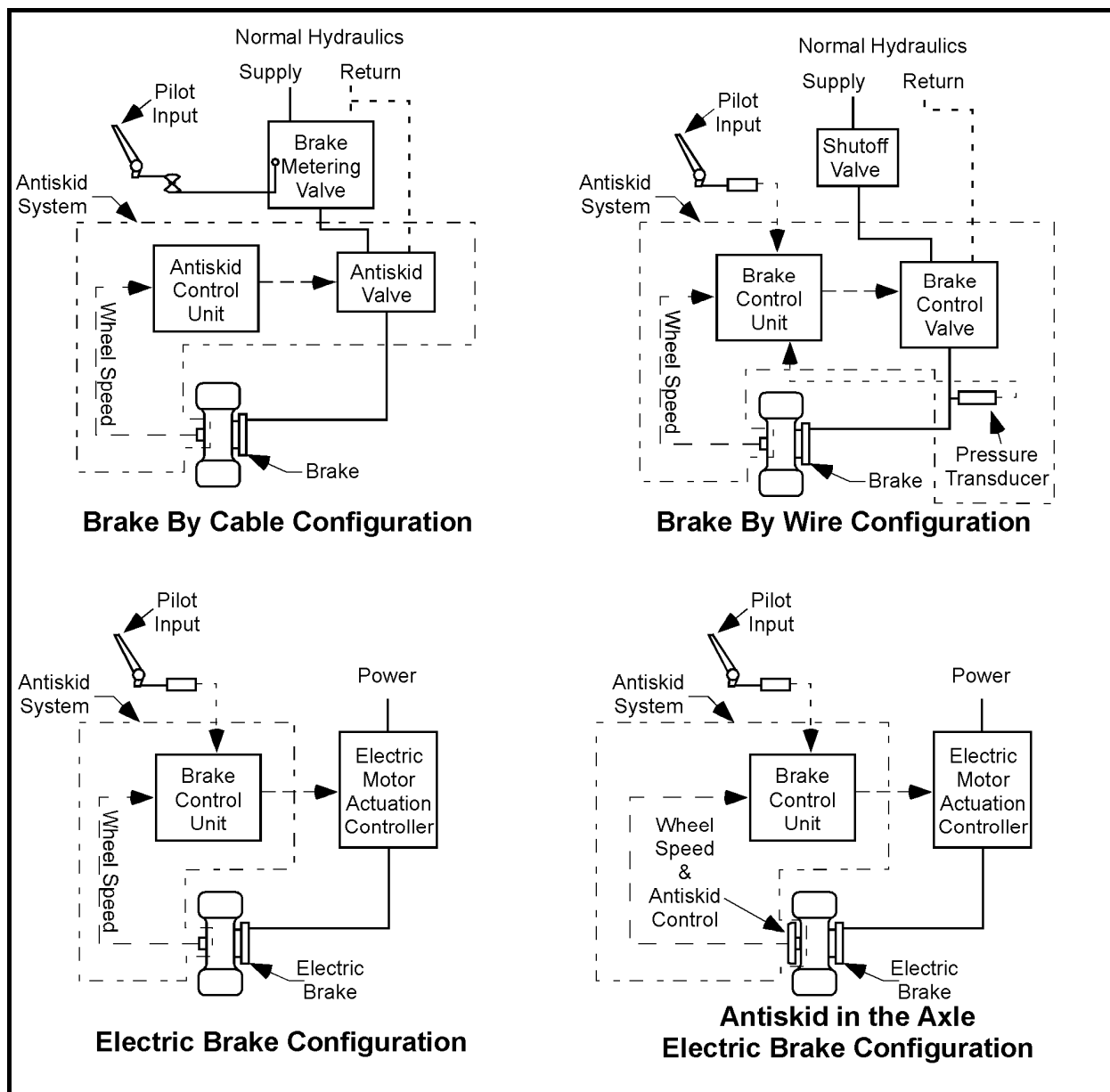


FIGURE 1 - ANTISKID SYSTEM SCHEMATIC

3.3.1 ON-OFF Systems

A typical on-off system is in use on the B-52 and consists of three components: a skid and locked wheel detector, a control shield, and a solenoid valve. The detector is an electro-mechanical device, providing logic signals to the control shield. The control shield is a power conditioner containing a series of relays. The relays interpret logic signals from the detector and apply an electrical signal to the hydraulic solenoid valve, to dump or reapply metered brake pressure.

The detector is the heart of this antiskid system. Its function in the system is to detect wheel decelerations above a preset value. As implemented in the B-52, the detector is mounted in the axle and is driven by wheel hub cap rotation. The skid sensing portion of the detector consists of an inertia flywheel and an overload-release clutch. The flywheel's inertia causes the spring loaded clutch to release when wheel deceleration exceeds a predetermined rate. Because the wheel is slowing down faster than the released inertia, a relative displacement occurs between the inertia and the drive, attached to the wheel, causing a set of electrical points to contact, thereby completing the skid circuit to the control shield. The shield in turn provides an electrical signal to the antiskid solenoid valve, resulting in a release of brake pressure. Feedback to the pilot to indicate that the wheel is skidding is provided either through pedal vibration or a cockpit light.

As the wheel accelerates back to synchronous speed, the contacts in the detector open, removing the signal from the antiskid solenoid valve. Thus, the pilot's metered pressure is again applied to the brake, allowing the skid cycle to repeat. In this type of system, the pilot must adjust the applied pressure level to minimize cycling in order to achieve good performance. Figure 2 shows an example of typical control using an ON-OFF system on a dry and a wet runway.

3.3.2 Modulating (Quasi-Modulating) Systems

Modulating antiskid systems generally rely on a wheel speed transducer which generates a signal proportional to wheel speed. Based on the input wheel speed information, the electronic control circuit determines if the wheel is going into a skid. A signal is supplied by the control circuit to an electro-hydraulic valve (the antiskid valve) which regulates brake pressure in a manner inversely proportional to control signal, releasing pressure when a skid is detected and reapplying it when the wheel recovers. But, unlike the ON-OFF system, the pressure is reapplied to a lower level and then ramped up until the wheel starts to go into a skid again. This eliminates the need for interaction by the pilot.

