DOT/FAA/CT-88/8-2

CHAPTER III

SECTION 4.0

ELECTRO-IMPULSE DEICING SYSTEMS

CHAPTER III—ICE PROTECTION METHODS

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SYMBOLS AND ABBREVIATIONS

Symbol	Description
ac	Alternating Current
°C	Degrees Celsius
cm	Centimeter
dc	Direct Current
EIDI	Electro-Impulse Deicing
EMI	Electromagnetic Interference
°F	Degrees Fahrenheit
FAA	Federal Aviation Administration
ft	Feet or foot
in	Inch
kHz	Kilohertz
kw	Kilowatt
lbf	Pounds force
lbsm	Pounds mass
LWC	Liquid Water Content
m	Meter
mm	Millimeter
NASA	National Aeronautics and Space Administration
SCR	Silicon Controlled Rectifier
USSR	Union of Soviet Socialist Republics
v	Volts
Vdc	Volts Direct Current

III.4 ELECTRO-IMPULSE SYSTEMS.

III.4.1 OPERATING CONCEPTS AND COMPONENTS.

Electro-Impulse Deicing (EIDI) is classified as a mechanical ice protection method. Ice is shattered, debonded, and expelled from a surface by a hammer-like blow delivered electrodynamically. Removal of the ice shard is aided by turbulent airflow; thus, relatively low electrical energy is required.

Physically, the EIDI system consists of ribbon-wire coils rigidly supported inside the aircraft surface to be deiced, but separated from the skin surface by a small air gap (figure III 4-1). A high-voltage (typically 800 to 1400 V) electric current is discharged through the coil (figure III 4-2). The circuit must have low resistance and inductance to permit the discharge to be very rapid, typically less than one-half millisecond in duration. A strong electromagnetic field forms and collapses, inducing eddy currents in the aircraft skin. The eddy current and coil current fields are mutually repulsive, resulting in a toroidal-shaped pressure on the skin opposite the coil. The peak force on the skin is typically 400-500 pounds (1780-2220 Newtons) and is delivered so sharply as to produce a sound resembling a metal-on-metal blow. Actual surface deflection is small, generally less than 0.01 inch (0.25 mm), but acceleration is rapid.

