



AEROSPACE RECOMMENDED PRACTICE

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Guidelines for Specifying Linear and Rotary Variable Differential Transformers

RATIONALE

There is a need to guide component designers and system integrators in the development of specifications for Linear Variable Differential Transformers (LVDTs) and Rotary Variable Differential Transformers (RVDTs) that are used for positional measurement in aerospace applications. This document addresses that need.

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1. SCOPE

This SAE Aerospace Recommended Practice (ARP) provides guidelines for specifying Linear Variable Differential Transformers (LVDTs) and Rotary Variable Differential Transformers (RVDTs). Information on the application, operation, design, and construction of LVDTs and RVDTs is also provided.

2. REFERENCES

2.1 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 a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in the document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies
AS4716	Gland Design, O-Ring and Other Seals
AS4941	Aerospace - General Requirements for Commercial Aircraft Hydraulic Components
AS5857	Gland Design, O-Ring and Other Elastomeric Seals, Static Applications
AS8775	Hydraulic System Components, Aircraft and Missiles, General Specification For

2.1.2 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

CS-25	Certification Specifications for Large Aeroplanes
CS-29	Certification Specifications for Large Rotorcraft

2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

14 CFR 25	Airworthiness Standards: Transport Category Airplanes
14 CFR 29	Airworthiness Standards: Transport Category Rotorcraft

2.1.4 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160	Environmental Conditions and Test Procedures for Airborne Equipment
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2.1.5 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-DTL-5541	Detail Specification for Chemical Conversion Coatings on Aluminum and Aluminum Alloys
MIL-PRF-8625	Anodic Coatings for Aluminum and Aluminum Alloy Performance Specification
MIL-STD-461	Electromagnetic Interference Characteristics Requirements for Equipment
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests

2.2 Definitions

Definitions provided below are either not found in ARP4386 or are used in a way that is specific to variable differential transformers.

AIR GAP: This is the radial running clearance between the moving and the stationary members of a rotary or linear position transducer.

BIASED OUTPUT: This is a transducer whose signal is such that there is no phase reversal over the entire operating range.

NOTE: A partially biased output transducer will have a phase reversal.

CLUSTER ASSEMBLY: This is the physical arrangement of individual transducers around a single, central measurand shaft.

DEMODULATION: This is the electronic processing of AC voltage signals into a DC signal.

ELECTRICAL ZERO (EZ): This is the rotational position (RVDT) or linear position (LVDT) of the measurand where the inphase differential output signal is zero. Signal phase reversal occurs at this location.

EXTENDED RANGE: This is an RVDT with an anti-backlash gearhead to obtain the usable rotational range of the measurand for as many as 1000 or more input shaft revolutions.

NOTE: Revolutions below 1000 but above the useful range of the sensor itself are possible.

FLEX-SPLINE: This is an input shaft on an RVDT with an ANSI aircraft spline whose teeth are individually separated to achieve radial compliance.

NOTE: It is used to self-align the transducer axis and to obtain the anti-backlash connection to the measurand.

HYSTERESIS: These are different output signals at the same position when approached from opposite directions of motion, which is caused by looseness in mechanical motion transmission (backlash, bearing play, pin-slot clearance, etc.).

INPHASE: This is that component of the output signal level that is sinusoidally in lockstep with the AC input signal.

NOTES:

- a. It is used mostly in legacy synchronously demodulated signal conditioning systems.
- b. It generally denotes the direction of rotation in one direction off of Electrical Zero.

180 DEGREE PHASE: This is the out-of-phase component in which the output signal level is 180 degrees sinusoidally out of phase with the excitation voltage.

NOTE: It denotes the opposite rotation off of Electrical Zero than the inphase signal in legacy synchronously demodulated signal conditioning systems.

LINEAR VARIABLE TRANSFORMER: This is a device, operating on AC, to measure linear position using variably coupling, an input-induced magnetic flux to an output coil set.

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER: This is the same device as an LVT, except that it has two outputs which differentially or ratiometrically combine to yield a single prime position signal.

MAGNETIC COUPLING: This is the act of directing magnetic force lines from one electrical coil circuit to another.

MAGNETIC FLUX: This is the flow of magnetism through a magnetic medium.

MEASURAND: This is a mechanical device whose angular or linear position is to be determined (measured).

MONOTONIC: This is a mathematical function relationship between two variables, which is characterized as always increasing without reversal of slope, no matter how small.

PERMEABILITY: The capability of a material to conduct magnetic flux.

QUADRATURE: This is the component of the output signal whose phase relationship to the input signal is 90 degrees.

RATIOMETRIC SIGNAL CONDITIONING: This is a more modern signal conditioning scheme that inherently compensates for thermal and input voltage variation effects.

NOTES:

- a. Positional information is derived by comparing the two output voltages with the equation $(V1-V2) / (V1+V2)$.
- b. Measurements are in total volts, and any phase-referenced parameters (phase angle, null voltage, etc.) need not be specified.
- c. A 5-wire or 6-wire sensor needs to be employed.