The first generation modulating systems generally act to release brake pressure when the computed wheel deceleration exceeds a preset value indicating an incipient skid. Brake pressure is held off for a time duration depending on the depth of the skid. As the wheel recovers from the skid, brake pressure is first stepped up to a low value and then gradually increased until a new incipient skid is sensed. During the wheel skid essentially all corrective action is based on a pre-programmed sequence, rather than the wheel speed/time history. These modulating systems can be tuned to provide very good dry runway performance; however, on slippery runways they are only able to extract a fraction of the maximum available friction because too much time is consumed in opening and closing the brake stack. The control dynamics of the modulating systems are not optimized for maximum performance on slippery runways. Figure 3 shows an example of typical control for a Modulating System on a dry and a wet surface.

Most modulating systems rely on an electronic circuit for intelligence. However, one system is in use which consists of only two hydro-mechanical components. A hydraulic modulator, upstream of the brake, controls initial pressurization volume and pressure application rate. The sensor, downstream of the brake, is located in the wheel axle and controls pressure release rate when an incipient skid is sensed.

3.3.3 Adaptive Systems (Fully Modulating)

Adaptive antiskid systems represent advanced control concepts which give optimized performance for both dry and wet runways. Usually high frequency wheel speed transducers are used which result in improved signal fidelity and response. Multiple data control functions, feedback of valve current, and nonlinear computing elements such as multipliers and dividers are combined to result in the adaptive control system. During the skid, corrective action on brake pressure is based on the sensed wheel speed signal. The major difference between the modulating and adaptive systems is found in the implementation of control in the electronic circuitry.

Adaptive systems, typically, compare braked wheel speed to a reference wheel speed. In almost all systems the reference wheel speed is derived electronically from the braked wheel during spin-up and brake release. However, one system is in use which measures the reference wheel speed with a separate and additional sensor in the nose wheel. In some systems, the control circuit cycles the braked wheel about a fixed slip ratio. Slip (or slip ratio) is defined as one minus the wheel rotational speed divided by the wheel rotational speed of a free rolling wheel. At least one system observes wheelspeed characteristics to seek out and modulate brake clamping force about the level that will just result in a skid. This is the level at which optimal braking occurs. Figure 4 shows an example of typical control for an Adaptive system on a dry and a wet runway.