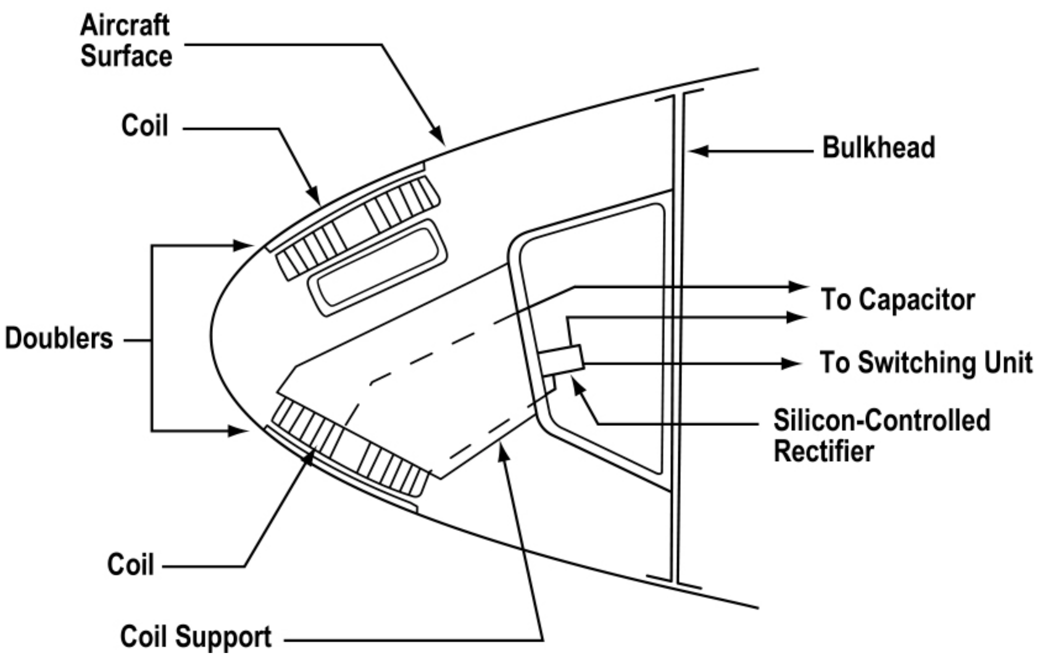


FIGURE III 4-1. IMPULSE COILS IN A LEADING EDGE

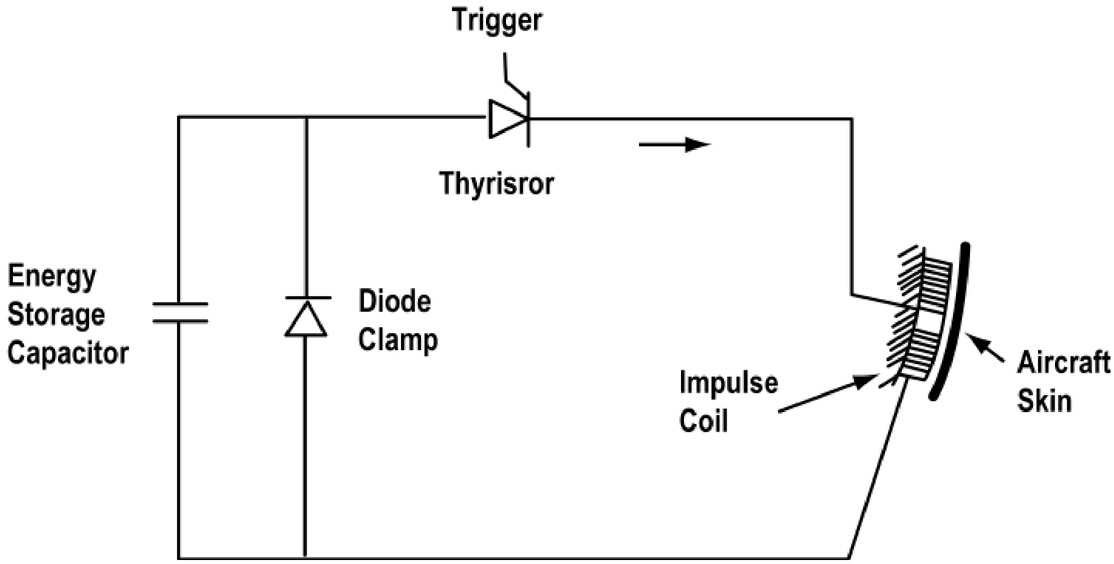


FIGURE III 4-2. BASIC CIRCUIT

The coil may be supported from a spar, a beam between ribs, or from the skin itself. In any case, the coil's mount or direct support should be nonmetallic to avoid interaction with the coil's magnetic field. At a leading-edge spanwise station there may be a single coil at the nose, a pair of coils at upper- and lower-skin positions near the nose, or even a single coil placed eccentrically on either upper or lower surfaces.

During EIDI systems operations, a coil receives two or three successive pulses from the capacitor unit with pulses separated by the time required to recharge the capacitor, typically 2 to 4 seconds. The spanwise extent of wing leading edge that each coil (or coil pair) will deice depends largely on the structural properties of the leading edge, but it is nominally 18 inches (0.5 meters). The capacitor is then switched to another coil station, and then to another until it cycles around the aircraft. The time to complete the deicing cycle must be less than the time for acceptable ice accretion for the protected surfaces.

The system consists of a power and sequencing box, often located in the fuselage, and a number of coils in the wing, empennage, and engine inlet lip surfaces which are connected to the power box. Figure III 4-3 shows the system in its simplest form. The capacitor discharge occurs when a solid-state switch is remotely triggered to close the circuit. This high-voltage, rapid-response switch is a silicon controlled rectifier (SCR) or “Thyristor.” Gas tube thyristors (“thyratrons”) are also available but have not been used in the USA for EIDI. The circuit often includes a “clamping” diode, as shown in figure III 4-2, to prevent reverse charging of the capacitors.

The first nation to use EIDI was the USSR, which had a fully equipped aircraft in 1972 and has equipped several transport-sized airplanes since (reference 4-1). No operational data are available.

The EIDI system has had extensive testing in the NASA Lewis Research Center’s Icing Research Tunnel (references 4-2 and 4-3) and limited flight testing in the USA by NASA and

Cessna Aircraft Company (references 4-3 and 4-4). Other testing has been done by Boeing Commercial Airplane Company (including a flight test series in a B-757), Rohr Industries (icing tunnel tests of engine inlets), Douglas Aircraft Company (laboratory and icing tunnel tests), Wichita State University (Fatigue and Electromagnetic Interference Tests, reference 4-5) and Electroimpact Inc. (Electromagnetic Testing of Modular Low Voltage EIDI Systems, reference 4-6).