ROTARY VARIABLE TRANSFORMER: This is a device, operating on AC, to measure angular position using variably coupling, an input-induced magnetic flux to an output coil set.

ROTARY VARIABLE DIFFERENTIAL TRANSFORMER: This is the same device as an RVT, except that it has two outputs which differentially combine to yield a single prime position signal.

REDUNDANT ASSEMBLIES: These are two or more identical but electrically independent transducers aligned and packaged together to operate from a single rotary input.

ROTOR: This is a high-nickel-content, corrosion-resistant steel slug-mounted between support bearings of an RVT or RVDT.

NOTE: It variably directs magnetic flux across an air gap within a transducer stator.

SCALE FACTOR: This is the relationship between the output signal and angular (or linear) position, usually stated in terms of millivolts per degree of rotation (mV/deg) or millivolts per linear displacement (mV/inch or mV/mm).

SENSITIVITY: This is the same as the scale factor.

STATOR: This is a high-nickel-content, corrosion-resistant steel cylinder, within which are deployed the stationary input and output coil sets of an RVT or RVDT.

TANDEM ASSEMBLY: This is the end-to-end stacking of individual transducer channels to achieve electrical redundancy.

TEMPERATURE COEFFICIENT: This is a change in scale factor (output slope) due to temperature change.

NOTE: It is usually specified in percent change per temperature measurement change (%/°C or %/100°F).

TOTAL VOLTS: This is the vector sum of the in phase (LQ0) and the quadrature (iQ0) components of the AC output signal.

TRANSLATION ERROR: This is an angular error in motion transmission due to nonalignment of the transducer/measurand axis, or due to takeoff gearing eccentricities.

V RMS: This is the square root of the mean square of the instantaneous values of an alternating voltage.

NOTE: VDTs are commonly powered by sinusoidal alternating voltage but can be powered by other waveform shapes.

2.3 Abbreviations

AC	Alternating Current
ANSI	American National Standards Institute
CCW	Counterclockwise Rotation
CRES	Corrosion-Resistant Stainless Steel
CW	Clockwise Rotation
EHSV	Electrohydraulic Servovalve
EMI	Electromagnetic Interference
EZ	Electrical Zero
ICD	Interface Control Document
LRU	Line Replaceable Unit
LVT	Linear Variable Transformer
LVDT	Linear Variable Differential Transformer
MTBF	Mean Time Between Failures
RVT	Rotary Variable Transformer
RVDT	Rotary Variable Differential Transformer
SCD	Source Control Drawing
VDT	Variable Differential Transformer
Vrms	Root Mean Square Voltage

3. DOCUMENTATION REQUIREMENTS

3.1 Variable Displacement Transducers Specific Documents

An LVDT or RVDT specification should include a section containing a summary of government, industry, and internal procuring company documents that are referenced in the body of the specification. The list should not include any documents not referenced in some fashion elsewhere in the specification. Furthermore, an LVDT or RVDT specification should make it clear that the applicability of the reference documents applies only to the extent cited in the body of the specification.

3.1.1 Envelope Drawing

An envelope drawing is an optional document that is useful for augmenting a VDT specification in a procurement package to define certain technical requirements most easily expressed within a drawing. If utilized, an envelope drawing and its embedded requirements should be cited in the specification. Commonly used parameters contained within an envelope drawing are space envelope and mechanical interface requirements. Electrical and other requirements, such as stroke and phasing requirements, are also commonly contained within a VDT envelope drawing.

Good requirements management practice suggests that detailed requirements should not be replicated in both the specification and envelope drawing. Instead, the specification should simply reference the envelope for defining the appropriate requirement. For example, if the phasing requirement is contained within the envelope drawing, the specification might properly say, "The transducer shall conform to the phasing relationships illustrated in envelope drawing B12345."

When the VDT design is completed, verified, and accepted by the customer, the customer converts the envelope drawing to a source control drawing by adding reference to the accepted source of supply.

3.1.2 Interface Control Document

An Interface Control Document (ICD) is an optional means for specifying certain interface requirements. For an LVDT or RVDT, it is more commonly used for electrical interface requirements than for mechanical interface requirements. Envelope and later source control drawings are more common for mechanical interfaces.

The benefit of an ICD to a system designer is that it is a single source of electrical interface data that can be used for all system components, avoiding the need to replicate its content in individual component specifications. For LVDT/RVDTs it may contain wire assignments, signal characteristics, phasing, or polarity requirements, among others. In addition, the ICD provides sufficient definition of both sides of the VDT interface such that the impact of a change on the VDT side can be assessed on the system as a whole.

If an ICD is used to define certain VDT requirements, the ICD should be referenced in the specification for the specific requirement. For example, if the lead wire color requirements are contained within the ICD, the specification might properly say, "The transducer's lead wire colors shall conform to that illustrated in ICD A12345, 4.3.1."

4. GENERAL DESCRIPTION

For many decades LVDTs and RVDTs have been mainstay technologies for position measurement in aerospace applications. Their desirable features include high accuracy, compact design, and reliability. The latter is attributable to their ruggedness and frictionless operation.