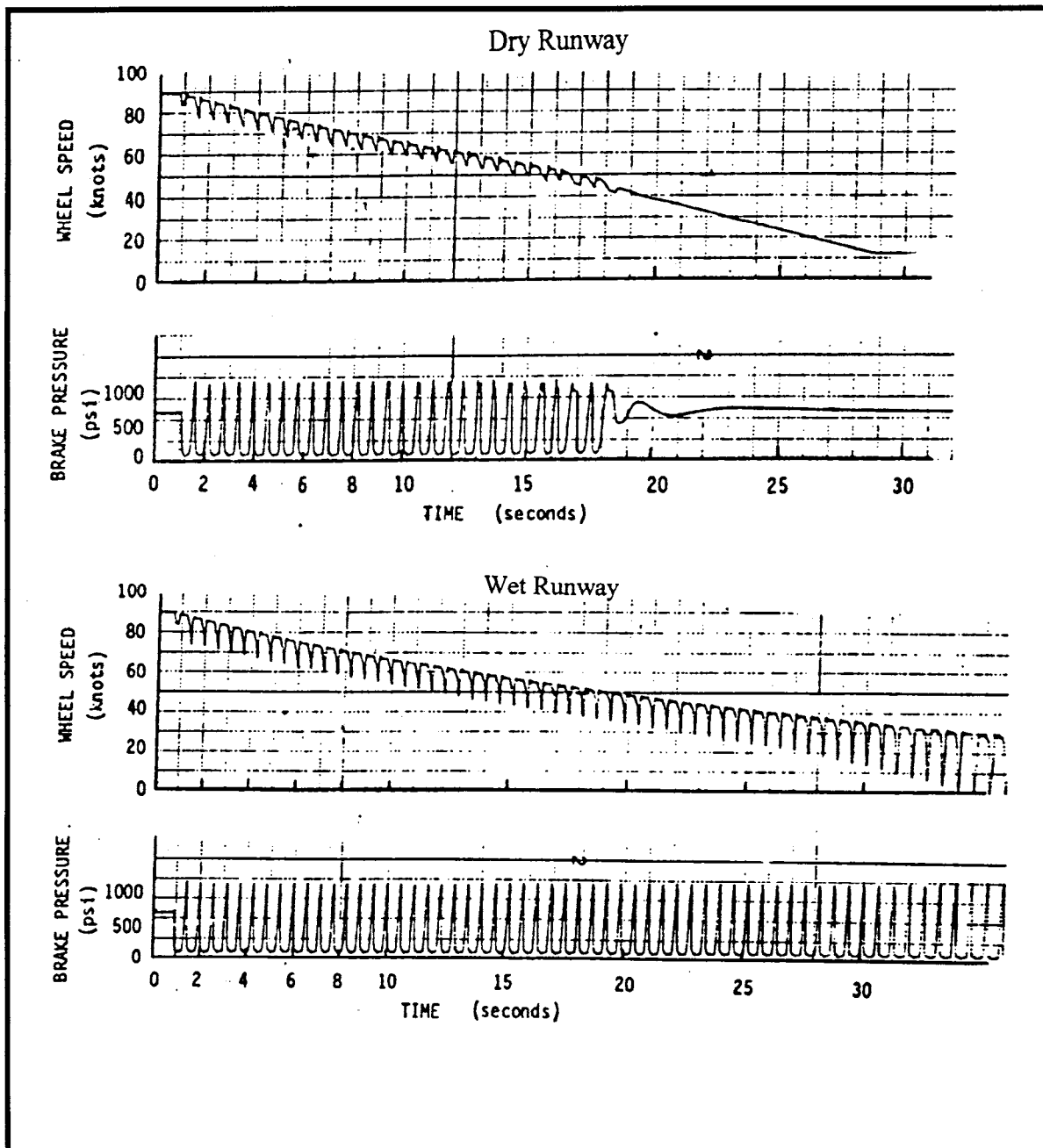


FIGURE 2 - ON-OFF SYSTEM OPERATION

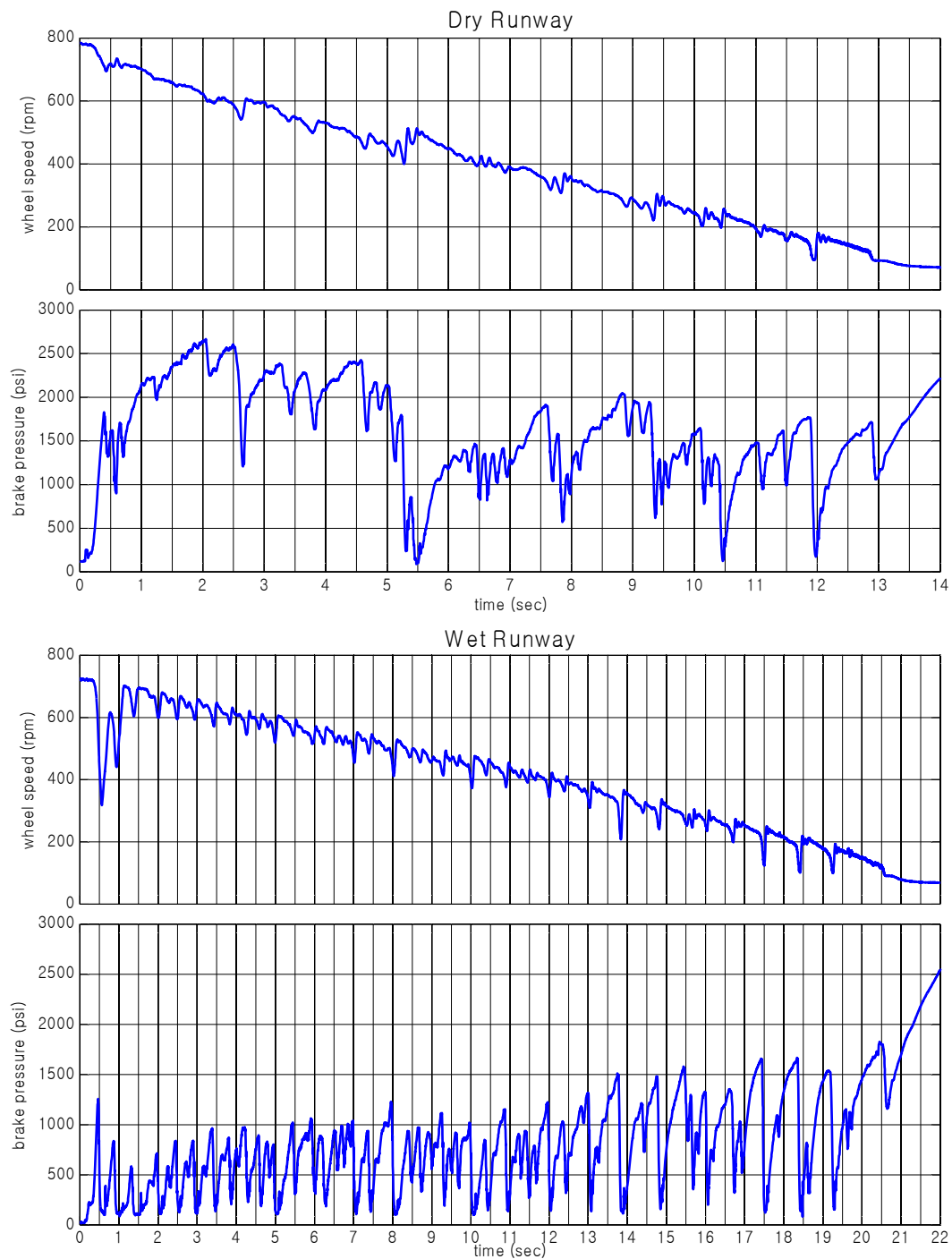


FIGURE 3 - MODULATING SYSTEM OPERATION

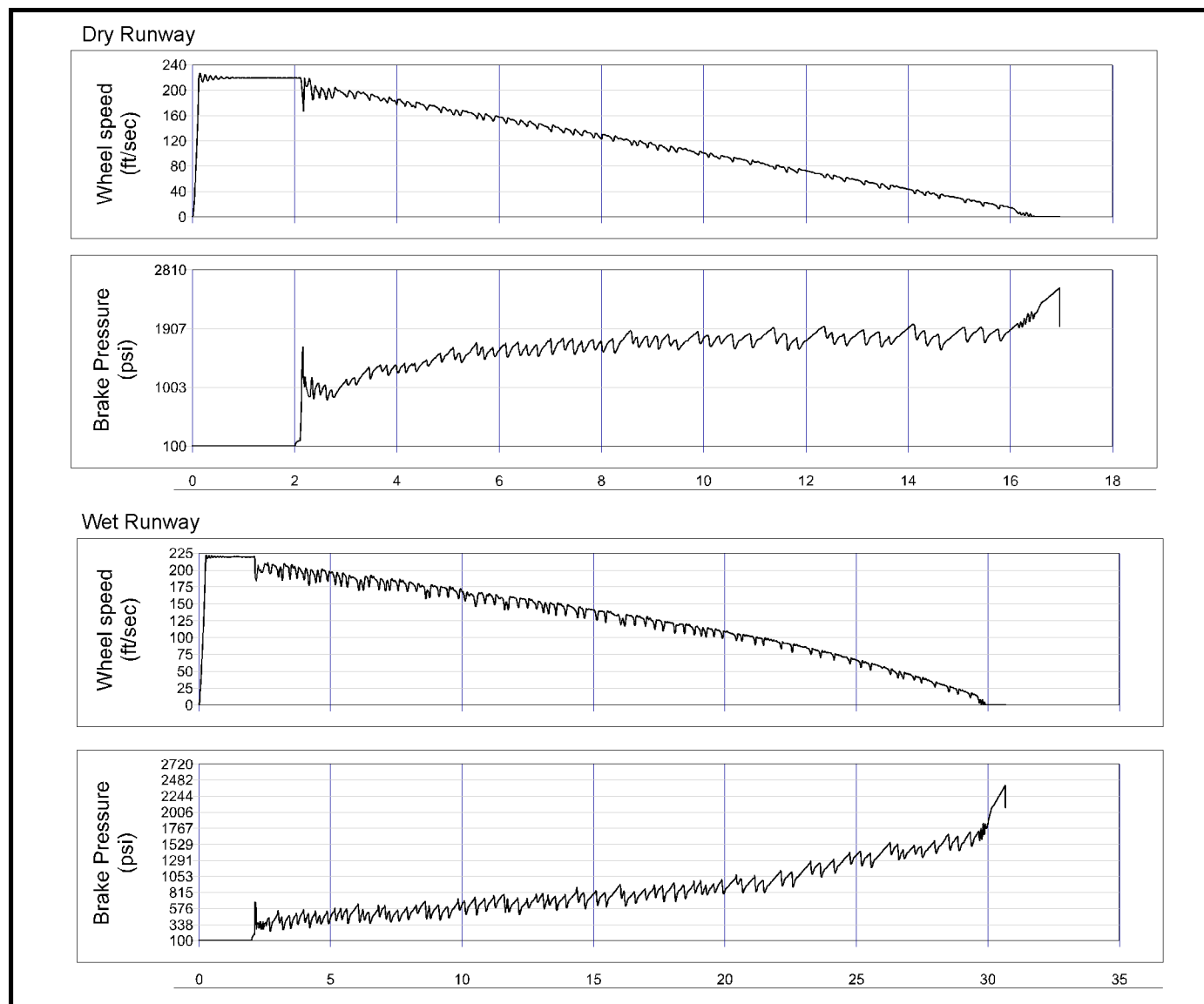


FIGURE 4 - ADAPTIVE SYSTEM OPERATION

3.4 Control Features

Experience has shown that several ancillary functions contribute to making the system work under all circumstances. These include wheel control grouping, touchdown protection, locked wheel protection, hydroplaning protection, and fault detection.

3.4.1 Individual Wheel Control

Individual wheel control is a system configuration in which each braked wheel is controlled by a separate valve and control circuit. Individual wheel control is the predominant control configuration in use because of its high efficiency.

3.4.2 Paired Wheel Control

In a paired wheel control configuration, two or more brakes are controlled together utilizing one control signal. This may be accomplished in two or more ways: the brake controller can produce one signal controlling one valve supplying pressure to two brakes or the brake controller can produce one signal controlling two valves with each valve supplying pressure to a separate brake. This configuration, while not as efficient as individual wheel control, has been used to assist in maintaining directional control where individual control can produce yaw moments which are difficult to control by the pilot. Paired wheel control has been used for the backup system on large aircraft with multiple braked wheels on each gear to reduce the amount of hardware required with only a small loss in performance. Differential control, by reducing pilot commanded pressure to the side opposite the direction of the intended turn, is possible in paired wheel control as long as there are separate valves for the left and right wheels of the airplane.

3.4.3 Locked Wheel Protection

Generally all antiskid systems for modern jet aircraft incorporate a locked-wheel protection feature. The wheel speed signals, on two (or more) wheels, are used to produce an "airplane moving" reference. In the event one of the wheels should lock up, a comparison of that wheel speed with the reference signal provides a basis for the release of the brake pressure of the slow wheel. A reference memory may be provided to maintain the reference should the two (or more) wheels lock up at the same time. The combination/location of wheels grouped (or paired) for locked wheel protection should be selected on the basis of airplane configuration, antiskid system configuration and failure modes. Typical pairing used include: inboard and outboard wheels across the airplane, adjacent wheels on a landing gear, and fore/aft wheel pairs on a truck (4-wheel bogie). Locked wheel protection can protect against hydroplaning (or aquaplaning) where loss of tire footprint contact with the runway may result in friction characteristics that fool the brake control into slowly controlling the wheel into a deep, prolonged skid.

3.4.4 Touchdown Protection