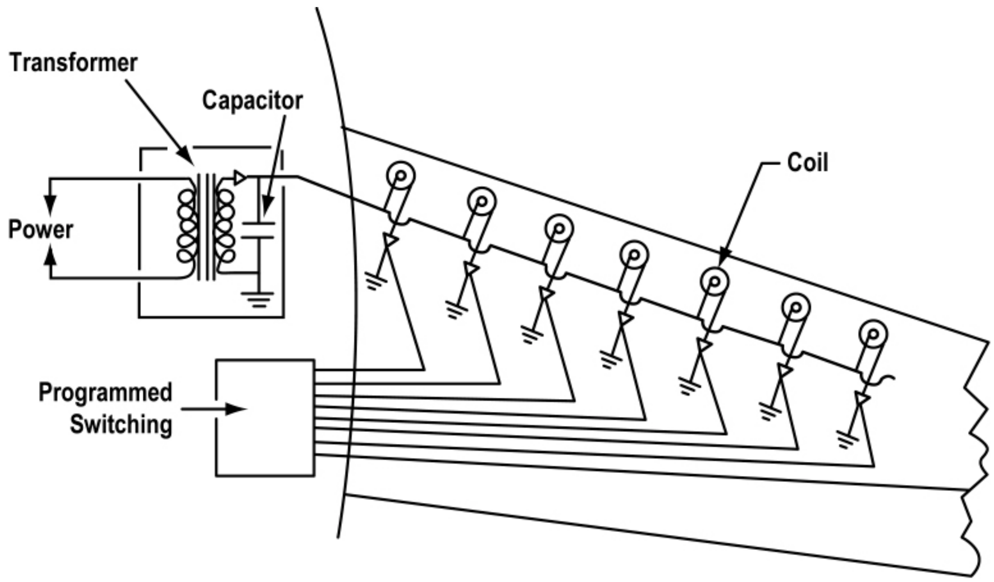


FIGURE III 4-3. A BASIC ELECTRO-IMPULSE DEICING SYSTEM IN A WING

III.4.2 DESIGN GUIDANCE.

III.4.2.1 Pulse Width Matching.

The EIDI system requires a careful and rather sophisticated design (references 4-7, 4-8, 4-5, 4-9 and 4-10). The current pulse width in the coil resulting from the capacitor discharge must be properly matched to the skin electrical properties (reference 4-2) and to the leading-edge structural dynamic response (reference 4-11). Failure to do this properly severely reduces the coil's ice expelling performance. When skin conductivity is too small, a higher conductivity metal disc is bonded to the inside of the skin opposite the coil. This disc is termed a "doubler" and should be slightly larger in diameter than the coil (figure III 4-1). Copper or unalloyed aluminum are the common doubler materials. Doublers increase the skin stiffness locally but may distribute the impulse load more evenly. A structural dynamic analysis will provide guidance for the proper placement of the coil for maximum efficiency.

III.4.2.2 Power Supply and Sequencing.

The power supply and sequencing may be packaged in a single box. The sequencing system can be confirmed for a single sequence around the aircraft or for continuous resequencing. Power supplies are available for common aircraft voltages and frequencies.

Installation of the power supply and control system in the aircraft should be done in a manner that minimizes the distance through which the high-energy electrical pulse must travel. Ideally, the capacitors should be located in proximity to the coils, while the power supply, with its "trickle charge" to the capacitors, should be located near the aircraft electrical generator and away from the capacitors. Figure III 4-4 shows a system schematic, and figure III 4-5 shows a large airplane application. Each aircraft will require a tradeoff study to determine the number of coils to be supplied by one capacitor. For large aircraft, the weight and electrical losses of the high-current lines require several capacitor sets. However, devoting a capacitor to each coil pair may result in a costly, heavy system, so a compromise between those extremes is needed.