4.1 Theory and Principles of Operation

4.1.1 LVDTs

LVDTs are displacement measurement transducers that utilize the principles of Faraday's law of electromagnetic induction in the application of a differential transformer. The object whose movement is to be measured in a linear direction is connected to an inductive armature (also commonly called the core) via a nonmagnetic shaft. The moving armature is placed in the proximity of a primary excitation electrical coil and two secondary coils, which are connected in a series-opposed fashion, therefore, the LVDT sensor measures the relative motion between the armature and the coils. This is illustrated conceptually in Figure 1.

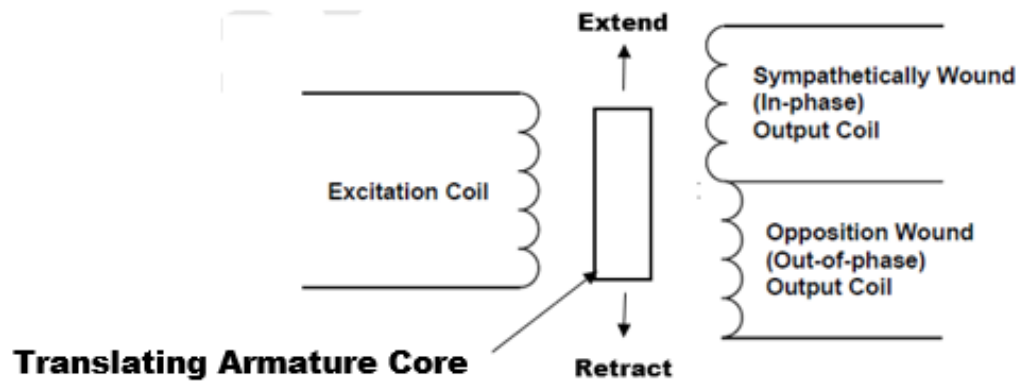


Figure 1 - LVDT schematic diagram (5-wire shown)

A fixed AC carrier excitation is applied to the primary stator coil. The translating solid iron core serves as a flux director that electromagnetically couples the primary to the secondary coils. This coupling is proportional to the linear position of the core if kept in the measuring range. No coils are required on the translating element, as the core acts as a flux path link between the primary and secondary coils. As the armature extends or retracts, the voltage linearly increases in one output coil and decreases in the other output coil due to the varying amount of armature iron providing flux linkage between the primary coil and each output coil. These output coil voltage magnitudes represent a known position of the device being measured and are converted to useful positional information by signal conditioning electronics, which are typically located within the system's control computer. Several types of LVDT signal conditioning circuits are used, and it is critical to correctly identify the signal conditioning type to the sensor supplier so that the sensor can be correctly designed and acceptance tested. Signal conditioning types are discussed in 4.4.1.

Figure 2 illustrates a typical LVDTs physical arrangement and the relationships between the secondary output signals and armature position. The coils are wound concentrically around the armature's axis. The signal voltages from output coils A and B can be independently monitored by the signal conditioning electronics, or the two coils can be connected in series to yield a single output voltage which is proportional to armature position.

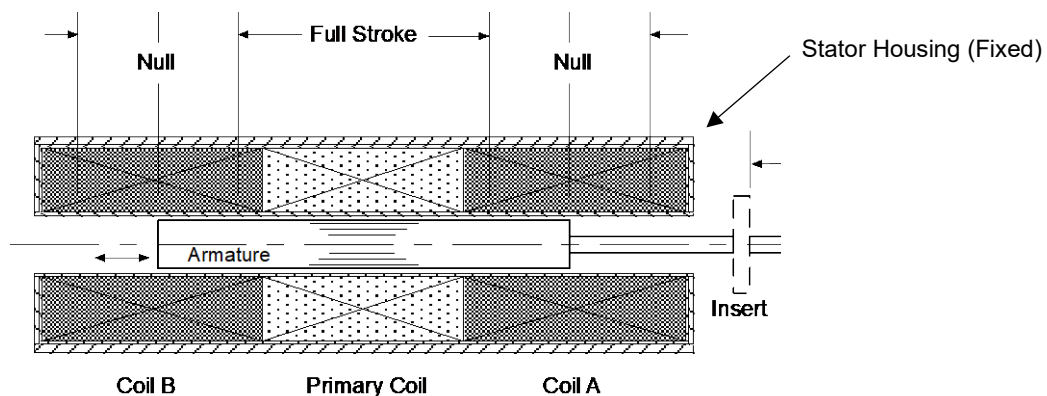


Figure 2 - Example of LVDT physical winding arrangement

4.1.2 RVDTs

RVDTs operate similarly to LVDTs in that an armature transforms voltage from a primary coil differentially to two identical secondary coils, except that the RVDTs mechanical input motion is rotational, and the armature rotates on a bearing set, with a rotating shaft input. Figure 3 and Figures 4a and 4b schematically illustrate the RVDT operational concept.