The purpose of touchdown protection is to make sure that braked wheels are free to rotate at touchdown even though the pilot had inadvertently applied brakes. The protection is normally implemented using the wheel speed signal and a signal from the airplane's AIR/GROUND logic system. If the AIR/GROUND signal indicates that the airplane is in the air and the wheel speed is lower than a preset level, a full dump signal is applied to the antiskid valve. A transition from air to ground indication will result in removal of the dump signal, normally after a delay to allow wheel spin-up. Spin-up of the wheel to a level higher than the preset level will also remove the dump signal even with an airplane in the air indication.

3.4.5 Hydroplaning Protection

Hydroplaning Protection provides an extended release of clamping force to a braked wheel which fails to spin up due to hydroplaning at high speed on a flooded runway. Hydroplaning protection may be implemented by the use of an airplane ground speed reference which is external to the antiskid system, such as an Inertial Reference/Navigation System, or via an internal antiskid system reference signal. Brake release is based on the wheel speed being less than a set percentage of the ground speed reference. The hydroplaning protection would also provide the touchdown protection feature. Note that the locked wheel protection feature provides some amount of hydroplaning protection without the need for an airplane ground speed reference, as long as at least one wheel in the locked wheel groupings does spin up.

3.4.6 Fault Detection

Antiskid systems normally contain fault detection capability to provide indication to the pilot that the system is not fully operational, so that the pilot can use appropriate stopping techniques and allow for timely maintenance actions. At the simplest, the fault detection may do nothing more than check continuity to valves and wheel speed transducers and the availability of power. More sophisticated systems run end to end checks to ensure the health of the system and to isolate problems to the line replaceable unit (LRU) level or lower. A significant issue with fault detection systems is that they can result in numerous no fault found removals of brake system components.

A significant improvement to fault detection systems in microprocessor based systems is the ability to save application and landing parameters to memory to be used in the determination of system degradation and precise troubleshooting decisions. Stored parameters may include: wheel speed, brake pressure, pilot pedal inputs, and valve currents or clamping force commands.

4. HARDWARE DETAILS AND FUNCTIONS

A discussion and description of the hardware components more frequently encountered in antiskid systems is included as an aid in understanding overall system operation. For the sake of brevity, only the more commonly used components will be discussed.

4.1 Wheel Speed Transducer

The purpose of the wheel speed transducer is to provide an electric signal equivalent to the angular speed of the braked wheel. The transducer is mounted in the wheel axle and must be rugged in design to withstand high linear and torsional accelerations as well as high temperatures and high vibration levels. Two basic transducers are in use, the AC Generator and the DC Generator. The use of an AC sensor yields better signal fidelity and improved noise immunity than the DC generator as long as a sufficient number of teeth are used on the rotor. Fiber optic based wheel speed transducers have been developed and lab tested but have not entered service. A non-contact Hall effects based wheel speed transducer has recently completed certification.