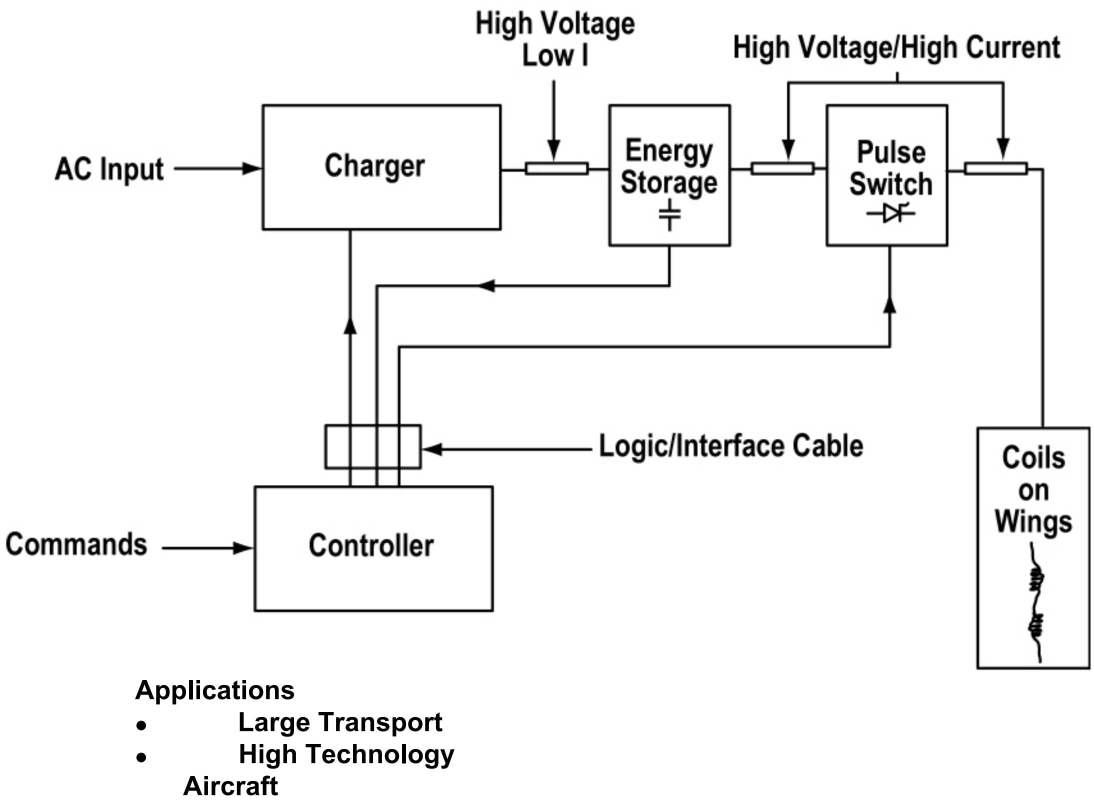


FIGURE III 4-4. EIDI SYSTEM SCHEMATIC

Redundancy can also be obtained by using multiple power boxes which are cross connected. This provides power to all coils at longer time intervals if one box fails. An alternate safety system, which increases cabling, is to supply alternate coils from different power sources. That is, connect odd numbered coils to one power supply and even numbered coils to another. In case of one power box failure, only limited amounts of ice will collect on the unprotected area, unless very stiff nose ribs separate the leading-edge segments.

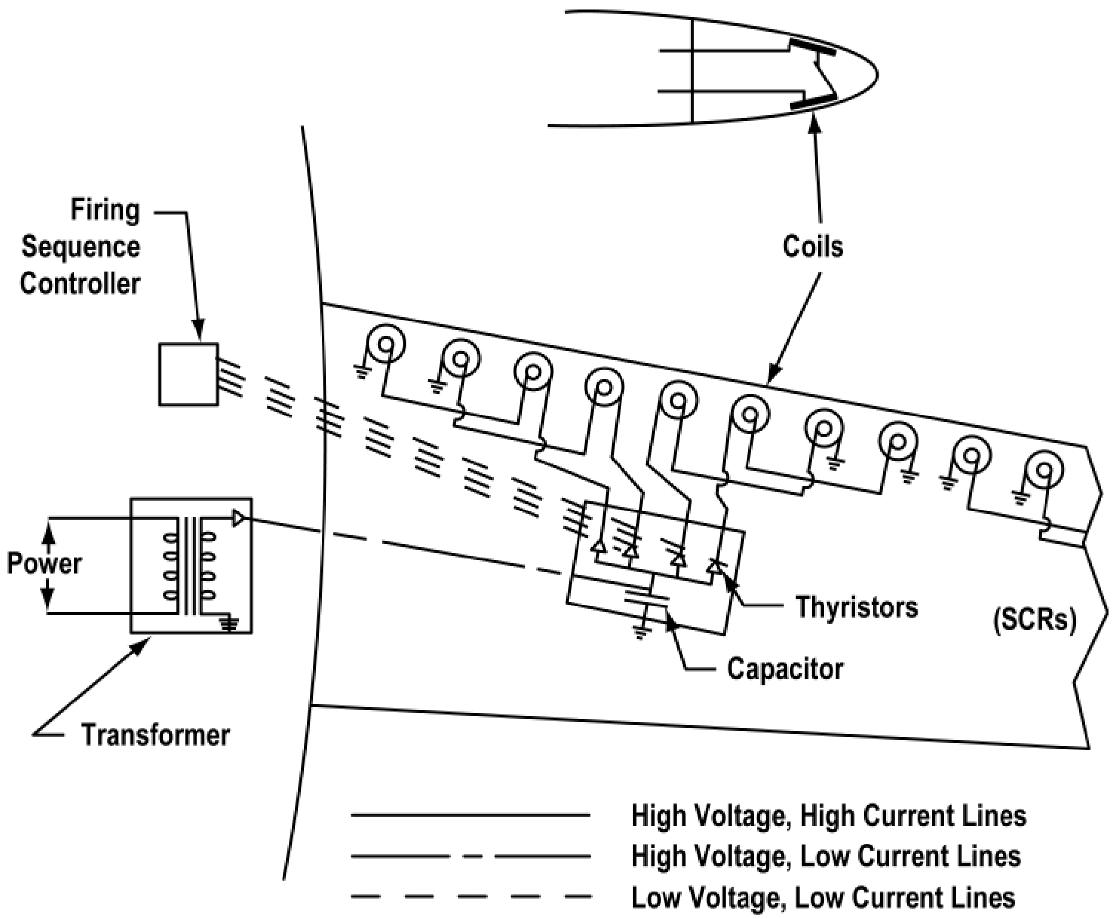


FIGURE III 4-5. EIDI SYSTEM IN A LARGE AIRCRAFT WING

Note in figure III 4-5 that the SCRs (thyristors) are placed on the capacitor side of the coil to avoid having high voltage on coils not being fired.

III.4.2.3 Coil Design and Installation.

Coil placement and mounting methods are critical. Coil mounts must be quite rigid to avoid energy losses due to mount flexing. Mounts are generally made of composite material. Typical coils are wound from copper ribbons and are about 2 inches (50 mm) in diameter, 0.12 to 0.20 inch (3 to 5 mm) thick, and contoured to match the leading-edge skin inner shape. A layer of insulating enamel and a thin layer of fiberglass cloth are usually bonded over the coil. The air gap between the leading edge inner surface or doubler and the coil must be sufficient so that the vibrating skin will not strike the coil.

Special attention must be paid to the attachment methods for the doubler since very high loads will be passing through the doubler into the leading-edge skin. If attachment of the doubler is done with mechanical fasteners, it should be done in a manner such that no part of the fastener will be drawn into the engine in event of fastener failure. However, adhesives are available for bonding of doublers, and so mechanical fasteners are not required for most installations.

III.4.3 USAGES AND SPECIAL REQUIREMENTS.

III.4.3.1 Airfoil and Leading Edges.

Coils are generally wired so that two spanwise positions are in series to reduce the number of cables and thyristors and to achieve better structural response. The two coil positions wired in series can be adjacent span stations or alternate positions. The thyristors (or SCRs) are usually located near the surface to be deiced to permit use of a common supply cable for several coils (figure III 4-3).

Installation is most satisfactorily accomplished as original equipment at the factory. Retrofitting can be accomplished, but may require structural modification to the leading edge to suit coil placement and spacing. The small radius of curvature of empennage leading edges on small airplanes often precludes the use of a single nose coil, requiring two smaller opposing coils at the upper and lower sides of the leading edge.

III.4.3.2 Windshields.

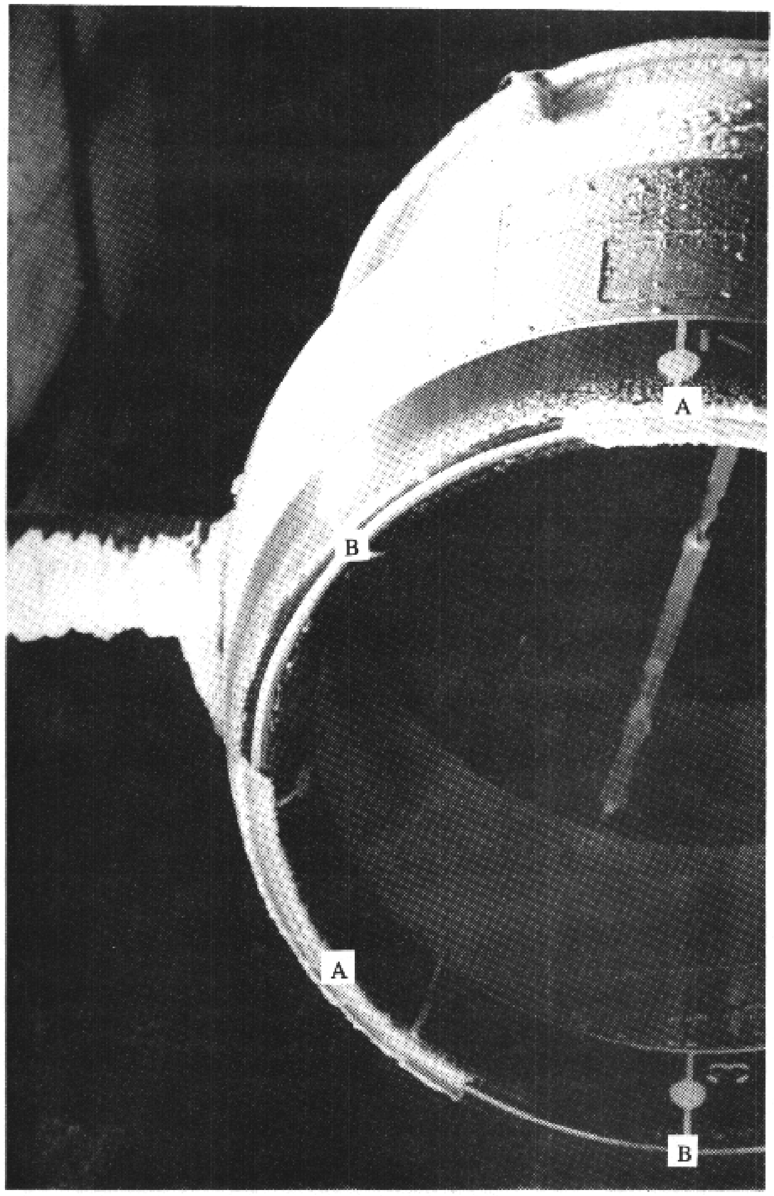
EIDI is not recommended for windshield deicing.

III.4.3.3 Engine Inlet Lips and Components.

Icing wind tunnel tests have been conducted on an EIDI system installed in a nacelle (figure III 4-6) from a business jet aircraft (references 4-8 and 4-12). These tests show EIDI to be a viable method for aircraft engine inlet lip ice protection. Since EIDI expels ice particles, some of which are ingested by the engine, ice pieces were collected in a net for examination. From these observations and high speed photographic studies, the general rule was proposed that the effective diameter of particles expelled will be no larger than three times the maximum thickness of the ice layer. For these specific observations ice particle thickness was no larger than 1/8 inch, and it was concluded that these particles could be ingested by the engine used in this application without damage. In addition, this type of engine ice ingestion must not cause an engine flameout. This requirement may call for more frequent impulses than for a wing or empennage protection system.