4.1.1 DC Generator

The DC Generator produces a voltage proportional to wheel speed. The device is completely self-contained and is mounted in the axle. The armature of the generator is attached to the wheel and rotates with it. The basic parts of the transducer as shown in Figure 5 are a permanent magnet, armature, commutator, and brush assembly. Rotation of the commutator in the magnetic field induces an electrical signal proportional to wheel speed.

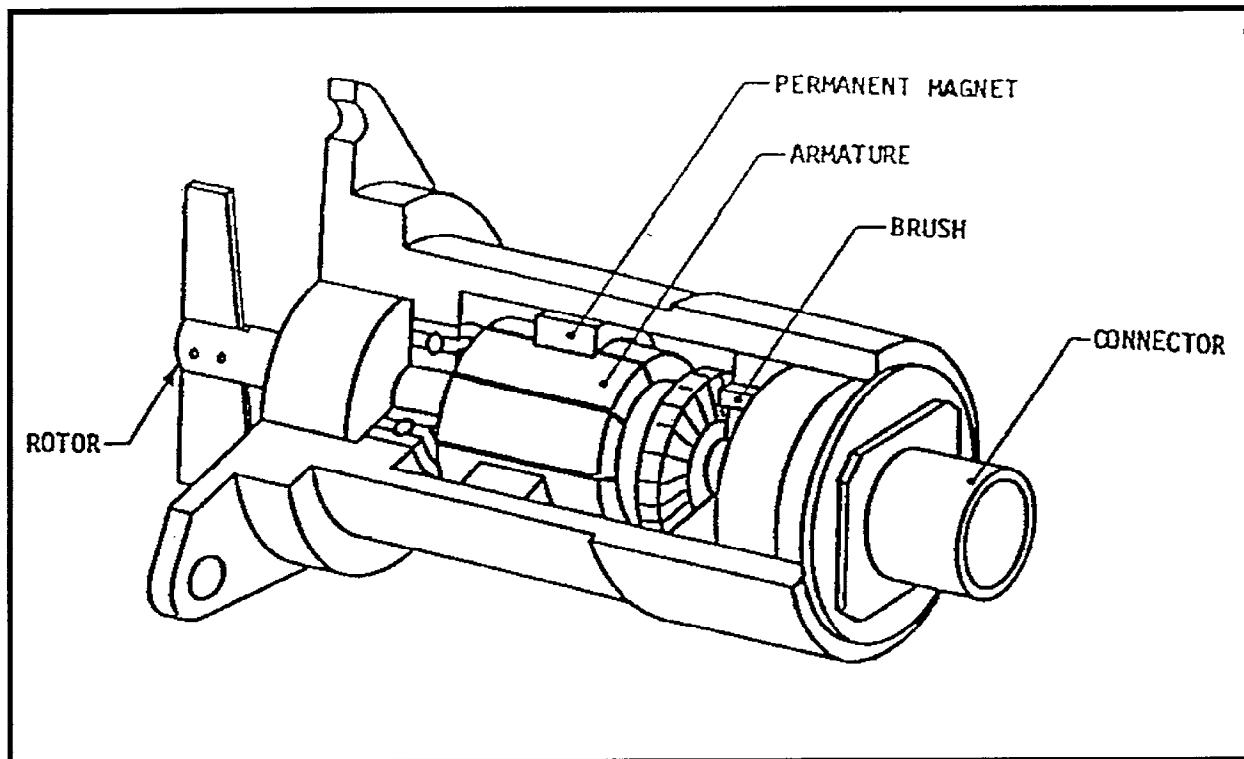


FIGURE 5 - DC WHEEL SPEED TRANSDUCER

4.1.2 AC Generator

The AC Generator is similar in appearance to the DC Generator but contains no brushes. The AC Generator produces an output voltage signal with frequency proportional to rotational speed and number of rotor teeth. A magnetic field is generated either with a DC current or a permanent magnet. As the rotor turns, the alternating alignment and misalignment of the teeth in the rotor and the stator vary the reluctance in the magnetic current. This results in an alternating current with frequency proportional to wheel speed. A typical AC wheel speed transducer is shown in Figure 6.