No difficulty was experienced in deicing due to added stiffness inherent in the inlet lip compound curvature. For inlets tested, a single coil on the inlet lip inner portion was better than either a nose coil placement or an inside-outside pair of coils. Spanwise spacing of the coils was about the same as for small airplanes, nominally about 18 inches (0.5 m). This system offers a significant reduction in the energy needed for ice protection when compared to hot air (bleed air) anti-icing systems.

The potential applications for EIDI in engine inlets are numerous and encompass large-diameter, high-bypass ratio turbofans, small-diameter business jet engine inlets, and circular or noncircular turboprop engine inlets. Considerations other than inlet type or shape will be the determining factor in the selection of EIDI as the best ice protection system. Initially, a determination should be made of the ice ingestion capability of the engine. EIDI can be designed to remove ice of a specified thickness, with larger thicknesses becoming progressively easier to remove. If the engine can handle short periods of cyclic ice ingestion of a specified size without undue compressor or fan blade erosion in the long term, EIDI can be safely used. The relatively small pieces of ice are a product of the removal mechanism that shatters the ice buildup. The ice will not shed in large continuous pieces if the system is properly designed and operated.



A. Accreted Ice on the Engine Inlet

B. Accreted Ice from the Engine Inlet Has Been Removed by EIDI

FIGURE III 4-6. FALCON FANJET ENGINE INLET BEING DEICED BY EIDI

III.4.3.4 Turbofan Components.

EIDI has not been applied to engine components, such as inlet guide vanes, because of their small size.

III.4.3.5 Propellers, Spinners, and Nose Cones.

EIDI is not considered applicable to propellers because of their small blade cross section and rigid structure in the small radius portion, which has the greatest tendency to accrete ice.

Spinners and nose cones can be deiced by electroimpulse. Coils can be supported on mounts fastened to nearby structure or can be skin-mounted. Nonrotating nose cones can be wired in the same manner as wing leading-edge coils. Rotating cones or spinners introduce the complexity of commutator rings to transmit electrical power. It is generally poor practice to transmit the EIDI pulse across commutator rings due to the high currents and voltages involved. This suggests placing the capacitors in the spinner and transmitting low-voltage recharge current across the commutator ring. A separate charging and firing circuit is then required for each spinner. This complexity may limit EIDI use for spinners.

III.4.3.6 Helicopter Rotors and Hubs.

Application of EIDI to rotorcraft rotors has not gone beyond the development stage. Retrofit is usually not possible because no leading-edge cavity exists in which to place the coils and cable runs. Because of the critical balance and aeroelastic requirements, the EIDI equipment should be designed into the blade at the factory. An unbonded metal leading edge will be required on a rotorcraft blade. This is usually the abrasion shield which is fitted tightly over the leading-edge substructure and bonded only at the downstream edges. The coils may be recessed into the leading-edge composite material with a gap between the coil face and the abrasion shield. If the abrasion shield has insufficient conductivity, a doubler of higher conductivity material may be bonded to it opposite the coil location.

Present design planning to use EIDI in rotorcraft locates the power and sequencing boxes in the rotating hub column, with a commutator ring bringing the low-voltage current to a transformer, and a rectifier in the hub for continuous recharging of capacitors. Care must be taken to deice opposing blades symmetrically.

The damping effect of the rotor substructure on the metal surface makes it necessary to have coils at closer spacing intervals than for the fixed-wing hollow structures. The small geometry usually dictates the use of a coil at the lower side rather than at the nose of the leading edge. Once the power and sequencing unit is provided in the rotor hub, the addition of coils to deice the hub's external surface is as easily accomplished as for a wing leading edge.

III.4.3.7 Flight Sensors.

EIDI is not applicable to flight sensing instruments.

III.4.3.8 Radomes and Antennas.

Aircraft radome and antenna deicing have not been accomplished with electroimpulse. Before using EIDI coils for such deicing, the possibility of electromagnetic interference with the transmitter/receiver should be evaluated.

III.4.3.9 Miscellaneous Intakes and Vents.

The minimum diameter of impulse coils is approximately 2.5 inches (66 mm), and only components with structural voids large enough to permit installation are possible candidates for EIDI protection.

III.4.3.10 Other.

EIDI coils can be varied in configuration and size for installation in structures whose remote locations or complex shapes make them difficult to deice by thermal or pneumatic boot systems. This is particularly true of surfaces which contribute drag but do not reduce lift when iced. Struts which are aluminum extrusions used for wing braces on small airplanes are easily deiced because of their structural dynamics (reference 4-2). Other candidates for EIDI usage are engine pylons and wheel covers.

III.4.4 WEIGHT AND POWER REQUIREMENTS.

Estimates of weight and power required for EIDI are tentative at this early stage of development. The data presented in table III 4-1 are, nevertheless, considered by the system developers to be conservative.

TABLE III 4-1. POWER AND WEIGHT ESTIMATES

Aircraft	Power*	Weight**
6-place, propeller driven	400 watts	60 lbs***
150 passenger turbofan transport		
no redundancy	2 kilowatts	250 lbs
full redundancy	2 kilowatts	400 lbs
250 passenger transport		
no redundancy	3 kilowatts	350 lbs
full redundancy	3 kilowatts	500 lbs

`Notes:
* Based on 3-minute cycle for all surfaces.
** For wings and empennage surfaces; for engine inlets, increase by 25%.
*** Also includes wing struts for small airplanes.

III.4.5 ACTUATION, REGULATION, AND CONTROL.

For critical surfaces not visible to the pilot, such as inboard wing areas or empennage, use of some type of ice detection sensor may be advisable. EIDI activation can be either manual, with appropriate cockpit display, or automatic.

III.4.6 OPERATIONAL USE.

A simple test of small airplane systems can be performed on the ground by placing one's hand on the leading-edge skin as each coil fires. Audible differences are evident for coils whose mounting has failed or whose circuit contains an electrical fault. An oscilloscope view of the current from the capacitor box may reveal changes in EIDI system physical geometry or electrical circuit faults. The more sophisticated units may have test circuitry installed in the aircraft for in-flight system checkout.

III.4.7 MAINTENANCE, INSPECTION, AND RELIABILITY.

Lack of sufficient operational experience at this time does not permit assessment of maintenance requirements or reliability. The power and sequencing box must be accessible for inspection. Terminals should be available in the box for attaching test leads to each coil's set of wires. For units using electrolytic capacitors, degraded performance may result if the capacitors are operated at 14° to -22°F (-10° to -30°C) temperatures (reference 4-13), and damage to the capacitors may result at temperatures below -40°F (-40°C). Inspection tests should evaluate capacitance after cold exposure. For many uses, the more costly metalized capacitors are required; these are not damaged by low temperature.

III.4.8 PENALTIES.

See limitations below.

III.4.9 ADVANTAGES AND LIMITATIONS.

- Advantages of the EIDI System are:

    a. Low power required. EIDI system power consumption is less than 1 percent of that required for hot air or electrothermal anti-ice systems. Power requirements for an EIDI system may be about the same as for the landing lights for the same aircraft (see section III.4.4 above).

    b. Reliable deicing. Ice of all types is expelled, with only light residual ice remaining after the impulses. Ice thicknesses from 0.03 to 1.0 inch (8 to 26 mm) have been consistently shed (figure III 4-7).

    c. Nonintrusive in the airstream, hence no aerodynamic penalty.

    d. Weight comparable to other deicing systems.

e. Low maintenance, theoretically, since there are no moving parts; however coils, capacitors, and diodes can fail.

f. No run-back refreezing occurs.

g. Pilot skill and judgment required to operate the system are minimal in that no threshold ice-thickness is required for turn-on.

h. System can include self-test circuitry.

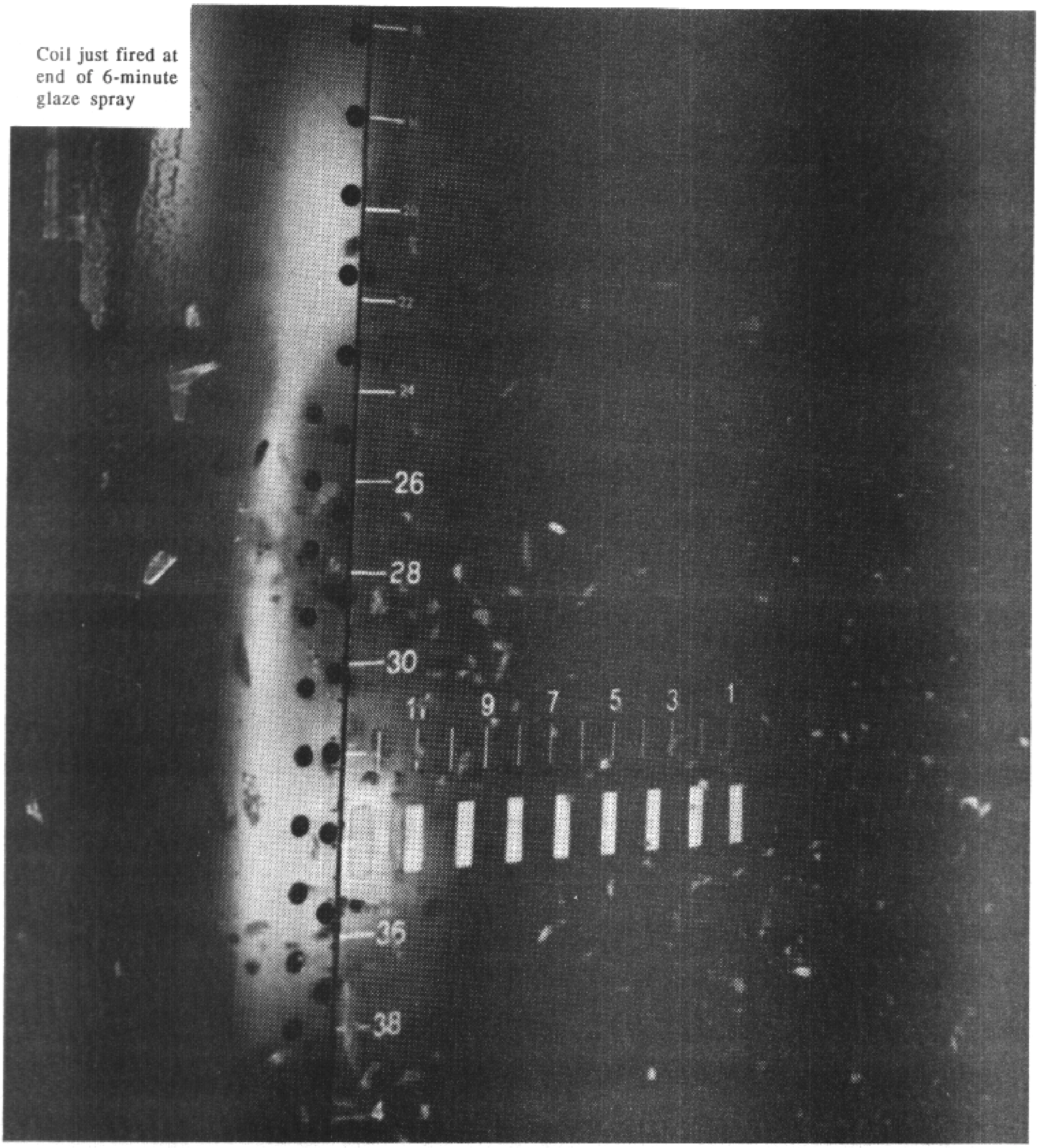
- Limitations of the EIDI system are:

  a. It has had limited use.

  b. It is not an anti-icing system, so some ice will be present over most of the aircraft leading edges during flight in icing.

  c. Outside the aircraft the discharges may be quite loud, resembling a light gunshot. Inside small aircraft, the impulses are audible but may be almost imperceptible in a large transport category airplane.

  d. Complex design requirements.



Courtesy of USAF/NASA Low Power Ice Protection Program

FIGURE III 4-7. ELECTRO-IMPULSE INDUCED ICE DEBONDING AND EXPELLING

III.4.10 CONCERNS.

Concerns not resolved because of lack of operational experience are:

a. Possible fatigue of skin, coil mounts, insulation, etc. Testing indicates that coil mountings must be well designed to avoid fatigue failure. Laboratory testing has been done with small airplane leading edges, both aluminum and composite, at low temperatures and for normal deicing electrical engines. No fatigue damage was found after impulses equaling the number expected in a 20-year aircraft lifetime. Similar laboratory tests for a transport aircraft slat exceeding 200,000 impulses showed no fatigue damage (reference 4-5). All of these used doublers with the skins.

b. Electromagnetic interference (EMI). The discharge of 1,000 volts to create transient electromagnetic fields might be expected to cause undesirable signals in communication, control, or navigation equipment. However, both laboratory and flight tests have failed to detect appreciable interference for metal air foils (references 4-3 and 4-4). The reasons suggested for this are: (1) the aluminum wing box provides a good shield (note that this might not be true for a nonmetallic leading edge), (2) the frequency of the pulse is below 3 kHz, which is below that of current aircraft avionics systems, and (3) the pulse is a pure wave (or half wave) without the "overtones" of a spark. In flight tests, added equipment has been carried specifically to detect EMI; these included LORAN-C, digital readout systems, and a radar pod mounted on the wing. One of these had control wiring which shared space with the EIDI cables. However, care should be taken to check for EMI, especially if nonshielded leads are physically near the EIDI power cables.

c. Possible adverse effects of lightning strikes. Since the EIDI system is electrical, there is the possibility of its being disabled by a lightning strike. Sudden overload protection of critical components may be required. If the EIDI system is installed in an aircraft whose structure is largely of composite materials, the EIDI cables could become the primary electrical paths through the structure when it is struck by lightning. Additional lightning paths through the aircraft may be required.

d. Failure modes and their consequences have yet to be clearly defined. Compliance with the failure analyses as described in Federal Aviation Administration AC 25.1309-1A (reference 4-14) is required. The failure modes and redundancy possibilities will be quite different, however, for small and large aircraft.

e. See reference 4-13.

III.4.11 REFERENCES.

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III.4.12 GLOSSARY.

Liquid water content (LWC) — The total mass of water contained in all the liquid cloud droplets within a unit volume of cloud. Units of LWC are usually grams of water per cubic meter of air (g/m^3).

Median volumetric diameter (MVD) — The droplet diameter which divides the total water volume present in the droplet distribution in half; i.e., half the water volume will be in larger drops and half the volume in smaller drops. The value is obtained by actual drop size measurements.

Thyristor — A solid state bistable device comprising three or more junctions using silicon controlled rectifiers. Used as a current limiting device or to reverse polarity. Also called pnpn-type switch.