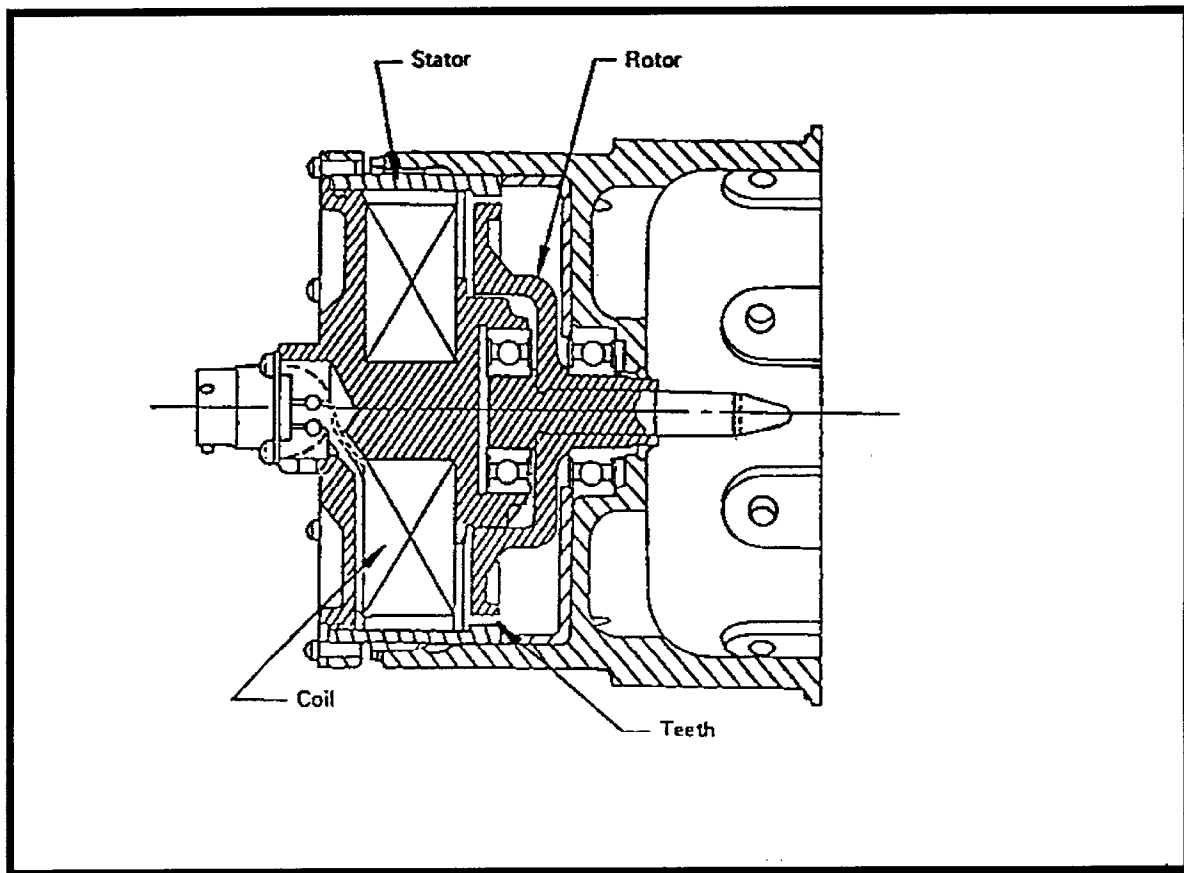


FIGURE 6 - AC WHEEL SPEED TRANSDUCER

4.1.3 Fiber-Optic Wheel Speed Transducers

Fiber-optic wheel speed transducers use light signals rather than electrical signals. A light source is normally located in the control unit and the light is transmitted through the transducer and back to a detector in the control unit via fiber optic cable. Within the transducer, the light is alternately transmitted and interrupted as the wheel rotates producing a detected signal with a frequency proportional to wheel speed.

4.1.4 Wheel Speed Transducer Couplings

The function of the transducer coupling is to connect the rotor of the wheel speed transducer to the rotating wheel, normally the wheel hubcap. In doing so, it must compensate for any misalignment between the axle centerline and the rotational axis of the wheel. There are a variety of methods for doing so. The normal method used is to have a drive arm mounted on the transducer shaft that fits in a radial slot in the part mounted in the hub cap. Figure 7 shows a spider/dog-bone coupling using this method. A shortcoming of this method is that if there is misalignment between the two axis, a one cycle per revolution sine wave is imposed on the wheel speed due to the varying arm length.

Another coupling currently in use is a bellows coupling, Figure 8. This coupling will accommodate large offsets, both angular and radial, with minimal effect on the signal quality.

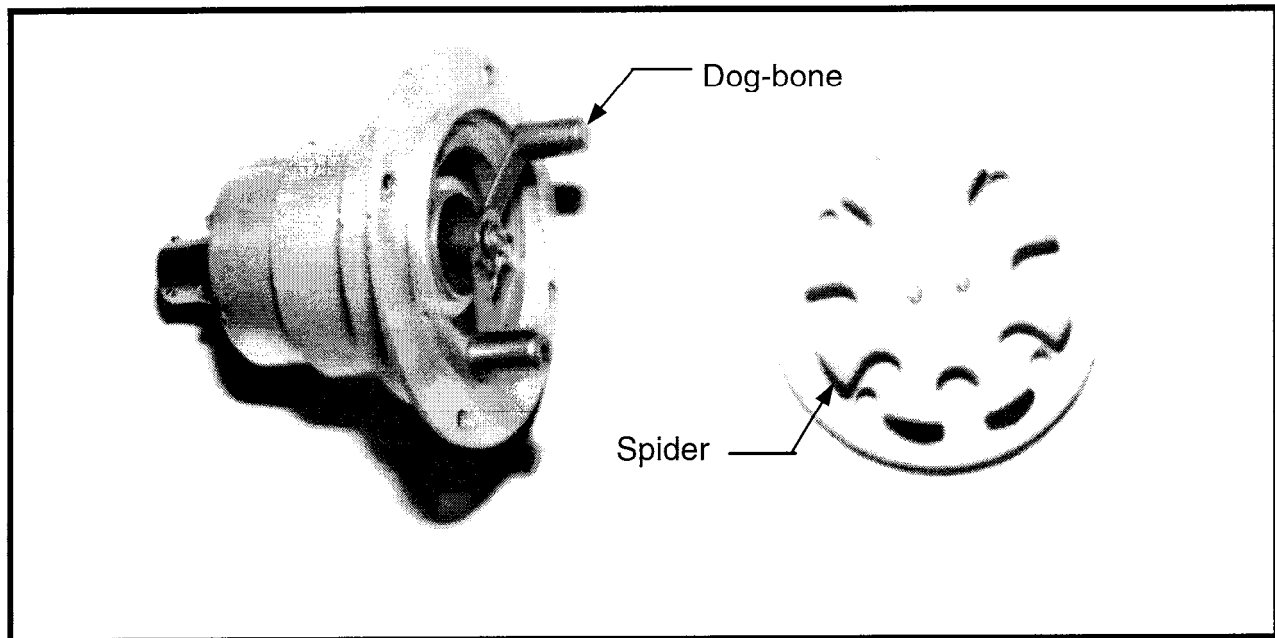


FIGURE 7 - SPIDER/DOG-BONE COUPLING

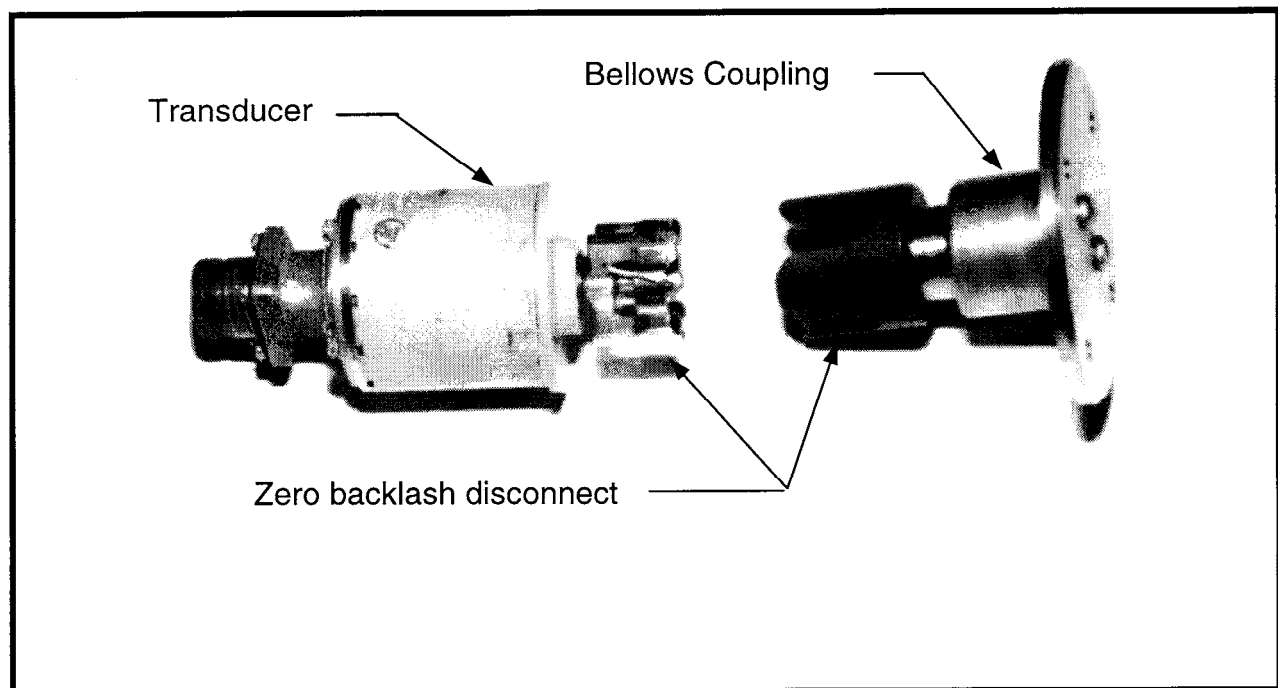


FIGURE 8 - BELLOWS COUPLING

4.1.5 Sensor/Exciter Ring, Wheel Speed Transducers

An alternate approach is the use of a sensor/exciter ring. The exciter ring is mounted to the rotating portion of the wheel/brake assembly while the sensor is mounted to the stationary portion. A sensor and exciter ring are shown in Figure 9.

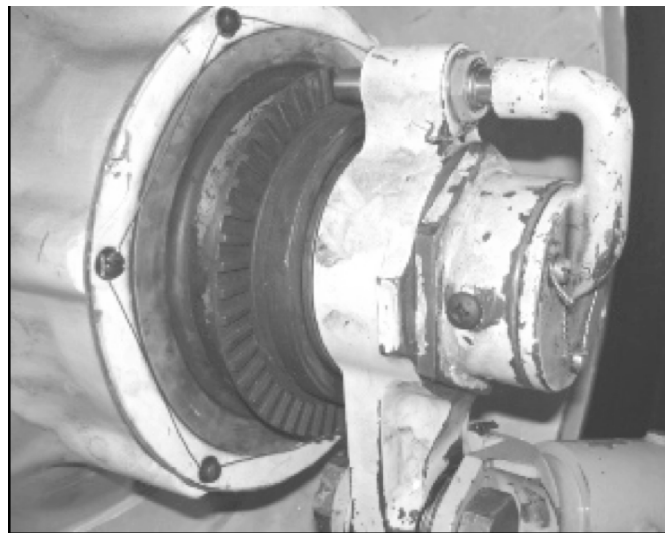
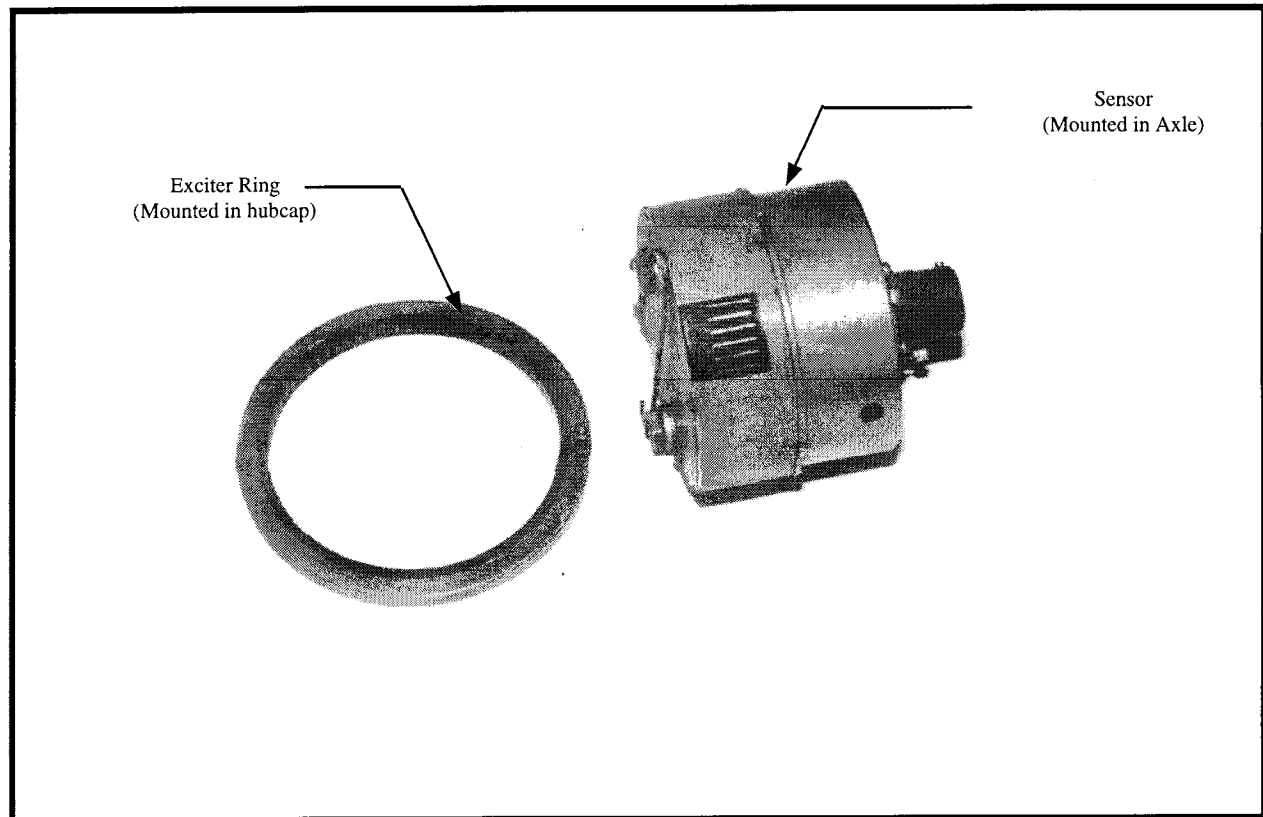


FIGURE 9 - SENSOR - EXCITER RING

4.1.6 Hall Effects Wheel Speed Transducers

Another “contactless” wheel speed transducer that has recently entered into service uses a ring of hall effects sensors mounted to the axle that measures the precise position of a ring of magnets mounted to the wheel. It can detect wheel speed down to zero and can differentiate between forward and backwards rotation. In one implementation, the antiskid control computer is located on the same circuit board as the hall effects sensors. The hall effects wheel speed transducer may be seen in Figures 10 and 11.

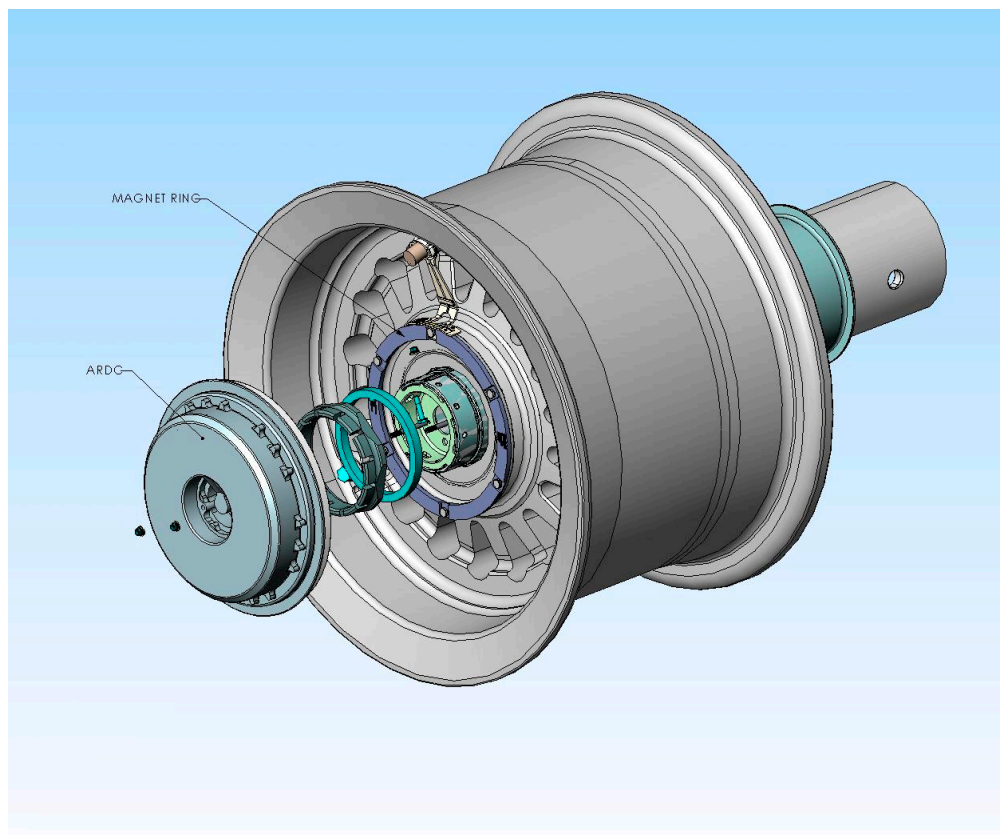


FIGURE 10 - AXLE RDC, BLOW UP

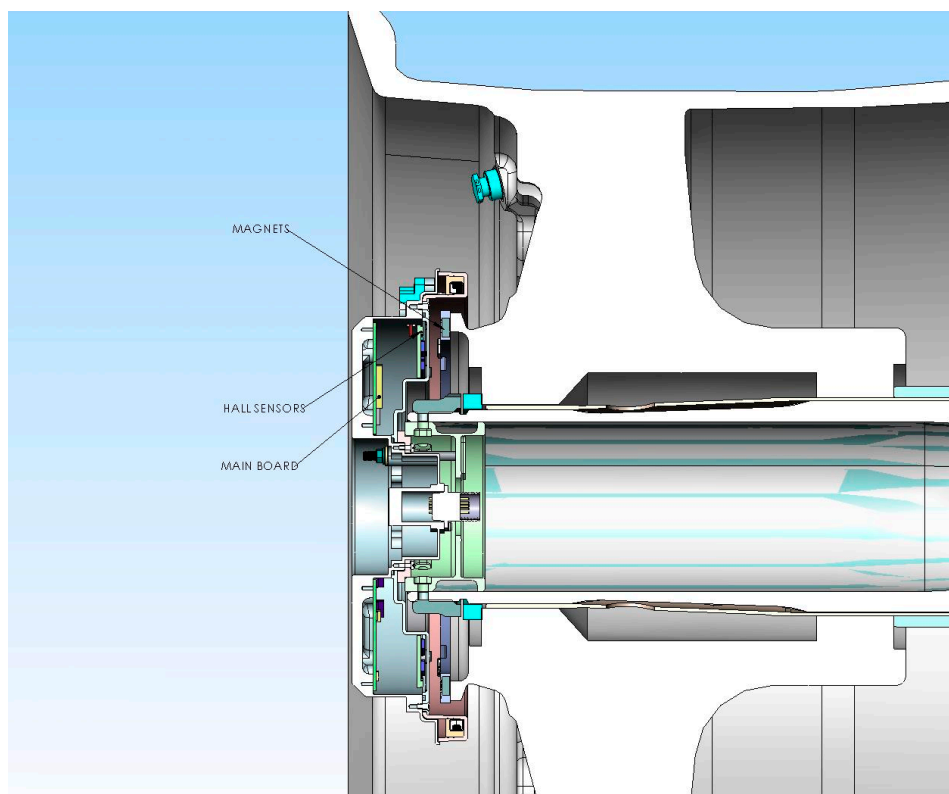


FIGURE 11 - AXLE RDC, SIDE VIEW